Qualifications

The General Certificate in Brewing (GCB)

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Introduction.

The **General Certificate in Brewing** (GCB) gives international recognition of a basic, under-pinning knowledge and understanding in the principles of brewing operations.

The GCB has been designed for candidates who may have little or no formal academic or technical qualification. Typically a candidate will be employed as a senior operator or team leader in a brewery or packaging plant, however the scope of these examinations will enable candidates from smaller brewing operations to obtain this recognised qualification. This examination is open to anybody with interest in brewing or beer packaging. They are a measure of basic knowledge (theoretical and practical) underpinning brewing, packaging and associated operations.

- The GCB can be an end in itself, or the start of professional development, leading to the Diploma in Brewing (Dipl. Brew) and, potentially, the Master Brewer (M. Brew) examinations. It counts as Recognised Prior Learning for the Diploma in Beverage Packaging Module 2 Unit 2.5 Brewing.

- The GCB takes the form of one multiple choice paper of two hours.

Candidates can register to sit the exam on-line instead of using the traditional paper format. Candidates sitting within the brewery or examination centres will be encouraged to take the on-line version.

The pass mark is set at 66% (40 correct answers from 60 questions) for General Certificate exams. Candidates attaining 90% or more achieve a Distinction pass and 80 - 89% achieves a Credit pass.

The full list of sections in the GCB syllabus is as follows:-

1. Beer types; their raw materials; sweet wort production.
2. Sweet wort production (methods and plant).
3. Wort boiling.
4. Wort clarification, cooling and oxygenation (aeration).
5. The basic principles of yeast fermentation.
6. Fermentation practice.
7. Yeast management.
8. Beer maturation and cold storage
9. Specialist section –

   Either 9A Bright beer preparation (for Mainstream brewery option A)

   Or

   9B Cask and craft beer preparation and packaging (for Craft beer option B)
10. Beer quality and process control.
11. Beer quality – Flavour.
12. Beer quality – Dissolved oxygen.
13. Beer quality – Microbiological contamination.
14. Quality management.
15. Plant cleaning – Detergents and sterilizing agents.
16. Plant cleaning – Cleaning in-place (CIP) and general cleaning.
17. Engineering basics and maintenance.
18. Utilities – Water and effluent in brewing
19. Utilities – Process gases.
20. Brewing and the environment.

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Section 1 Beer types and their raw materials; sweet wort production.

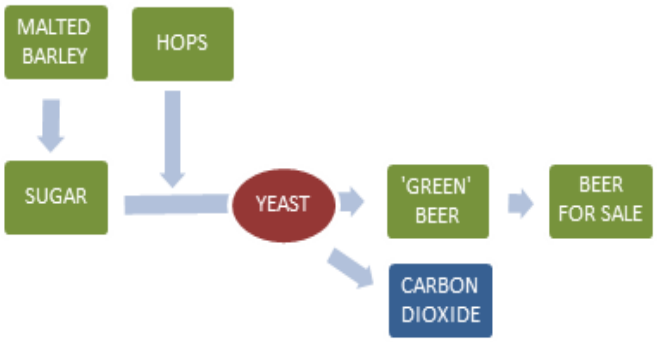
1.1 Definition of Beer

In its basic sense, beer is an alcoholic beverage produced by the fermentation of sugars derived from malted barley and flavoured with hops. There are some minor differences where malt is supplemented with adjuncts or where the hops are replaced by other flavours, but this definition would be recognised by the majority of people round the world.

The manufacture of all alcoholic beverages utilises the ability of yeast to ferment sugar into alcohol.

Wine is made from grapes, cider from apples, whereas in the case of beer, the sugar is derived from malted barley, and flavour and character comes from the addition of hops.

The full process also involves preparing the immature or green beer for consumption.



Beer types:

Different types of beer.
Different areas around the world have developed their own types of beer.

The variations have come about through a combination of the materials available for its manufacture and the tastes of the consumers.

Lager. The German for "store". This beer type forms by far the largest proportion of beer sold. The beer is typically light yellow / gold in colour, with the delicate flavour due to:-

- The use of a malt that is relatively undermodified and lightly kilned.
- A relatively low bitterness.
- The use of a bottom fermenting yeast, probably selected by the extended cool brewing storage processes.
- Cold maturation.

Note however that there are also dark lagers brewed, using darker malts for stronger flavoured beers.

Ales are produced traditionally in the United Kingdom and the Republic of Ireland, though increasing volumes are now produced around the globe, principally in micro-breweries.

Their flavours come from:-

- The use of a well modified and biscuity flavoured malt which is sometimes highly coloured, leading to malty and toffee characteristics and rich amber or dark colours.
- Sometimes they are very bitter.
- The use of a top fermenting yeast, though again, many beers are now produced using bottom fermenting yeasts.
- Fermentations which are warmer and quicker than lager fermentations, leading to higher levels of fruity flavours.

Ales come in various forms, bitters, pale ales and mild beers.

Wheat beers were originally produced in Belgium (Wit Beers) and Germany (Weiss Beers) using large proportions of malted wheat instead of malted barley. They are usually brewed using a top fermenting yeast. The beers are often served unfiltered or bottle conditioned with noticeable yeast content and cloudy appearance.

Stouts are very dark in colour and richly flavoured from the use of highly coloured malts or roasted barley. Other characteristics include

- The use of top fermenting yeasts.
- Warm, fast fermentations.
- Possible burnt and or bitter aftertaste, due to the malt or roast barley.
- Traditionally, high alcohol content, though more recently stouts usually have alcohol levels similar to other ales.

Low alcohol / alcohol-free beers are produced by several different processes and their definition varies in different countries.

Usually alcohol-free means less than 0.05% (vol/vol) alcohol and low alcohol means less than 0.5% (vol/vol) alcohol (less than 1.2% in UK). The exact definition is set by individual governments.

- Often produced by removing alcohol from standard strength beers (for example, by evaporation or reverse osmosis methods).
- Can be produced by limited fermentation processes either by using wort with a very low fermentability or by exposing wort to yeast at cold temperatures and/or for a short time.

Low alcohol and alcohol free beers must not be confused with malt drinks, which are essentially unfermented wort.

Low-carbohydrate beers are brewed by producing wort that is more fermentable than in "standard beers" by several techniques. This could be by extending the malt mashing time to create more fermentable sugar, but could also be by adding additional enzymes to convert more of the non-fermentable sugars into fermentable sugars. These enzymes may be produced from unboiled wort and added to conventional wort, or from commercial suppliers derived from fungal and/or bacterial sources and added during wort production or during fermentation.

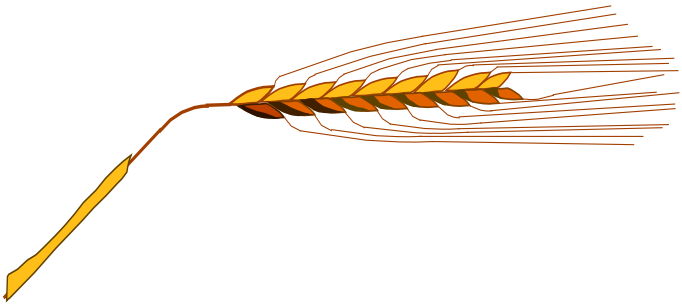
The overall objective by making the wort more fermentable (or "super-attenuated) than standard is to brew products that have lower carbohydrate content in the finished beer.

1.2 Malt and Barley

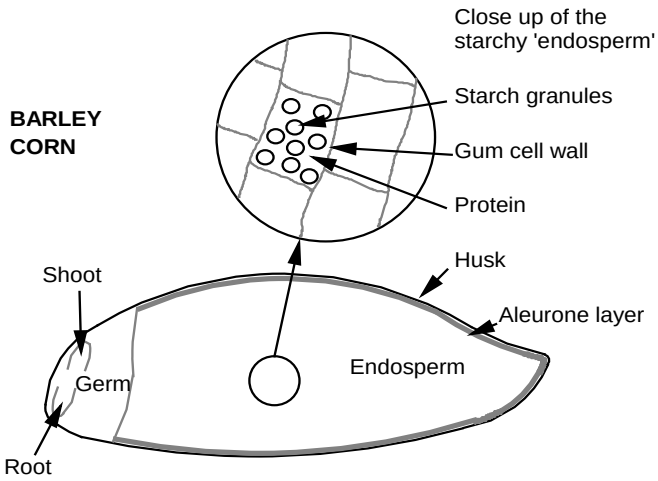
Apart from water, malted barley is the main raw material used in the brewing of most beers. Malt provides the sugar that will be fermented into alcohol in the brewing process.

Barley is a cereal traditionally grown in mild maritime climates and for centuries it has been used in the production of beer.

Malting Barley



All cereals contain carbohydrates in the form of starch which is the source of food for the growing plant when the seed is germinating. Usually the starch is locked away or protected until it is needed.



The diagram above illustrates the key features of the barley corn. It shows the location of the starch granules which are the main carbohydrate food reserves.

Starch is present as granules which are embedded in a protein matrix. This matrix is surrounded by cell walls containing a gum called β-glucan. The starch granules are therefore inaccessible and protected from attack by the amylase enzymes that are produced during germination.

During the malting process however, the cell walls and the protein will be dissolved by other enzymes which are produced naturally as the seed grows.

Barley is the principal grain used in brewing for a number of reasons:-

- The plant can be grown in many parts of the world ranging in latitude from near the polar circles to the equator.
- Its uniform and convenient size makes it easy to handle on an industrial scale.
- The grain contains 60 – 65% by dry weight of starch. Together with proteins, enzymes, vitamins and minerals, the grain provides a complete package for yeast nutrition.
- It contains sufficient lipids for yeast metabolism under anaerobic conditions, in some other grains excessive levels of lipids can have deleterious effects on beer processing or quality.
- The husk is relatively tough, and can form a filter bed in the brewhouse.

The barley selected for processing into malt must meet certain specific requirements:-

- It must be capable of germination, with a minimum of 95% of the barley corns ready to grow. The key stage of the malting process is germination when the barley seed starts to grow. Barley that is not ready to grow, sometimes referred to as 'dormant', is not suitable for malting.

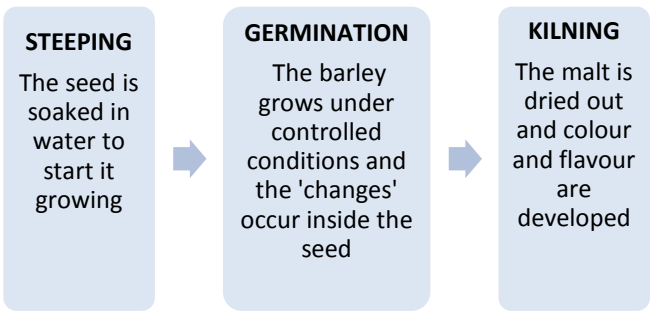
- It must have an acceptable balance between protein content and carbohydrate content, the balance struck to be determined by the beer type being brewed and the brewhouse processing equipment being used.
- The grains should be of an even size. That way they are more likely to grow evenly.
- The grains should be consistent colour, helping indicate the same barely variety and lack of damage due to for instance, moisture.
- The grains should be large. Large corns are easier to process when the malt gets to the brewery.
- The barley must be of a 'malting variety'. Malting barleys are low in protein and the cells containing starch as described above, are easier to break down.
- The corns must be undamaged, free of split or pre-germinated grains and free of disease or pests such as beetles or moths.
- They must be free of other cereals, or other barley varieties.
- The moisture level must be suitable. If freshly harvested, not more than 18%, and suitable for drying to 12% prior to storage at the maltings.

The Malting Process

The purpose of malting is to:-

- Make starch readily available during the mashing process to be converted to a range of fermentable and unfermentable sugars.
- Provide a source of amino acids and proteins for the yeast to be able to grow healthily during fermentation. Note that some of this protein breakdown may take place in the brewhouse, depending on the beer type, malt type and brewhouse equipment.
- Develop desirable colours and flavours which are not present in barley itself.
- Produce a final product which is stable, capable of storage and transport to the brewery.
- Produce a food product which is wholesome and meets food quality criteria.

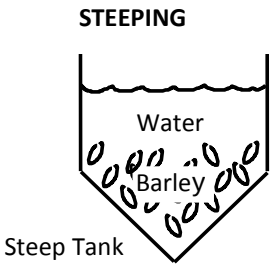
The malting process:



There are three stages in the process of converting barley into malt:-

- Steeping
- Germination
- Kilning.

Steeping:
Barley is soaked in water to simulate the conditions that start germination or growth. This is carried out in a steep tank.



During steeping the grain is aerated, (normally by draining and drawing air through the wet grain bed, before resoaking) to reduce the numbers of grains dying off due to "drowning" and to increase the rate of water uptake. The barley is usually steeped and aerated a number of times - at the end of steeping the moisture content of the barley should be around 45%, dependant on the type of malt being produced.

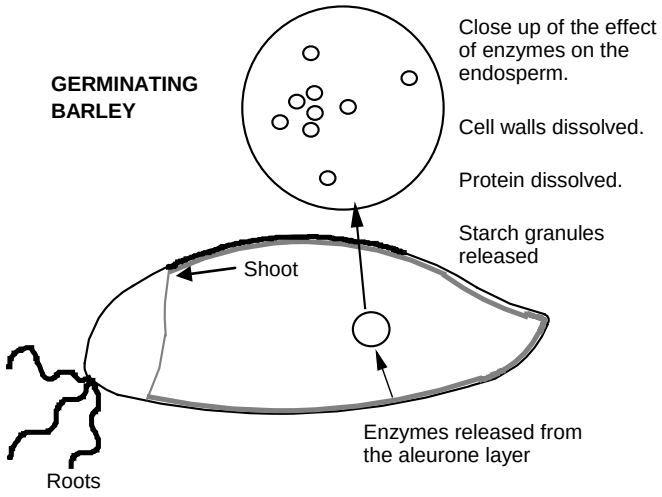
Germination:
On completion of steeping, the barley seed is allowed to grow. During germination two major changes occur:

Firstly, hormones stimulate the production of enzymes in the aleurone layer.

Secondly, these enzymes start to act. During malting they will break down the gummy cell walls and break down the protein matrix inside the starch containing cells. This breakdown releases the starch granules making them accessible for conversion into sugar. The changes taking place during germination are called 'modification'.

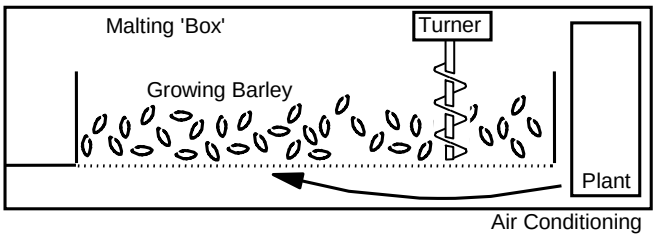
The maltster can influence the degree of modification during malting by controlling the moisture content of the grain, its temperature and the time allowed for germination.

During germination the seed grows rootlets and a shoot.



Germination usually takes place in a chamber or vessel where air is blown, or more normally drawn through the growing malt to prevent it suffocating in the CO2 produced, and to control its temperature and moisture content. Turners mix the malt to prevent the growing roots from matting together and creating masses of grain impermeable to the air. The time required for germination is typically around 4 days.

GERMINATION



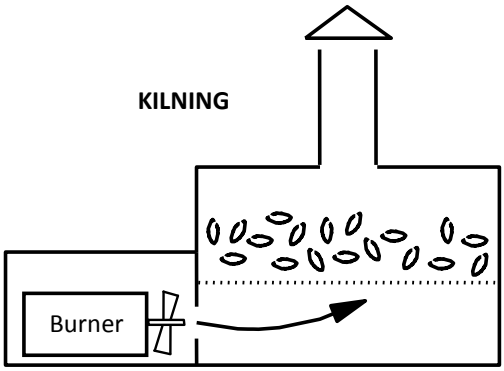
Kilning:
During this stage of the malting process, water is removed from the green malt. The malt then becomes stable and can be stored without deterioration. The malt may also be slightly roasted to give it colour and flavour.

Some of the enzymes, for example those required later in the brewing process for starch and protein conversion must be preserved. The combination of high grain moisture and high temperature would normally destroy the enzymes developed during germination.

The malt kilning process is manipulated so that the malt is dried at a relatively low temperature (around 50°C) using high flows of air. When the malt is dry, with a moisture content of around 10%, the kilning temperature is increased (up to 90°C) so that the malt develops colour and flavour.

At the completion of kilning, the malt's moisture content will be 3 - 5%. The finished malt is normally allowed to rest for at least two weeks before use as this produces a more consistent final product for the brewer to use.

KILNING



The table below details the changes that occur during the malting process:-

Parameter	Barley	Germination	Malt
Moisture	About 12% after drying on the farm or maltings.	About 44 - 48% after steeping.	3 - 5% after kilning.
Extractable carbohydrate	Virtually zero because the starch is protected.	Very high because the starch granules have been released. They are now accessible to enzymes that convert starch into sugar.	Kilning does not change the level of extractable carbohydrate but it does fix it by reducing moisture and stopping germination.
Colour	Very low.	Very low.	Colour is produced when sugars and soluble protein react together at high temperature. An increase in colour occurs depending on the degree of kilning and the levels of sugar and soluble protein present.
Protein Calculated from total nitrogen (TN) content TN x 6.25 = % protein	Malting grade two-rowed barleys for pale ale malts have nitrogen contents of about 1.4 – 1.6% (8.8 – 10% protein). Two-rowed lager malts may have more nitrogen, typically 1.5 – 1.8% (9.4 – 11.3% protein). Some brewers use six-rowed barleys, which have much higher nitrogen contents, typically 1.9 – 2.2% (12 – 13.5% protein).	The overall level of nitrogen does not change, but a lot of the protein is converted into a more soluble form by enzymic action during germination. The important parameter is the ratio of the Total Soluble Nitrogen (TSN) to the Total Nitrogen (TN) in the malt. There are several ways of measuring this parameter, based on the type of mashing system used for the analysis. Soluble nitrogen (protein) includes all the malt enzymes.	Kilning temperatures will reduce some enzyme activities by denaturing the protein. Lighter kilned malts (lower colour) tend to have higher enzyme levels). Dark malts (see Section 2.2) have no enzyme content.

The extent to which the barley endosperm cell walls, proteins and to a lesser extent the starch granules themselves are broken down is termed the 'Degree of Modification'.

Lager malt contains enzymes from the aleurone layer, but without extensive breakdown of the cell walls and proteins, and the malt grain remains comparatively hard and is not very friable. Lager malt is termed 'undermodified'.

Ale malt normally has extensively broken down (modified) cell walls and intracellular proteins. The malt grain is softer and friable compared to lager malt. Ale malts are generally described as 'well modified".

Because of the lack of protein breakdown in lager malt, beers brewed using lager malt may require some additional processing, to enable further protein and β glucan breakdown during mashing in the brewhouse. This may require the use of decoction mashing (requiring mash kettles), rising temperature infusion mashing (mash vessels with heating and stirring facilities) and/or additions of enzymes produced by bacteria or fungi to the mash to ensure appropriate breakdown of the starch granules into sugars.

Beers brewed using ale malts may be brewed in simple mash tuns, with no additional mixing or heating, although modern larger breweries typically use mash mixers with heating and mixing facilities, and heat up from the mash temperature to circa 77 °C prior to wort run off.

Coloured malts may be used with any mashing system.

Adjuncts used in addition to malt may also need specific processing equipment or conditions in the brewhouse to enable their use (see section 1.3).

The principal constituents of malt

Constituent	% content of malt
Starch	58
Sucrose	3 – 5
Soluble Gum	2 – 4
Hemicellulose	6 – 8
Protein	8 – 11
Amino acids/peptides	1 – 2

Typical analysis of lager malt using Analytica-EBC methods

Parameter	Value
Extract, fine grind (% dry basis)	82
Colour (°EBC, 25mm)	3.0
Moisture %	4.0
Kohlbach Index (ratio of soluble N_2 to total N_2)	42
Total protein % dry basis	10.3
Free amino nitrogen, mg/l at 12°P	190

Typical analysis of ale malt using IoB methods

Parameter	Value
Hot water extract, l°/kg	310
Colour	5.0
Moisture %	2.5
Soluble nitrogen ratio (ratio of soluble N_2 to total N_2) % dry basis	0.60
Total protein % dry basis	9.4
Free amino nitrogen, mg/l at Brewer's gravity 48	210

Malt checks at malt intake

The brewer should always check the quality of the malt prior to intake into the brewery malt handling system. Checks typically include

- Verification of type and batch against delivery plan - ensure load/delivery details match the delivery schedule prior to unloading.
- Visual assessment to ensure the malt is free from pests such as beetles, weevils or moths.
- Visual assessment to ensure the grains are of uniform and adequate size. This may be backed up by a screening test where a sample is checked using a shaker with fixed slot sizes of a number of sizes to check particularly for undersized grains. Large corns yield more extract. A range of corn sizes indicates poorly screened barley or uneven germination and will also result in extra brewery screenings or poor milling.
- Visual assessment to ensure the grains are free from broken grains and missing husk, which can create unnecessary dust and losses.
- Visual assessment to ensure the grains are free from other seeds, stones, metal, string etc.
- Visual assessment to ensure the grains are not different colours ('magpie effect') – due to uneven kilning conditions
- Visual assessment to ensure the grains are free from mould. Malt infected during germination can cause gushing. Post kilning mould infection has mycelium over the surface which tends to bind corns together and smells mouldy. Such mould aromas are easily transferred to beer.
- Cut or bite. Well modified malt is friable. A longitudinal or horizontal cut will reveal steely (hard, unconverted / undermodified) parts of the grain or, in the case of crystal type malts any non-glassy (undermodified) areas.
- Flavour malt grains are sucked, not chewed - husk has a high silica content and is abrasive. Pale malts should have a slightly sweet, biscuity flavour and as colour of the malt increases so the biscuity nature increases until in chocolate and darker malts, distinctly acrid flavours predominate. No off notes should be detected.

Notes.

Draw a flow diagram of the malting process. Make notes of the inputs and outputs.

Why can kilned malt be stored and green malt not be stored?

Why is it easier to mill (crush) malt than barley?

1.3 Adjuncts and Coloured Malts

Adjuncts are solid or liquid brewing raw materials that are used to supplement the malt in the grist.

They are used for a number of reasons:-

- To change the character of the beer by altering its colour or flavour.
- To improve the quality of the beer, for example improve the head stability, increase (or decrease) wort fermentability or reduce the potential for haze formation.
- To increase the capacity of the brewhouse by the addition of liquid adjuncts to the wort boiling vessel (copper/kettle).
- To reduce production costs.
- To increase brewhouse capacity.
- To improve brewhouse yield by, for example, replacing some malt with sugar syrups.

Categories of Adjunct.

There are four major categories of brewing adjunct:-

- **Malted cereals** that are used in the grist along with the malted barley.
- **Processed cereals** that are also used in the grist.
- **Unprocessed cereals** that require additional processing in the brewhouse.
- **Sugars or syrups** which are added to the copper/kettle or later in the process.

Coloured Malt
Coloured malts are used to increase beer colour, and or to modify flavour. Because of their nature they produce a more stable beer. During the extra kilning used for coloured malts, the proteolytic and amylolytic enzymes will have been destroyed.

Crystal malt is produced by a different kilning procedure. Un-kilned germinated (green) malt, or kilned pale malt rewetted to achieve high moisture content is heated on the kiln and is 'stewed' before it is dried and kilned (again). This produces a high colour and a distinctive toffee flavour. Crystal malt is used in ale brewing to provide a rich red colour and a distinctive flavour. Colour typically 140 - 170 ^{O}EBC.

Carapils and Munich malt are similar to crystal malt but they have a lower colour and a more delicate flavour from using undermodified malt followed by less kilning.

Carapils and Munich malt are used to add colour and flavour to lagers. Munich malt has a colour of approximately 17 – 30 ^{O}EBC. Carapils has a colour of 15 – 30 ^{O}EBC.

Amber malt is produced by roasting almost fully dried malt (the level prior to final kilning) in a drum to give it a slightly higher colour and biscuity flavour. Colour typically 90 – 190 ^{O} EBC. This can be used as an alternative to crystal malt, giving a drier finish to the beer than crystal.

Brown malt is produced from standard malt that has had extra kilning, usually by wood burning fires. It is used to add a lot of colour and an oaky character to the beer. Colour typically 140 - 160 ^{O}EBC. Often used in porters and stouts.

Black malt and Chocolate malts are produced by roasting finished malt in a drum. Both malts have a very high colour and a dry bitter flavour. They are used in stouts to give a very dark and highly flavoured beer. Very small quantities may be used to add colour to bitter type beers, without adding the flavour that crystal or amber malt would give. Colour typically 1200 – 1400 ^{O}EBC.

Roasted Barley is used to contribute colour and the distinctive burned coffee flavour to stouts. Colour typically 900 – 1500 ^{O}EBC.

Wheat
Wheat is a cereal like barley and it can be malted in the same way. It does however, have different characteristics. For example it has a very thin husk and its starch is less protected. The flavour it produces is different and the nature of its protein is different from barley protein, increasing head stability, but it will not clarify on the addition of finings.

Malted Wheat is used as the main carbohydrate source in Munich Weissbier. It contributes to the beer's distinctive appearance, colour flavour and outstanding head stability. It may in extreme cases be used at up to 50% of the grist.

Torrified Wheat is produced by heating the moistened but unmalted grain to rupture the internal structure and release the starch so that it is accessible when mashed in the brewhouse. Torrified wheat is used at up to 10% to improve the beer's head stability and because it is cheaper than malt, to save costs.

Wheat Flour is produced by milling wheat, the process releases and separates starch from the embryo and the protein that is present at high levels. It is used at up to 10% to improve the beer's head stability, to reduce protein levels in the grist and to save costs because it is much cheaper than malt.

Maize
Maize (or corn) is a common crop grown in warm and temperate climates. It is a cheap source of carbohydrate. The starch is readily accessible but it must be 'gelatinised' at high temperature before it can be converted into fermentable sugar. Maize is typically used at up to 20% of the grist in lager to reduce malty flavours and produce a clean delicately flavoured beer.

Maize grits are produced by milling the maize and at the same time removing the germ which contains protein and oil. Maize grits must be cooked in the brewhouse to gelatinise the starch. Maize grits are cheaper than malt and can reduce costs.

Maize flakes are produced by processing grits through hot rollers which gelatinises the starch and makes it accessible to the malt enzymes.

Rice

Rice is a very common crop and a major source of carbohydrate. Rice is used in brewing for the same reasons and in the same way (up to 30% of the grist) that maize grits and flakes are used. Both grits and cold rolled flakes require cooking with temperature stable enzymes before being added to the mash. Steam treated rice, rolled into flakes may not require cooking if the heat treatment has been adequate.

Oats

Although not widely used, oats can be added in flaked form to the mash tun or mash conversion vessel, where the malt enzymes can work on the starch in the oats. Typically oats are added to stouts in a style associated with those traditionally brewed in Scotland. They give a smooth silky mouthfeel and creaminess to stouts and porters.

Rye

Associated with German Roggenbier and made popular by North American micro brewers, rye can be added as malted rye, or unmalted to the mash conversion vessel / mash tun, or as whole grains to a cereal cooker at 10 – 20 % of the total grist. The rye increases palate fullness, and a crisp slightly spicy flavour.

Sorghum

Barley is not able to grow in semi-arid regions of the world whereas sorghum grows well. It is possible to malt this cereal and use as a replacement for barley malt. However it has a high gelatinisation temperature and therefore a unique mashing process, involving heat stable enzymes, has to be used. Like wheat, it is a 'naked' grain, which means that its husk is thin and lost during handling. Consequently it is best used with a mash filter.

Sugars

Sugar can be grown naturally as in the case of sugar cane or beet. It can also be produced from starch, often from maize. The method of production will dictate the type of sugar - sucrose from cane sugar, glucose or maltose from starch. A range of fermentabilities and flavours are available. Sugars are used at up to 30% of the grist, though most brewers use a considerably lower rate.

Sucrose is mostly used in liquid form. It is highly fermentable and is usually added to the wort copper / kettle. It is used to supplement the malt where malt processing plant (storage, mills, mash tuns etc.) is a limiting factor.

Sucrose can be added to the beer after fermentation as 'primings' to provide sugar to encourage conditioning or to increase sweetness.

Invert is produced by hydrolysing sucrose and it can be liquid or solid. It is added to the copper/kettle and is used for the same reasons as sucrose although it has a more distinctive flavour.

Glucose is produced from starch and is used in liquid form in the same way that sucrose is used. Its fermentation characteristics are very similar to sucrose.

High Maltose and Maltotriose syrups etc. are produced from starch and are used in liquid form in the same way that sucrose is used. Their fermentation characteristics depend on the sugar type so that they can be used to modify the fermentability of the wort and therefore the character or alcohol content of the beer.

Lactose is produced from milk whey and is used to contribute body and a creamy mouthfeel to milk stout. It is normally added to the wort copper / kettle, but may be added as priming sugar after fermentation. It is unfermentable.

Caramel is extremely dark and has a burned toffee flavour. It is produced from sugars and is used to contribute colour and flavour to beers like stouts and dark milds. It may be added in the wort copper / kettle or post fermentation, typically to adjust the beer colour, though some brewers look for the distinctive caramel flavour to be evident.

Use of Adjuncts

Malted cereals are used in the grist in varying proportions along with the malted barley.

Un-malted cereal adjuncts are typically used in the brewery or distillery in one of three ways.

Cereal cooker – in a cereal cooker the **unprocessed adjuncts** generally contain starch in their unrefined forms, such as grits, flour, dry grain or starches. These adjuncts need to be gelatinised (to allow the starch molecule to be enzymatically converted to fermentable sugars) and liquefied to allow solubilisation and pumping to the main malt mash in a second vessel where the malt enzymes can now be used to modify the starch from the adjunct and create fermentable sugar.

Mash conversion vessel – if the starch gelatinisation temperature is lower than that of the malt conversion (or saccharification) temperature required, or when the adjunct has been **pre-gelatinised** by flaking or torrification, or pre-refining (syrups), then the adjunct can be added directly to the malt in the single mashing vessel.

Brew kettle – liquid brewing sugars are usually added directly to the wort kettle, where it is readily dissolved in the boiling wort.

As well as un-malted cereals such as maize, rice, and wheat being used by brewers as adjuncts, the use of un-malted barley is also common as it gives a rich and grainy flavour to the beer (as well as being typically cheaper than the malted equivalent). It will help improve foam retention at the detriment to physical stability due to the higher level of nitrogen and proteins.

In order to improve the abilities of a malted cereal (such as malted barley) to convert an un-malted adjunct to fermentable sugar there are a number of techniques available in the mash. High enzyme malts are available which deliver the enzymes required to convert gelatinised un-malted cereals into the highest amounts of fermentable sugars. These malts are produced using specialised barley varieties and processing regimes and are commonly used in the grain distilling industry. The modern use of separately produced enzymes in the mashing process - for starch liquefaction in a cereal cooker, for saccharification in a mash cooker, for mash separation improvement - or for fermentability improvement, for beer filtration improvement, or for optimal beer stabilisation downstream of the brewhouse, has changed the range of a brewer's abilities over recent years as development and availability of these enzymes has continued.

1.4 Mash Conversion

Mashing is the process where the grist of crushed malt or crushed malt and suitable dry adjunct is mixed with water under specified conditions so that enzymic action can take place to convert the starch into fermentable sugar and in certain cases break down proteins into more soluble forms.

Milling, Mashing and Conversion

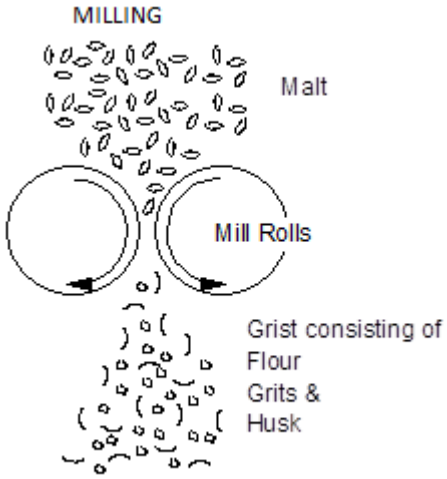
Beer production starts in the brewhouse where the malt is processed to release fermentable sugars.

MILLING	MASHING	CONVERSION
The malt is crushed	Crushed malt is mixed with water to start the conversion process	The starch is converted into sugar by the malt enzymes

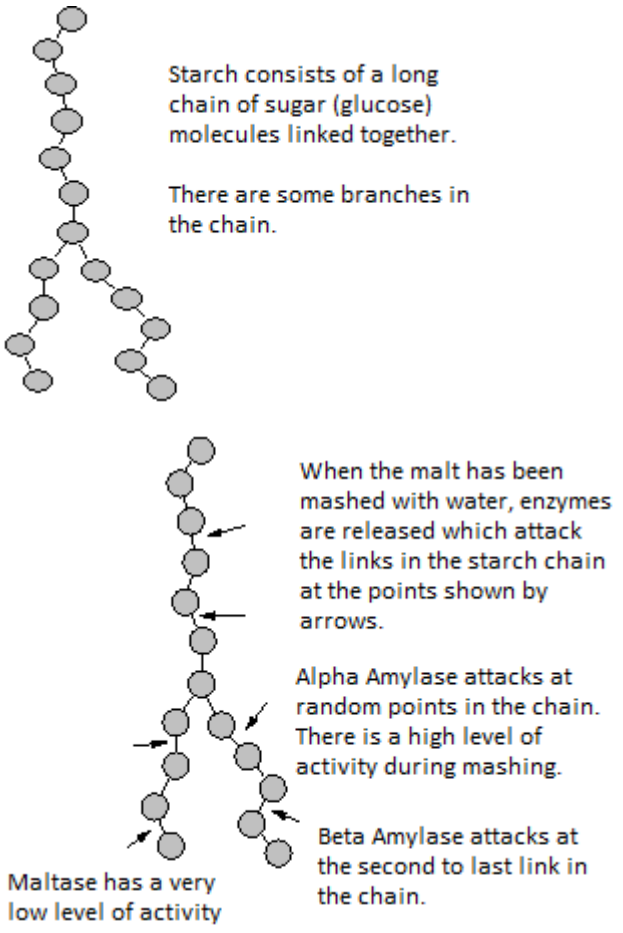
First the malt is **milled** to grind the starch into flour while protecting the malt husk because undamaged husk is required later.

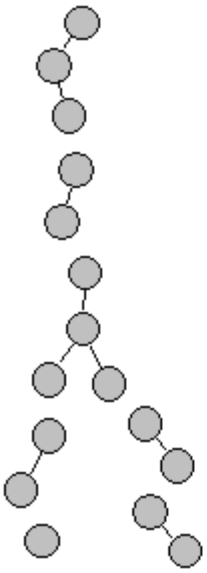
Then the milled malt or grist is **mashed** in with controlled quantities of water of specified mineral composition and pH at specific temperatures. This process brings the enzymes present in the malt into action and they convert the malt starch into sugar. If necessary, this starch degrading stand is preceded by a proteolytic stand to break down the cell protein content and release the starch granules.

The production of fermentable sugars from starch is a complex biochemical reaction starting with 'gelatinisation' of the starch by heat. This is where the spiral configuration of the starch molecule is unwound so the enzymes can attack.



Conversion follows and the diagrams below illustrate how the enzymes in the malt attack the long chains of sugar units that make up the starch molecule and convert them into fermentable wort:-

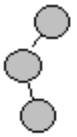




The result of the enzyme attack is shown here.

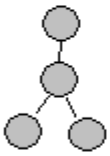
These units are sugars and they dissolve in the water used in the mash. The liquid is called wort.

Most of these sugars are fermentable but some are not.



This sugar is called maltotriose. It will ferment slowly.

This sugar is called maltose and it ferments quickly.



This sugar is a dextrin and it will not ferment.

This sugar is called glucose and it ferments very quickly.

The range of sugars produced during conversion determines the fermentability of the wort. If the enzyme attack is complete, the wort will be very fermentable. If the enzyme attack is incomplete, the wort will be only partially fermentable.

Enzymes are sensitive to the conditions that they work in. They are affected by how much water is present, temperature and pH (mash acidity), and mineral ions present, particularly calcium which reacts with phosphates from the malt, and results in a reduction in pH. They take time to work, so the length of time that is allowed for mash conversion will affect the degree of conversion.

There are optimum conditions for mashing and these are illustrated in the table below:-

Condition	Low	Optimum	High
Temperature	Low temperatures do not adversely affect the enzymes much, but the starch must be gelatinised first. Gelatinisation temperature for malt starch is between 60°C and 65°C, dependant on barley variety.	60 - 65 °C	High temperatures inactivate enzymes including α-amylases and β-amylases. The action of amylases is stopped at temperatures over 70 °C.
pH	Acidic conditions kill the enzymes. Enzyme action is stopped if the pH is below 5.0	5.4	High pHs slow enzyme action, but it does continue at pHs of 7 or above.
Water (mash thickness)	Enzymes are more sensitive to heat in a thin mash. The enzyme is degraded more quickly in thin mashes, and because there is a lower concentration of enzyme and starch in a thin mash, contact between the starch and enzyme is not so easily achieved. Thicker mashes also have higher viscosity and results in slower sugar extraction, particularly in wort runoff.	Between 2.5 and 3.5 litres of water per kilogram of dry grist.	Enzymes are less sensitive to heat in a thick mash. There is a higher concentration of enzyme and starch in a thick mash.
Time	Enzymes take time to attack the starch. Conversion will be incomplete in less than 30 minutes.	30 minutes	Conversion will be virtually complete after 30 minutes. A longer time will not increase the yield of sugar but may make it more fermentable.

Proteolysis is the term used to describe enzyme action that breaks down proteins into simpler soluble forms. The action of proteolytic enzymes is very similar to that of the starch breakdown enzymes except that their optimum temperature is slightly lower at 50 - 54°C and pH 5.5.

- It becomes necessary for proteolysis to take place during mashing when the malt is undermodified and the proteins surrounding the starch granules have not been completely broken down during malting (see section 2.1).

- Mashes with undermodified malt, for example lager malt, will allow for this by having a low temperature stand for the proteolytic enzymes to work, followed by a 'saccharification' stand for the starch enzymes to work.

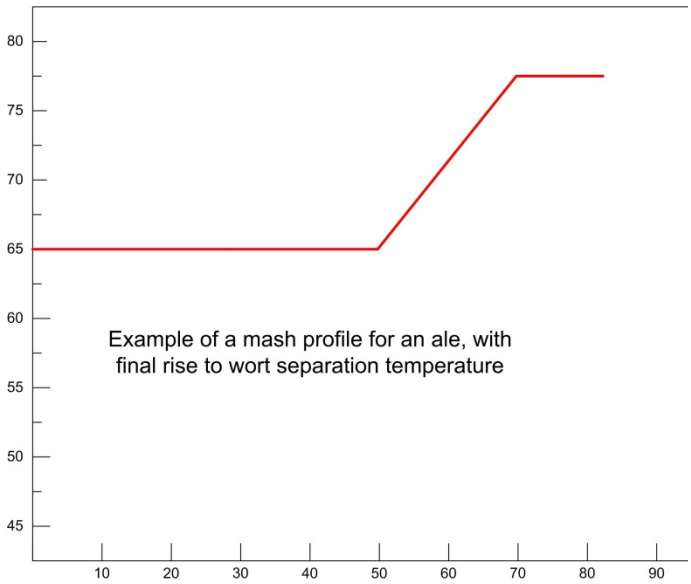
- Mashes with well modified malt only need a saccharification stand.

Amylolysis is the term used for the breakdown of starch into sugars of varying degrees of complexity. α-Amylase, which randomly attacks the starch chains has an optimum temperature of 67°C, and pH of 5.2. β-Amylase, which attacks the ends of the starch chains has an optimum temperature of 62°C, and pH of 5.25. The amylolytic stand temperature is therefore a compromise of the two optima to achieve the desired fermentability.

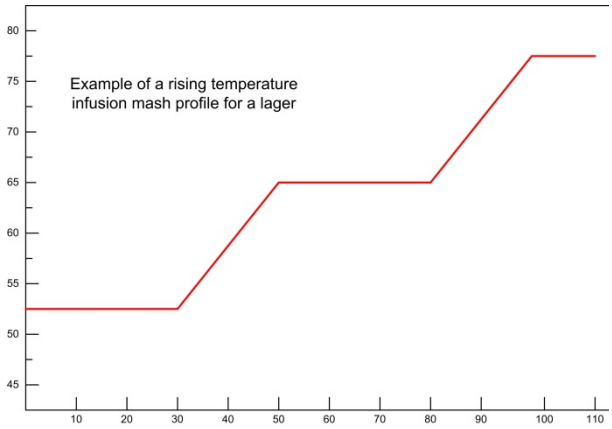
β-Glucanase, which breaks down the β-glucans in the endosperm cell walls has an optimum temperature of 56 °C, and pH of 6.0, which is why it is sometimes considered necessary (where permitted) to add additional β-glucanase to the mash.

These principles are illustrated in the examples below:-

Ale mash with final temperature rise -



Rising temperature infusion mash – lager



The temperature rise to 77 °C at the end of the amylolytic stand is to improve filterability in the wort separation system by reducing the viscosity, and to stop any remaining enzymatic activity which would affect wort fermentability.

Monitoring starch breakdown

At the end of the saccharification process it is advisable to check that the starch has been fully broken down into sugars, and no starch remains. This is quickly carried out using the "iodine" check.

The iodine colouration with starch and higher dextrins only occurs in the cold mash, so the mash sample must be cooled. The cold mash sample is then brought into contact with a drop of tincture of 0.02N iodine solution in a porcelain dish or block. No dark blue / black colouration of the yellowish iodine solution, which would indicate the presence of unconverted starch, must occur.

1.5 Grist Composition and Extract Performance

The components of a brewing grist: The ingredients used in a brewing recipe determine the brew's volume and the beer's alcoholic strength and flavour. Complex calculations are required to ascertain how much of each component is needed to end up with the desired beer.

The following example illustrates the principles of the calculations to produce 50,000 litres of wort with a specific gravity (SG) of 40 degrees.

Malt - 95%

Contribution – from a malt with extract value of 300 litre degrees per kilogram.

$$\frac{50{,}000 \text{ litres} \times 40 \text{ degrees} \times 95\%}{300 \text{ litre degrees per kilogram}} = \mathbf{6{,}333\ kg}$$

Coloured malt 5%

Contribution - Extract value of 250 litre degrees per kilogram.

$$\frac{50{,}000 \text{ litres} \times 40 \text{ degrees} \times 5\%}{250 \text{ litre degrees per kilogram}} = \mathbf{400\ kg}$$

Water for mashing and sparging

Contribution - Volume of water used for mashing and sparging.

Approximately 8 litres of water per kg of dry grist
(6,333 + 400) X 8 = **53,864 litres**

Compensation for losses is made below.

Make-up water

Contribution – To dilute the boiled cooled wort to the required specific gravity.

Approximately 0.75 litres of water per kg of grist is left in the spent grain.

(6,333 + 400kg) X 0.75 = **5,050 litres.**

Approximately 8% of water is lost through evaporation during boiling.

(53,864 litres – 5,050 litres) X 8% = **3,905 litres.**

Water from mashing and sparging –	53,864 litres
minus spent grain	5,050 litres
minus evaporation	3,905 litres
	44,909 litres

Water required to make up to 50,000 litres, with a specific gravity of 40° = 50,000 – 44,909 = **5,091 litres.**

Explanations:-

- The specific gravity is measured and as a true SG, would read for example, 1.0400. However, for simplicity, the whole digit is removed, and so the SG is specified as 40.0 (termed Brewer's Degrees).
- All materials that contribute to the carbohydrates in the brew have an extract value. This may be stated in litre degrees per kilogram: this means that one kilogram of the material will contribute '300 litre degrees' to the brew. A litre degree is one litre at one degree. Our brew needs 50,000 litres times 40 degrees = 2,000,000 litre degrees.
- Note that different materials have different amounts of available extract. For instance, pale ale and lager malts have an available extract of around 300 - 310 litre degrees / kg. Coloured malt such as crystal malt has an available extract of around 270 - 275 litre degrees / kg. High maltose syrup used for addition to the wort copper (kettle) has an available extract of around 310 - 315 litre degrees / kg. Note that the values used in the calculation have been adjusted for simplicity.
- The quoted malt extract values are always for 'best case' and refer to laboratory values or '100% Extract Efficiency' (see below). Most brewhouses will not be able to recover 100% of the available extract, and this will have to be factored in to the grist calculation. This simplified calculation assumes that 100% of the available extract in the malt is extracted into the wort.

Brewing Water:-

Product water (brewing water and water used in the production of beer, i.e. it will eventually be consumed by the customer) makes a major contribution to the quality of the beer that is produced.

Salts dissolved in the water affect the beer's flavour, they influence the pH (acidity/alkalinity) of the process and the final product and they provide essential trace elements for yeast growth.

For more details of brewing water see Section 18.

Measurement and control of extract yield and efficiency

Malt is an expensive raw material and achieving good extract levels is therefore very important.

Extract Yield is a measure of how much of the available material in malt and adjunct has been converted to useful extract for the production of beer.

Extract Efficiency is a measure of the effectiveness of the brewhouse in its use of malt and adjuncts. That is how much material from the malt and adjunct has been converted, as compared to the total amount of extract available to the brewer.

Extract Yield is calculated as follows:-

Total amount of dissolved material in the wort divided by the total weight of raw materials used.

Using Specific Gravity:

$$\frac{\text{Volume collected X specific gravity}}{\text{Weight of malt + adjuncts}} = \text{litre degrees / kg}$$

Example - 10,000 **litres** of wort at a S.G. of 60° are collected from 2000 kilograms of malt. The extract is:-

$$\frac{10{,}000 \times 60}{2{,}000} = \textbf{300 litre degrees / kg.}$$

300 litre degrees of extract was obtained from every kilogram of malt used.

Or using degrees Plato and EBC extract units:

The relationship between degrees Plato and specific gravity (SG) is not linear, but a good approximation is that 1° Plato equals four "brewer's degrees"; thus 12° Plato corresponds to an SG of 48.

Example - 10,000 **kg** of wort at a S.G. of 15° Plato are collected from 2000 kilograms of malt. The extract is:-

$$\frac{10{,}000 \times 15}{2{,}000} = \textbf{75\%.}$$

75 % of the weight of the malt has been converted to extract.

Both of these calculations are based upon the total weight of raw material being used, and represent the brewhouse yield.

Remember that a large percentage of the malt or adjunct is insoluble, such as malt husk which is removed with the spent grain, and does not contribute to brewhouse extract.

A yield of between 285 and 300 litre degrees per kilogram, or between 74% and 79% would typically be expected.

Extract Efficiency is calculated as follows:-

Total amount of dissolved material in the wort divided by the theoretical maximum amount of dissolved material available from the malt and extract used.

By obtaining a theoretical maximum extract yield for each of the malt and adjuncts using laboratory conditions, it is possible to compare the extract obtained in the brewhouse with the maximum extract available in the malt and adjunct used.

The malt supplier will normally perform this laboratory analysis, expressed as the fine grind laboratory extract, on each batch of material produced. It is normally expressed 'as-is' (or as supplied to the brewery) or on a 'dry' basis, in which case it can be corrected for the moisture content of the material supplied.

Example –

Fine grind extract (as-is) – 310 litre degrees per kilogram.

Brewhouse extract yield – 300 litre degrees per kilogram.

$$\text{Extract Efficiency} = \frac{300}{310} = \textbf{96.8\%}$$

Example –

Fine grind extract (dry basis) – 320 litre degrees per kilogram

Malt moisture – 3%

Fine grind extract (as is) =

$$320 \times \frac{(100-3)}{100} = 310 \text{ litre degrees / kg}$$

$$\text{Extract Efficiency} = \frac{300}{310} = \textbf{96.8\%}$$

By calculating extract efficiency, a brewer can compare the performance of the brewhouse equipment and procedures and, unlike the calculation of extract yield, the variable nature of the raw materials will not affect the result.

By knowing the typical extract efficiency of the brewhouse, a brewer can compensate for this factor when calculating the components of a brewing grist.

Note that most, if not all, brewhouses do not achieve 100% extract efficiency. Potentially available extract from the raw materials is lost for a number of reasons, including:-

- dust and grain losses in the malt intake, handling and milling systems.
- the wort separation system. Simple mash tuns recover less than lauter tuns, which in turn recover less than modern mash filters.
- wetting losses throughout the brewhouse and wort transfer system to the fermenting vessels (FV).

It is common practice therefore to calculate the brewhouse extract efficiency based on extract actually achieved in the FV compared to the theoretically available extract.

Practice question

Calculate the yield of malt extract, and the extract efficiency of the following brew :-

3,000 kilograms of malt supplied at 300 litre degrees / kg (78.4% available extract) are used.

200 hectolitres of wort is collected.

The original gravity is 1.044° SG (44° brewers degrees or 11°P)

Answers:

200 hl = 20,000 litres of wort at specific gravity of 1.044

(A) SG Method:

Potential available extract = 3,000kg x 300 ldk

= 900,000 litre degrees

Actual extract achieved = 20,000 litres x 44°

= 880,000 litre degrees

Extract yield = $\frac{20{,}000 \times 44}{3000}$ = **293.3 litre degrees per kg.**

Extract efficiency = $\frac{\%\ \text{actually extract}}{\%\ \text{potential extract}} \times 100$

= $\frac{880{,}000 \times 100}{900{,}000}$ = **97.7 %**

(B) EBC/ASBC Method (° Plato)

°Plato is % weight/weight, or kg extract / kg wort.

Given that we have a **volume** of wort (200hl), and not a **weight** of wort, we need to perform a simple conversion using specific gravity.

200 hl = 20,000 litres of wort

20,000 x 1.044 = 20880 kg of wort

Now we can use 11°P to convert to kg of extract within the mass of wort (11°P is equivalent to 11 kg extract per 100 kg of wort). So,

20880 kg wort x $\frac{11\ \text{kg extract}}{100\ \text{kg wort}}$

= 2296.8 kg extract

Dividing by the mass of malt gives us:

Extract yield = $\frac{2296.8\ \text{kg extract}}{3000\ \text{kg malt}} \times 100$

= 76.56 %

Extract efficiency = $\frac{\%\ \text{actually extract}}{\%\ \text{potential extract}} \times 100$

= $\frac{76.56 \times 100}{78.4}$ = **97.7%**

Notes.

Write down the ingredients used in a brew that you are familiar with.

What is the theoretical (potential) extract of each of these materials?

What is the volume of wort produced?

What is the gravity of the cooled wort before fermentation?

Carry out the above calculations using the material quantities and extract potential of each of them.

What adjuncts, if any are used, and why?

Qualifications

The General Certificate in Brewing (GCB)

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Section 2 Sweet wort production (Methods & Plant)

2.1 Brewing process overview

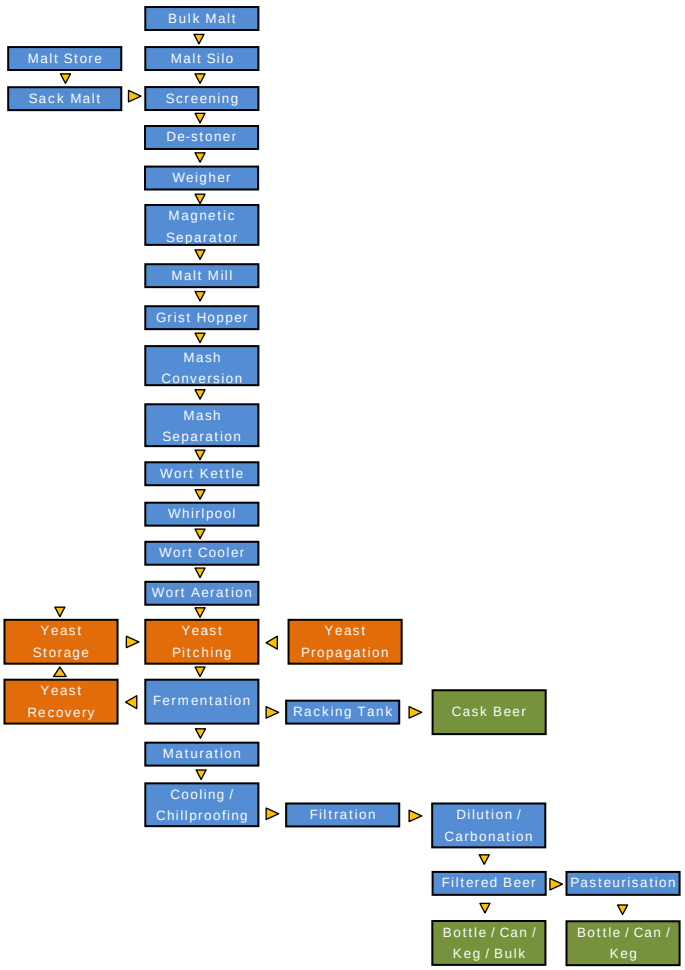
Overview of the brewing process

The sequence of events from raw material intake to the production of wort for fermentation all occur in the brewhouse, as summarised below:-

- Malt is taken into the brewhouse and stored until required. If small volumes of beer are being brewed, the malt is likely to be received and stored in sacks. This can be as whole malt, or pre-ground malt if the brewery does not have a malt mill. In larger operations, malt is normally received in bulk deliveries of a number of tonnes at a time, and transferred to malt silos.
- Adjuncts such as flaked maize, rice or wheat flours may be received and stored, again in sacks or in bulk. Sugar adjuncts may be received in granular form, or as syrups.
- The majority of breweries have their own mills. Malt is taken from the malt storage area, screened to remove unwanted debris, including stones and metal, weighed and milled into a grist case.
- The malt and where used, adjuncts are mixed with warm water (mashing) to allow release of fermentable sugars (conversion).
- The wort is then separated from the grains, normally using a mash tun, lauter tun or mash filter. The sweet wort extracted from the malt is boiled with hops (or occasionally other ingredients) to stabilise the wort by inactivating the enzymes, to sterilise and concentrate the wort, and to extract the desirable flavours from the hops or other ingredients. See section 3, wort boiling for details. The unwanted solid material, the spent grains are normally used for animal feed, but occasionally for biofuel.
- The boiled wort is then clarified to remove the bulk of the solids entrained in the wort, cooled to a suitable temperature to allow the yeast to grow and aerated to allow the yeast to grow healthily. See section 4, wort clarification, cooling and oxygenation for details.
- The cooled wort has yeast added (pitching) and is then allowed to ferment under controlled conditions to produce green beer. See sections 5, 6 and 7 for details.
- The green beer is then matured, to remove the bulk of the yeast and allow the final desirable beer flavours to develop, and undesirable flavours to be removed. See section 8 for details.
- If beer is to be packed in bottle, can or keg, the beer is normally filtered to remove the remaining yeast and haze forming materials. See section 9 for details of filtration processes including kieselguhr and kieselguhr free filter systems and stabilizing processes up to and including bright beer tank.
- If beer is to be packaged in cask, or as naturally conditioned beer in bottle, after maturation, the beer is normally filled into casks or bottles without filtration. Sometimes, beer is filtered first and yeast added back to allow in package conditioning.
- Packaging of filtered beer in bottle can or keg is covered in detail by the General Certificate in Packaging.

Brewery process overview diagram

The following diagram shows an example of the typical stages of production of a brewery with a milling system, and final package into a variety of package types.



2.2 Plant operation – grain handling & milling

The purposes of milling

The purpose of milling is to prepare the malt for mashing and starch conversion by making the centre of the malt corn accessible. Where a wort separation system like a mash tun or lauter tun is used, milling must crush the starch into fine particles while preserving the husk so that it can be utilised as an effective filter during separation. Water may be added to the malt prior to milling to reduce the damage to the husk, either as a small percentage (conditioning) or with the entire mashing water (wet milling). Where a mash filter is used, the preservation of the husk fraction is less important and a mill that crushes the whole dry grains into fine particles can be used.

Malt must be screened before milling to remove unwanted material such as straw, stones or dust. The stones in particular are likely to damage roller mills used for lauter tuns and mash tuns. Malt must also be screened using magnets for hard ferrous objects as these can cause sparks, which may lead to explosions or fire.

In general terms, the less well modified the malt, the finer it needs to be ground, and the faster the extraction process, the finer the malt has to be ground.

Grist fraction analysis

The quality of the grist or crushed malt that leaves the mill has a major effect on subsequent performance in the brewhouse.

- If it is too coarse, the starch will remain protected from mash water and the enzymes will not be able to convert it into sugar. The extract efficiency is also likely to be low due to incomplete conversion and due to slow extraction of the sugars out of the large particles during wort run-off.
- If it is too fine, wort separation will be slow because the filter bed will become choked. Considerable quantities of fine solids from the malt are also likely to be washed out with the wort.

Grist quality can be judged by 'eye' or by sieve analysis.

- To the eye, the grist for mash tuns and lauter tuns should contain large pieces of empty husk and small pieces of white grist and a little flour.
- A sieve analysis is more objective and the mills settings should be adjusted to give the required (optimum) performance, in terms of extract efficiency, run-off time and wort clarity for plant. "Ideal" ratios of husk, grits and flour are specified by the suppliers, and the actual grist is likely to be close to, but not exactly matching this ideal, due to variations in associated plant and the malt being milled. There are two widely used sets of sieves, each with a number of accurately manufactured mesh sizes set one above the other, EBC and ASBC.

ASBC analysis – 6 sieves		
Sieve	**Mesh width mm**	**Characteristic**
1	2.0	Coarse husk held
2	1.4	Medium husk held
3	0.5	Coarse grits and small husk held
4	0.25	Medium grits held
5	0.18	Fine grits held
6	0.15	Ordinary flour held
Base	-	Fine flour collected

The husk volume retained by the 2.0 and 1.4 mm sieve may be weighed separately, the volume measured separately, and the result converted to volume per 100 grams grist. It is useful to be able to calculate these fractions separately and together. They provide a good guide to the lautering capability of the grist. It has been found that when there is a husk volume of 600 mls / 100 gm of material retained by the 2 and 1.4 mm sieves, efficient extract recovery and total turnaround times can be achieved when using a lauter tun or mash filter.

Typical critical grist fractions for a lauter tun where a six sieve laboratory analysis set is in use are as follows:

- Top three sieves: Husk
- Middle two sieves: Grits
- Bottom sieve and pan: Fines
- The husk fraction for conditioned malt should be > 600 ml / 100g husk
- The fines fraction for conditioned malt should be 10 - 15 % w/w.

EBC analysis – 5 sieves		
Sieve	**Mesh width mm**	**Characteristic**
1	1.27	Coarse husk held
2	1.01	Medium husk held
3	0.547	Coarse grits and small husk held
4	0.253	Fine grits held
5	0.152	Ordinary flour held
Base	-	Fine flour collected

Note that in practice, the sieve sizes for both these sets of sieves often use values slightly different from the nominal values according to the manufacturer. However, the percentages obtained from each value vary little.

Examples of grist analyses for mash tuns, lauter tuns and mash filters are shown in the following table. In practice the target percentage for each depends on whether emphasis is on extract or throughput (or these days both), malt quality, lautering and control capability, so there is no one optimum value.

Grist analysis EBC			
	Mash tun	**Lauter tun**	**Mash filter**
Sieve 1 > 1.25 mm	30 %	20 %	1 %
Sieves 2 & 3 1.25 – 0.5 mm	24 %	45 %	9 %
Sieves 4 & 5 0.5 – 0.125 mm	40 %	25 %	55 %
Bottom < 0.125 mm	6 %	10 %	35 %

Malt mill operations

Brewhouse mills are designed to meet the requirements of different types of malt and the different mashing and mash separation systems in use.

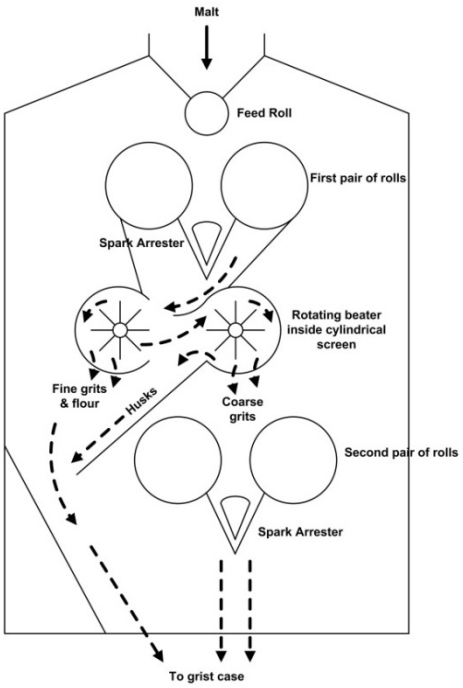
Four roll mills

Four roll mills are often used for milling well modified ale malts where the starch is readily accessible and a mash tun will be used for mash separation. Because the malt is well modified, and friable, the malt does not need to be broken into fine particles for effective wetting and enzyme action.

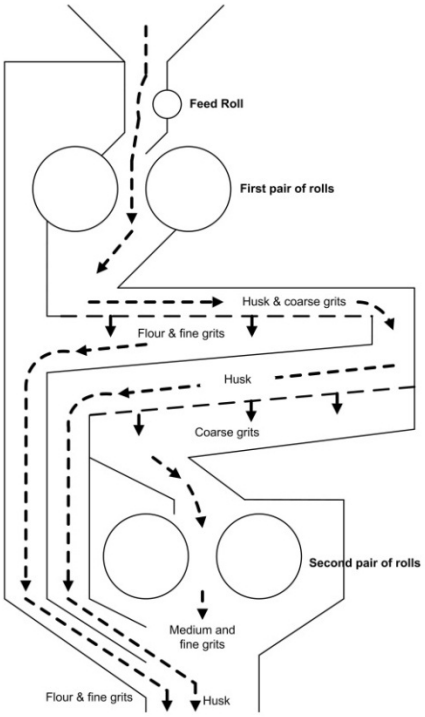
A four roll mill is therefore generally considered adequate for mash tun operations. The following describes the actions of a 4 roll mill with beaters and screens.

- The feed roll controls the flow of malt into the mill.
- The first (upper) pair of rolls crack open the malt to release most of the endosperm.
- The beaters and separation screens send fine particles and the husks straight through to the discharge and coarse particles through to the second pair of rolls.
- The second pair of rolls crush the coarse particles.

Typical 4 roll mill with beaters and screens



Typical 4 roll mill with screens only



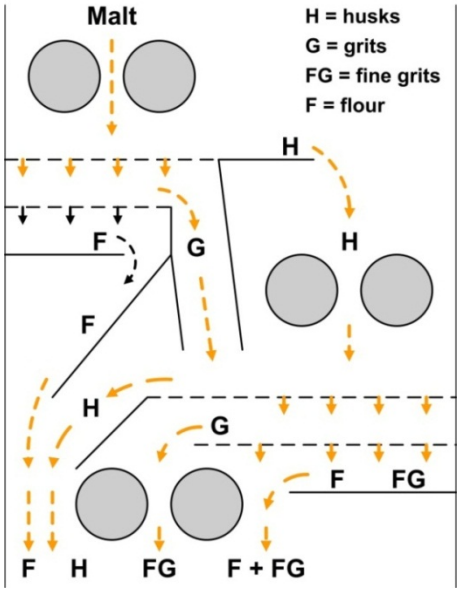
Six roll mills

Six roll mills are often used for milling less well modified lager malts where the starch needs to be finely ground to allow rapid wetting in the mash vessel. The husk has to be protected as complete as possible to allow rapid lautering and good extracts. The malt may be "conditioned" with steam or warm water prior to milling to help soften the husk, so making it less likely to break up into small pieces.

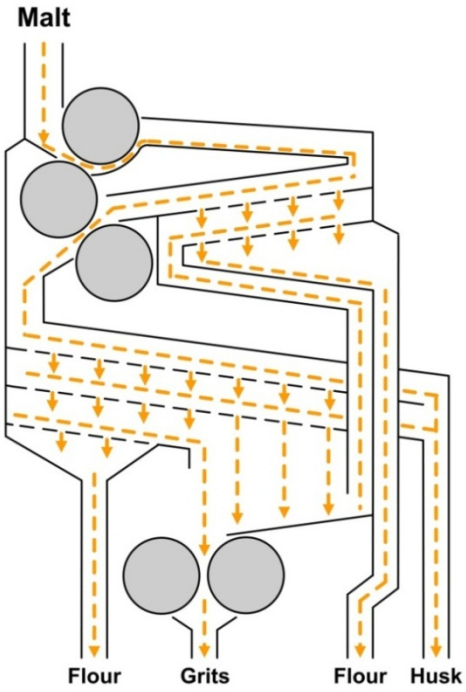
- The feed roll controls the flow of malt into the mill.
- The first (upper) pair of rolls crack open the malt to release most of the endosperm.
- The first (upper) screen sends flour straight through to the discharge, grits to the third pair of rolls, and coarse particles through to the second pair of rolls.
- The second pair of rolls crush the coarse particles.
- The second (lower) screen sends flour straight through to the discharge, husk straight across the screen to the discharge, and grits to the third pair of rolls.
- The third pair of rolls crush the grits to produce fine grits.

5 roll mills

This design of mill is very similar to the 6 roll mill. In effect, one of the rolls of the first pair is used as one of the rolls of the second pair, as indicated below. These are less commonly used than 6 roll mills, as there is little real financial gain.



Typical 6 roll mill



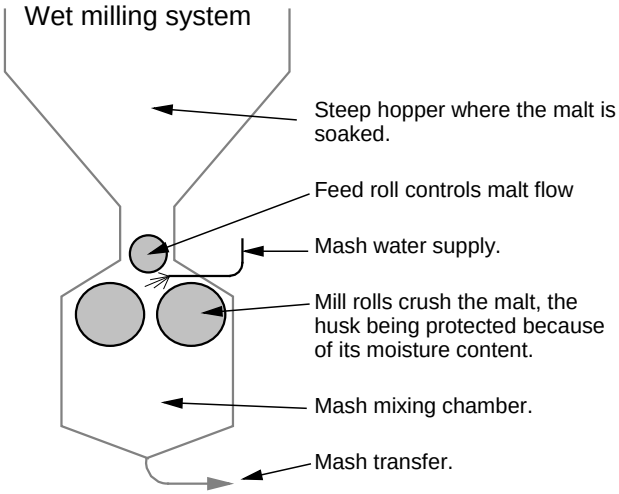
Typical 5 roll mill

Two roll mills

Two roll mills are most commonly used by smaller brewers. The grist composition cannot be as accurately controlled compared to those produced by four or six roll mills.

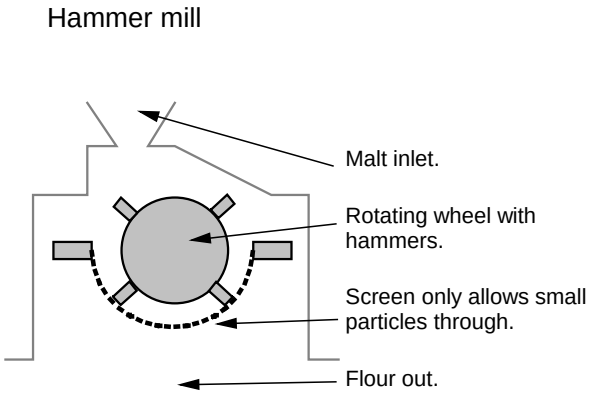
Wet mill

A wet mill may also be used for lager production. In this system the husk receives extra protection because it is steeped in water before milling proceeds. Typically these only have a single pair of rolls.

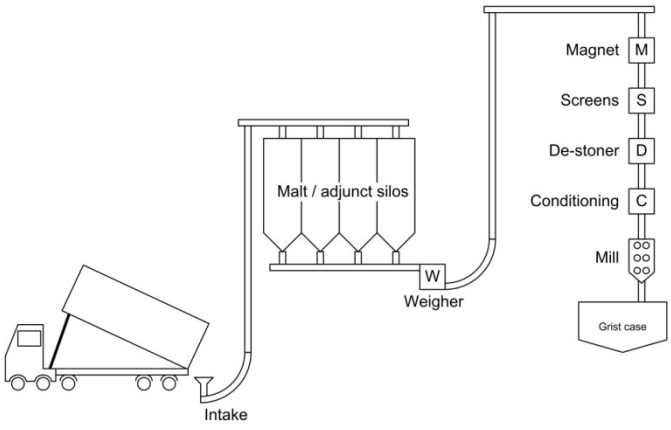


Hammer mill

A hammer mill may be used if the mash is to be separated in a mash filter. Here the filter bed is very thin and husk protection is not necessary. A hammer mill produces a very fine grind, giving good wetting and subsequently enzyme activation, and rapid extraction of the sugars from the particles.



Grain handling and safety



Storage
The different types of materials (grains, flakes, grits, and flours) must all be stored separately until required for processing.

Most storage silos are normally constructed from steel but they can be made from concrete. Silos must have smooth walls with hopper bottoms to ensure easy grain withdrawal. The malt and cereal adjuncts are stored at their delivery moisture levels to:-

- Discourage the growth of pests such as insects, moulds, fungi and bacteria.
- Prevent alteration to the biochemical structure of malt/adjunct prior to use (i.e. turning slack).

Malt and adjuncts should be delivered and stored in sufficient quantities to defend against unforeseen shortages that could halt production. However, storage should not be excessive – providing for only a few days' requirements. Otherwise money becomes unnecessarily tied up in expensive storage capacity and the materials themselves.

Weighers
The location of the weigher(s) varies depending on the history of the design / build. Ideally, all malt (and adjuncts) should be weighed after the malt has passed through the destoners, screens and magnets, so that only clean, usable malt is weighed. In the example shown, based on a brewery, the weigher has been located at the silo discharge, to improve the accuracy of the charge of grist. Conveyors should only be stopped and started when empty under normal conditions. The amount of malt a long conveyor system holds can vary considerably, and can affect the volume / gravity of wort collected due to variable amounts delivered whilst emptying out the conveyors etc. when milling has been completed.

Different sized weighers may be used for different malts and adjuncts. For instance a brewery may use a 25 kg weigher for white malts, but a 2 kg weigher for coloured malts. Each weigher requires dedicated feed conveyors and cleaning systems. The discharges are normally merged prior to the mill, but again, separate mills may be used for coloured malts and white malts.

Screening and dressing
To ensure uniformity of milling, it is necessary to have a reasonable consistency in the size of corns and the degree of modification. To obtain such consistency, prior to despatch from the maltings batches of malt are often mixed. To obtain consistency of size, the malt is screened. To minimise unwanted material, it is "dressed" by passing through screens to remove foreign objects by passing through magnetic separators to rotating, cylindrical, oscillating or flat-bed screens. Not only are corns of unwanted size rejected (these are sold for animal feed wherever possible), but foreign matter such as straw, stones, string, sacking and metal particles are removed.

It is usual to carry out further screening and dressing after silo storage at the brewery, prior to milling.

Magnets
It is essential that pieces of metal that may be in the malt should be removed before they reach the mill, because such metal can cause a spark and start a fire or explosion. Separation is effected by placing permanent magnets either in the malt chute to the screening machine (dresser) or across the feed to the mill.

Malt should flow over the magnet in a thin layer and at the same rate as it is being ground, thus allowing the magnet to extract any ferrous metal that may be in the malt.

Dressing
The malt dresser was usually a cylindrical screen revolving inside a wooden casing that has detachable doors on either side for easy access. The last part of the screen consists of a mesh large enough to let malt pass through to a small hopper feeding the weigher or the mill. Any foreign matter such as pieces of wood, metal, or stone, which are too large to pass through this mesh, is carried forward to the end of the screen where it is rejected via a spout into a bag.

In modern installations there is a separator/dresser to remove foreign material based on size, and separately, a de-stoner that separates material according to density. In this way small stones of the same size as the malt grains can be removed.

Dust Removal
Dust is a dangerous substance because of the risk of explosion and also irritation to the lungs. It is now covered by COSHH (Control of Substances Hazardous to Health Act) regulations (and similar legislation outside the UK) and it is extremely important that dust is not allowed to accumulate. If a film of dust appears, measures must be taken to eliminate the source of dust and any deposits cleaned up. The presence of dust indicates a failure in the dust extraction system or leak in the plant.

Fans suck the dust through metal ducts or pipes from various points such as the elevators, dresser and weighing machine. It is normally blown into a cyclone from which it drops down into a bagging point. A regular system of emptying the dust sacks or containers is necessary to allow the plant to operate efficiently. Periodic examinations must be made of the pipe ducts to and from the fan to avoid build up and blockage by dust.

Even if there is good housekeeping, it may not be possible to completely eliminate the risk of explosions in hoppers and conveying equipment. For this reason, explosion vents are provided to allow an explosion to pass harmlessly into the atmosphere without damage to equipment and people.

Malt handling – key risks

Risk	Potential Effect	Prevention
Damage	▪ Poor Brewhouse. performance. ▪ Excessive dust generated.	▪ Gentle handling. ▪ Mechanical conveyors not pneumatic.
Moisture pick-up	▪ Biochemical change. ▪ Infestation.	▪ Keep system dry. ▪ Intake under cover. ▪ Good housekeeping
Contamination (stones, metal)	▪ Damage to mills. ▪ Explosion risk.	▪ Magnetic extractor. ▪ Screens/ explosion vent/ dust extraction.
Environmental hygiene	▪ Food safety. ▪ Infestation.	▪ Pest control. ▪ Cover intake hopper.

Safety

Malt dust is hazardous, fine dust in the atmosphere is explosive and breathing in the dust can cause respiratory problems.

- Malt mills are designed to prevent explosions. Magnets fitted to collect any steel or iron debris that could cause a spark. Stone separators are also installed to prevent sparks and to protect the rolls from damage/wear.
- The modern mill and malt handling plant is fitted with explosion doors which would direct a blast safely outwards should an explosion occur.
- People working on the malt plant need to wear dust masks to avoid breathing in any dust.
- Safe systems of work (permits to enter confined spaces) are required for people entering malt silos.
- The milling plant and local environment must be kept clean, accumulations of dust being particularly hazardous.
- Malt handling equipment is a noise hazard. The design of the equipment and buildings can help, but hearing protection in the vicinity of working equipment is essential.

Notes

Draw a diagram of the mill used in the brewhouse you are familiar with.

Why was that specific design of mill chosen?

What safety features are incorporated into the malt handling and milling system in your brewery?

2.3 Plant operation – mashing & conversion

Mashing Objectives

Ground malt and solid adjuncts (grist) are mixed with a set volume of water to achieve a specified temperature. The mash is then allowed to stand for a period of time, typically around an hour, during which the enzymes in the malt convert the starch to sugars to produce a sugary liquid called wort. Depending on the type of malt, it may be necessary to heat the mash to specified temperatures so different enzymes work close to their optimum temperature. During mashing:-

- Cell wall components may be broken down to release the starch (non-isothermal mashes only, where the endosperm has not been fully broken down during malting).
- Proteins are broken down to amino acids.
- Starch is broken down and converted to sugars.
- The pH drops.

The enzyme reactions are dependent upon:-

- The substrate and the enzymes available as they are specific to each other, e.g. a proteolytic enzyme will only breakdown proteins, not fats or starch.
- The duration of the temperature stand(s). This will influence the level of substrate degradation and brew house throughput.
- The pH of the mash. The activity of the different enzymes will change according to the mash pH. pH is controlled mainly through the composition of the brewing water. Additions of calcium and magnesium ions lower the mash pH. Bicarbonate salts from the liquor raise the mash pH by reacting with hydrogen (H+) ions. It may also be necessary to reduce the bicarbonate (temporary hardness of the brewing water) and to add mineral salts to regulate the pH for brewing. The final pH of the mash is a compromise between the best pH for the different enzymes present.
- The temperature. Enzyme activity changes with temperature. Each has its own specific optimal temperature. Destruction will occur at high temps, above the optimum for each specific enzyme.
- The grist to liquor ratio – will affect activity and rate of degradation of the enzymes. This also affects the concentration of dissolved products. Generally speaking, thicker mashes help protect enzymatic action.

At the end of mashing, most enzymes become inactivated during the sparging process. Deactivation is completed during heating to boiling point.

The wort should contain:-

- A range of sugars suitable for fermentation, leaving sufficient unfermentable sugars to contribute to the desired mouthfeel of the finished beer.
- Proteins which will help form foam, essential to presentation in most finished beers.

- Amino acids, to allow healthy yeast growth.
- Lipids and fatty acids, to allow healthy yeast growth.
- Mineral salts and vitamins, to allow healthy yeast growth.

Mash conversion systems and their operating differences
There are several different mashing systems and these depend on the type of malt and adjuncts used and the type of beer being produced.

Isothermal mash tun
The (isothermal) mash tun is a combined mashing in, conversion and wort separation vessel. Well modified malt is needed because there is no facility for mixing and heating the mash, and so only isothermal (single temperature) mashes can be made. They can only use well modified malt, normally comparatively coarsely ground. Poor quality malts or malts requiring a protein stand cannot be handled. They are not particularly suitable for large batch production. Brewhouse extracts are considerably lower than obtainable from lauter tuns or mash filters, though their simplicity makes them ideal for small operations.

Prior to mashing in, the plates must be covered with hot water to pre-heat the mash tun and to reduce the amount of solid material from the mash blocking the plates, or dropping through the slots or holes in the plates.

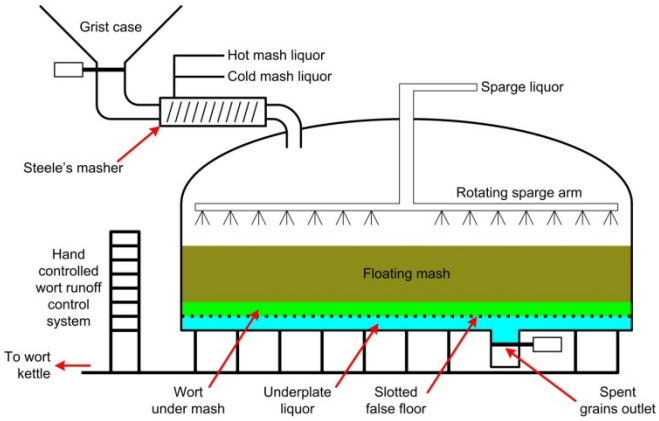
In larger operations, mashing in is then carried out using a Steele's masher. This is a rotating screw into which the grist drops. Water at the correct temperature is run into the screw at the same time to achieve the required mash temperature. The screw "mashes" the grist which then runs into the mash tun. It is rare for weak worts to be added back to the mashing liquor.

In smaller operations, the mash tun may simply be flooded with the correct volume of hot water, and then the grist is added, simultaneously stirring in rapidly to wet the grain, and ensure there are no hot or cold spots in the mash.

Because no heating jackets are fitted, it is therefore not possible to heat using external heat if the initial mash temperature is low. Because of the lack of mixing facilities, it is very difficult to add extra hot (or cold) water and ensure the mash temperature is consistent after addition, particularly in larger tuns. The spent grains discharge rakes, if fitted will not ensure mixing, and may knock air out of the mash, so making run off more difficult. There are also no cutting rakes similar to those fitted to the lauter tun which might be used to help mixing.

The mash is then simply allowed to stand for a period to allow the enzymatic action to take place. During the period, the mash gradually rises due to air entrained in the grist particles, so the bottom of the mash may be several cm above the false floor plates. It is essential to maintain the entrained air as this also helps to keep the mash porous during wort run-off to allow consistent wort / sparge flow through the bed as there are no rakes to help break up a compacted bed.

After mashing in, typically to a depth of 0.9 to 1.2 metres, but often considerably more, and sometimes somewhat less, the mash is simply left to stand for a fixed period, before starting to run off the wort.



Mash conversion vessel
The mash conversion vessel (MCV) is a vessel fitted with heating and stirring facilities which can be mixed to ensure homogeneity, particularly whilst heating, and to ensure good heat transfer. Less well modified malt can be used here because different temperature stands can be used. However the mash has to be transferred to a lauter tun or mash filter for recovery of the wort.

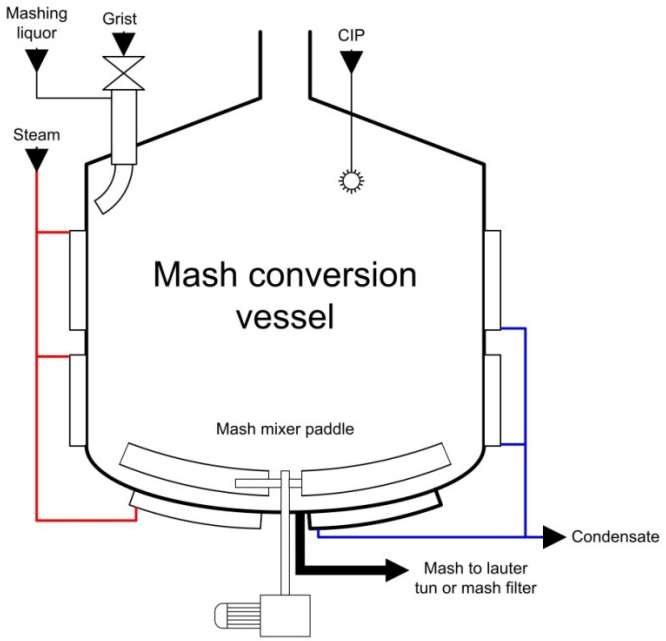
In many installations, the entire mash is mashed into, and converted in the MCV, prior to transfer to a lauter tun or mash filter. However, the MCV may also be linked with a separate mash cooker, or a cereal cooker as described briefly here:-

- The mash conversion vessel with separate mash cooker. This is the traditional decoction system which was in use before thermometers were readily available, though is still used with vastly improved accuracy since the development of accurate control systems. The MCV in this case does not need heating, but is simply insulated to reduce heat loss. Correct stand temperatures are achieved by transferring specified volumes of mash from the MCV across to the cooker, boiling this portion of the mash up, and returning it to the main mash. The mash has to be transferred to a lauter tun or mash filter for wort separation.

- The mash conversion vessel with separate cereal cooker. This decoction system is similar to above, except that the cooker is used to boil a mash of maize or rice. The maize or rice is nowadays treated with enzymes which are stable and active at 80 C plus. Maize and rice have high gelatinisation temperatures and cooking is required if their starch is to be made available for enzymatic action to convert the starch

into sugars. This process is avoided in many breweries by using pre-gelatinized maize or rice in the form of flakes. The flakes may then be added directly to the MCV.

The diagram shows an MCV with grist top entry, though in many newer installations, the grist enters at the bottom of the vessel to reduce oxygen pickup.

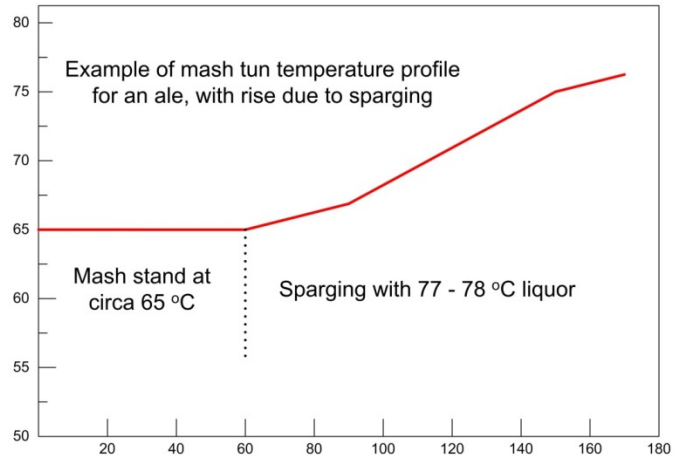


The basic design of a mash cooker is as above, though without the facility to mash in, but with connections to allow transfer from and back to the MCV. The design of a cereal cooker is as above, but the transfer is to the MCV, not directly to the lauter tun or mash filter.

Typical mashing parameters

Isothermal infusion mash

The following is an example of the temperature profile of a simple infusion mash, as used in a mash tun. The temperature rise as a result of sparging is shown.



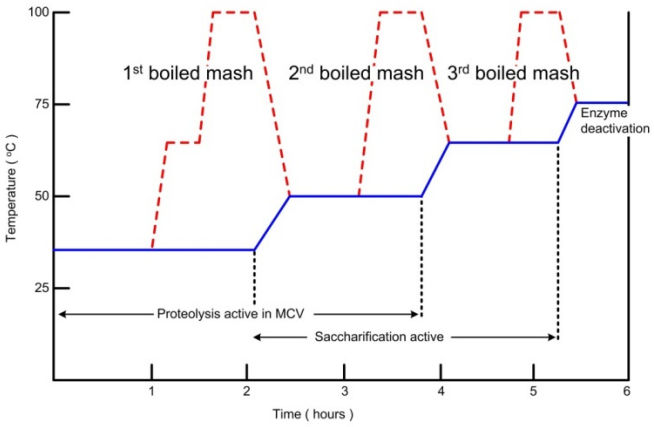
A mash rate of between 2.1 and 2.5 hl / 100 kg is generally used, though it may be up to 3.0. The false floor loading, expressed in terms of kg dry grist / m^2 is typically around 500 kg / m^2, though can be up to 800 kg / m^2.

Decoction mash grist : water ratio

A mash rate of between 2.2 and 3.5 hl / 100 kg is generally used, though this can be higher. This applies to all variations of decoction mash. The exact ratio is determined by the wort extraction system and the amount of pumping / mixing required. Thinner mashes use less energy to mix and transfer than thick mashes, though the more water added to the mash, the less can be used for sparging, with subsequent risk of poorer extracts.

Triple decoction mash

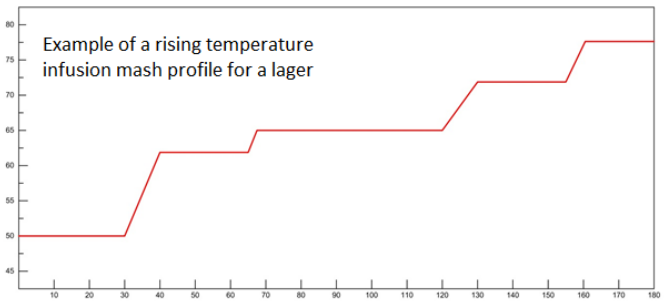
The following is an example of a triple decoction mash, as developed when accurate temperature control of heating was not available. The temperature control is by means of transfer of portions of mash into a mash cooker, followed by transfer back to the mash vessel. Note how long this process takes. Largely for this reason, triple decoction mashing has been replaced by rising temperature infusion mashes, where the heating, mixing and stands all take place in a single vessel. See next paragraph for an example temperature profile.



Rising temperature infusion mash

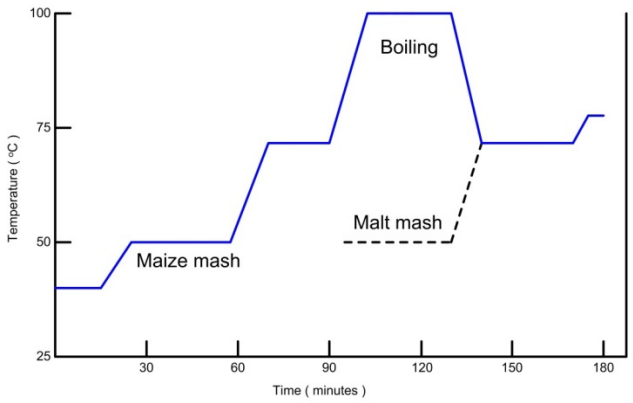
Due mainly to the cost of equipment and the time taken to carry out a traditional decoction mash, rising temperature infusion mashes are the most commonly used method of handling poorly modified malt. Note that this profile does not allow for use of adjuncts such as rice or maize, which require the use of a cereal cooker.

The following example shows the regime for undermodified malt, which traditionally would have used a decoction mash system. If using well modified malt, a simpler process may be used, perhaps as simple as a single 65 °C stand, followed by heating to 77 °C prior to transfer to the lauter tun or mash filter.



Adjunct mash / double mash

Adjuncts with higher gelatinisation temperatures than barley must be pre-cooked before addition to the main mash, and hence the double mash system. The maize or rice grits are boiled up in the cereal cooker to gelatinise the starch. Once gelatinised, the adjunct is added to the main malt mash. The two mashes are carried out concurrently in separate vessels and combined to give a single temperature rise. Generally, other temperature rises if required are made by heating the mash vessel, rather than transferring a portion back to the cooker. The following diagram shows an example of an adjunct mash requiring gelatinisation of maize grits.



Assessment of starch conversion

At the end of the conversion stand(s), there should be no residual starch. This will result in loss of extract. In addition, any residual starch may be washed out during sparging, and carried through to the wort kettle. Here it can be gelatinized, and then be carried through the brewing process to form hazes in the final product.

It is important to regularly check mashes for residual starch immediately prior to raising the mash temperature, starting transfer or run-off. The normal quick method is to use a weak solution of iodine in potassium iodide. A small quantity of the mash is put on a white tile or similar, and a few drops of the solution added. Any residual starch shows up as blue black particles or possibly even as a blue/black colour of the liquid.

It is normally too late to affect that particular mash, but changes can be made to subsequent mashes, and the affected mash monitored throughout the rest of the process, and corrective action taken.

2.4 Plant operation – wort separation

When conversion is complete, the mash will consist of a sugar solution called wort and the husks and endosperm residues of the malted barley. The purpose of wort separation is to separate the sugars in the wort and malt residues from the husks etc.

The husks and other particles contain tannin which is bitter and will make the beer unstable after packaging. They also contain fatty substances like lipids which will reduce head stability and will also make the beer go stale.
The objectives of effective wort separation are the removal of unwanted material while at the same time extracting all the available wort.

Effective wort separation means:-

- Maximising extract recovery.
- Absence of particles in the wort.
- Absence of starch in the wort.

To achieve these objectives, wort separation systems use some common principles:-

- Filtration using the husk as the filter bed
- The filter bed is supported by the slotted base of a mash or lauter tun or a filter sheet in the case of a mash filter.
- The wort flow is controlled to ensure wort clarity and maximise filtration efficiency.
- The strong worts (containing the sugars dissolved during mashing) are extracted first followed by sparge water to wash out remaining extract.
- The grain bed is then sparged (washed) with hot water to extract the maximum amount of soluble extract as weaker worts.
- On completion of filtration, the spent grain (waste husk and endosperm) must be removed and disposed of.

Wort separation methods

There are many systems in which wort can be separated from the mash, the most common being:-

- The mash tun.
- The lauter tun.
- The mash filter.

Other types of plant, for example the Strainmaster, may be used but are less common and will not be discussed here.

The operation of different wort separation systems are illustrated in the diagrams in the following sections.

Mash tun

The mash tun acts as conversion vessel and wort separation vessel. Filtration gives very bright wort through a deep bed, but it is slow and extract recovery is moderate.

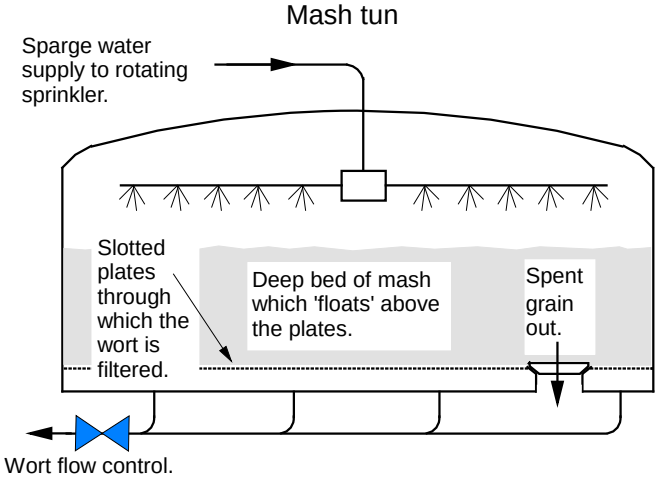
The wort is run-off through one or more discharge pipes, each pipe serving approximately the same area of the base.

The wort may be recycled on top of the mash until clear, to remove the fine solids below the mash, but this is frequently not carried out due to the tendency to blind the bed.

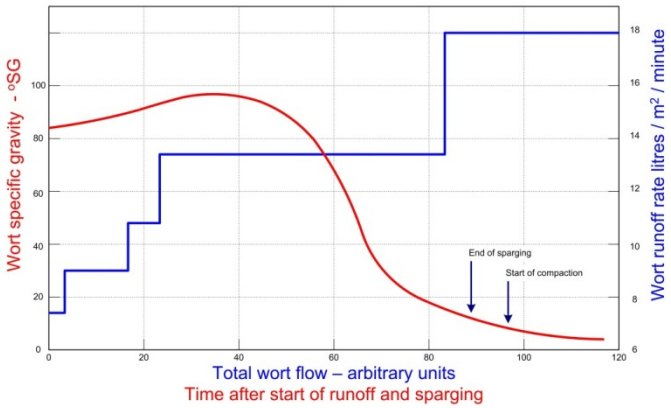
The rate of run-off is typically controlled by a variable height "weir" system (valentine), or a single flow control valve, or a series of valves at different heights.

Strong wort is run off slowly because it is more viscous than weak wort and initially the mash bed must not settle onto the plates. Once some of the strong worts have been run off, but before the mash has settled on the false floor and started to compact, the sparge is started. The rate of sparge must match the rate of wort run-off so that the bed does not rest on the false floor and compact excessively until the final drain down. The diagram below shows a typical run-off profile for flow rate and gravity.

Once a fixed volume of sparge has been added, the tun is allowed to drain down. Spent grain is removed through a port in the base either manually or by using sweeper arms similar to those used in many lauter tuns.



Example of wort gravity and flow rate during run off from mash tun.



Lauter tun

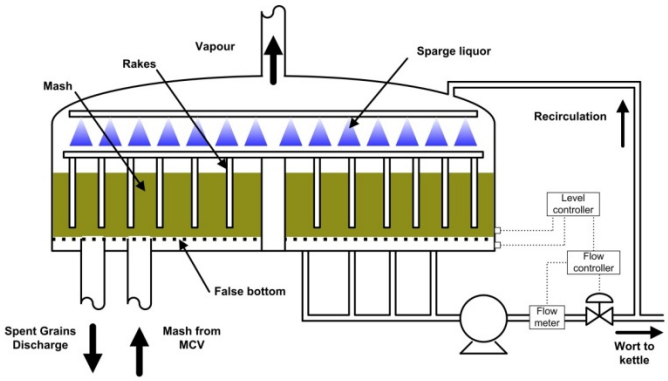
The lauter tun is will give good wort quality and extract recovery. However its effectiveness does depend on balancing turn round time against wort quality and extract recovery.

The different lauter tun suppliers all control their lauters differently in terms of run-off rates, sparge rates and raking depth and speed. The run-off control has also changed somewhat as lauter tun physical design has changed, and as improvements have been made in automated control systems. However, there are a number of common operations as follows.

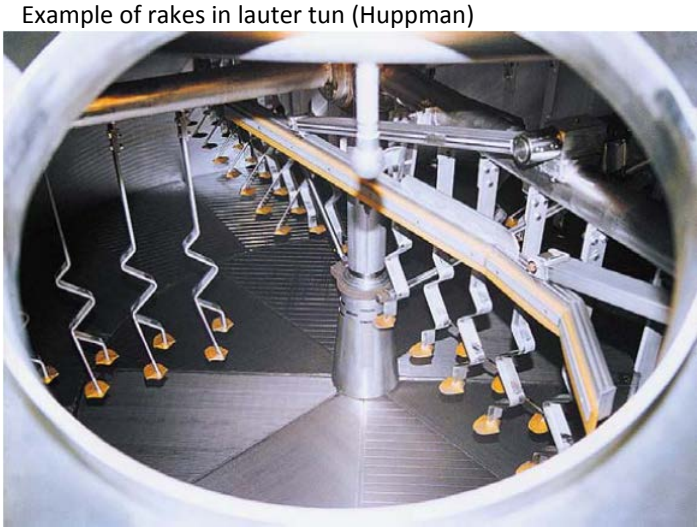
For all malt brews, a mash rate of between 2.5 and 3.5 hl per 100 kg is generally used. The false floor loading is expressed in terms of kg dry grist / m^2, and varies according to the milling regime and the turnround time required. In general terms, to achieve the same extract efficiency, the higher the bed loading, the fewer brews can be processed, ranging from 6 up to 12 (for a modern lauter tun) brews per day. Bed loadings are lowest for dry milling which tends to produce most fine husk material (130 to 180 kg m^2), slightly higher for conditioned milling (140 to 190 kg m^2), and even higher for wet milled malt (190 to 250 kg m^2).

- At the start of the cycle, the lauter false floor is flooded with hot water and the rakes moved to their highest position.
- The converted mash is transferred from the MCV to the lauter tun. Modern vessels are filled from the base to avoid aeration and damage to the husk. When the transfer from the MCV is almost complete, the recirculation of cloudy worts (vorlauf) can be started. The rakes may be used to help spread the mash evenly across the lauter floor, but are subsequently raised to the highest position.
- The recirculation is to remove the cloudy wort from under the bed and some of the very fine material in the bottom layers of the bed so the material is not transferred into the wort kettle. It also transfers the underlet to the top of the bed which can then be used more effectively to extract the sugars from the malt material.
- Run-off starts normally without the rakes running or being lowered into the bed.
- The rakes are then operated continuously with height and speed varied to maintain a constant differential pressure (DP) across the bed. Increases in intensity (depth, speed) can cause the wort to go cloudy for a significant period of time. The wort flow rate may also be varied to achieve the fastest flow rate possible whilst maintaining the DP.
- When some of the strong wort has been run-off, and before the grain bed is exposed, sparging commences at a rate to match the run-off rate. This may take the form of continuous sparging, or batches at high flow rate. The bed must never be allowed to dry out, to prevent bed compaction and oxygen pickup.
- The volume of sparge water is fixed, and when the required amount has been added, the bed is allowed to drain down without restriction.
- The spent grains are then removed through a port in the base by discharge gear attached to the rakes (e.g. Huppman, Steinecker) or reversing the raking direction to form a sweeping action (Briggs).

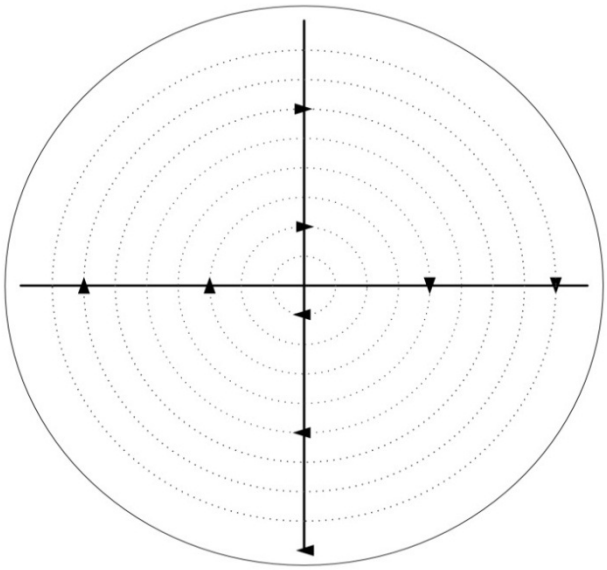
The increased complexity of a lauter tun compared to an isothermal mash tun can be seen in the following simplified drawing.



Example of rakes in lauter tun (Huppman)



The position of the rakes is such that the track of one does not overlap with another track, as shown here, the individual rakes being indicated by the black arrows.



The diagram at the end of this section shows an example of a lauter tun sparge and run-off profile, and demonstrates how much more complex lauter tun operations are than mash tuns.

This is for a lauter tun capable of a four hour turnaround time, but forms the basis for up to 12 brews / day.

Mash filter

The mash filter is becoming more popular worldwide due to the rapid turnaround times and high extracts achievable. The mash filter's numerous plates and frames, which overall form a very large area of very thin beds rather than a single smaller area of deep bed enable a very fast run-off of wort and effective sparging.

In a mash filter, all the chambers need to be filled completely and consistently. Consequently it has to operate with a standardised size of mash.

The basic principle of operation of a mash membrane filter is described here, with sparge in a single direction. Please note that some filters alternate the direction of sparging every alternate fill (e.g. Ziemann).

Some filters, (e.g. Meura 2001 and later) have membranes built into the plates which allow the cake to be squeezed and thus obtain a slightly higher yield and drier cake than non-membrane presses, and allow variability in capacity of from -20 % to +10% of the nominal throw. Two membranes are fitted to alternate plates in the original 2001 filters. More recent ones have a single membrane fitted to every plate.

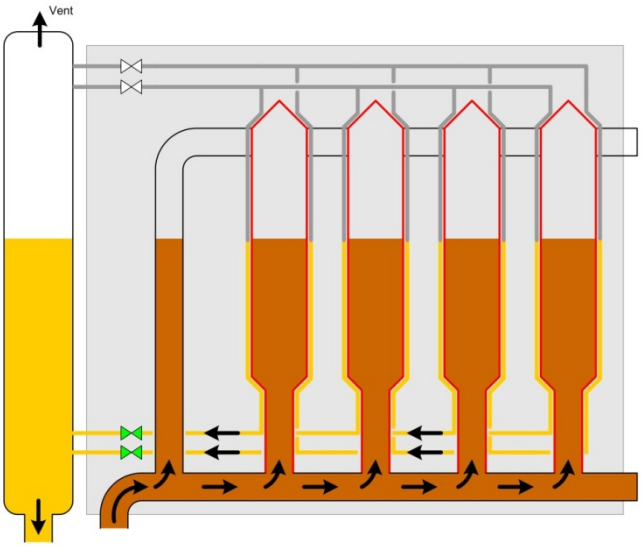
Modern filters have polypropylene plates as opposed to the cast iron or stainless steel of the classical filter making them lighter and easier to handle.

The filter is constructed of alternate frames to hold the mash and plates to channel wort run-off and sparging, all separated by filter cloths which either hang over the plates or are hung from the individual plates, depending on the design.

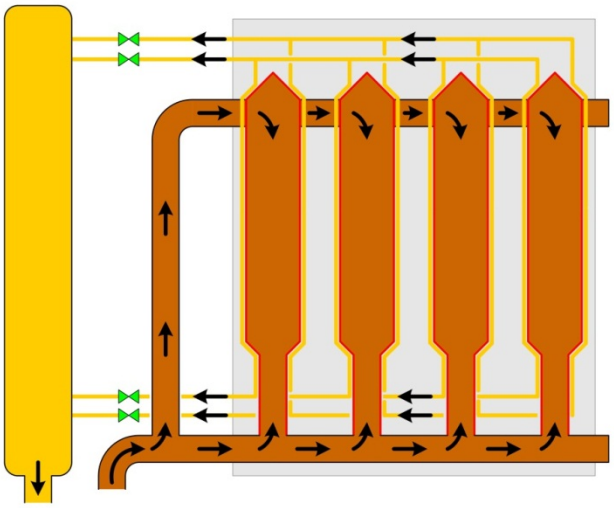
The general operating principles of a mash filter are explained below:-

- The filter is first pre-heated and flushed with hot water before the converted mash from the mashing vessel is transferred into the mash frames. In the early mash filters, this is through a top central channel which by-passes the wort collection plates. In later designs, this is from the bottom of the plates initially, to reduce oxygen pickup.

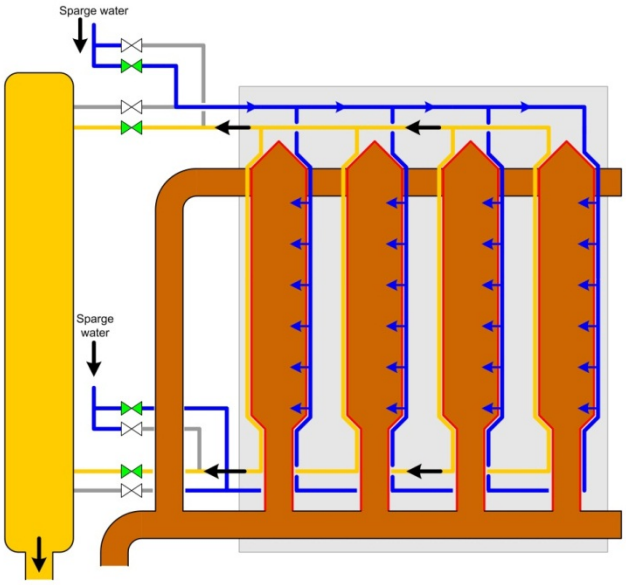
- Wort is run off as the filter fills.



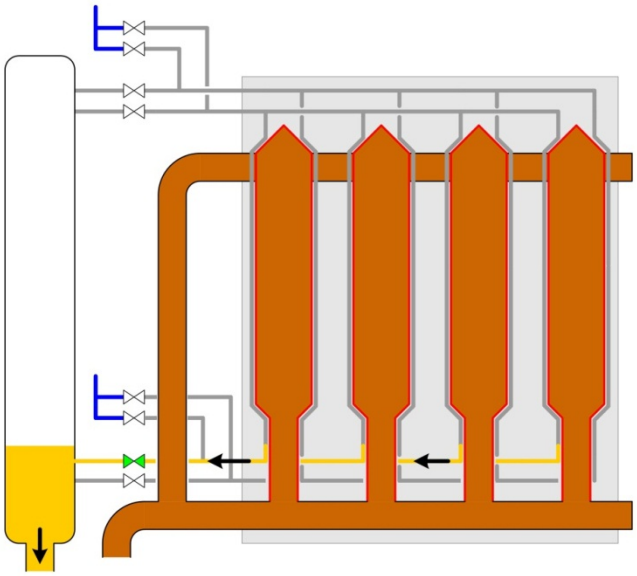
- When the filter is virtually full, mash is transferred into the filter via the top and bottom ports, and later the top ports only. Wort drains from the mash into the collection chambers in the adjacent plate or frame and into the wort collection channels (top and bottom) to the collection buffer tank, and from there into boiling copper/kettle. The wort run-off rate and mash transfer rate are balanced to ensure consistent solids loading throughout the chambers.



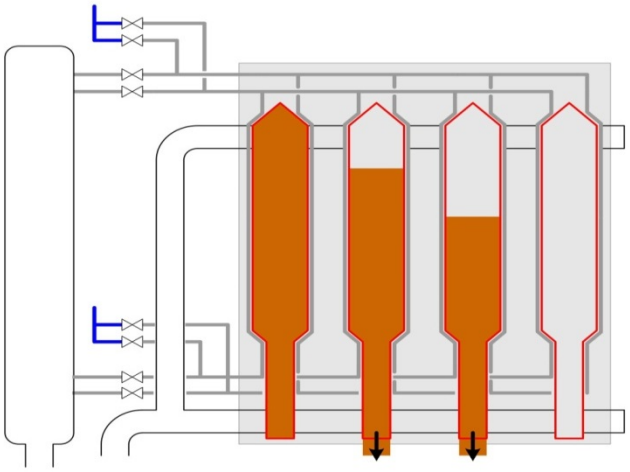
- In membrane mash filters, the frames are fitted with an expandable membrane which once the mash has been transferred, is inflated with compressed air to squeeze the grain bed, extracting much of the entrained wort, so improving the extract yield (not shown in this series of drawings).



- When sparging is complete, in membrane mash filters, the expandable membranes are then inflated in order to extract much of the remaining weak wort. This also gives a much drier spent grain cake with a lower effluent loading. If no membranes are fitted, the filter is simply allowed to drain down whilst emptying the buffer tank.



- To wash out all the wort from the mash, water is run into the plate on the other side of the layer of mash (using a separate sparge plate, or run-off port as shown here), across the mash bed and then through wort channel.



- The spent grain is dropped from the filter at the end of the cycle when the filter is opened.

Summary of the principal differences between wort separation systems

	Mash Tun	Lauter Tun	Mash Filter
Milling system	4 roll dry	6 roller dry or wet mill	Hammer mill
Grist	Coarse	Medium/fine	Very fine
Mash system	1 vessel	2 vessels	2 vessels
Liquor to Grist ratio (litre / kg)	2 to 2.5	2.5 to 3.5	3
Sparge volume (litre / kg)	4.5	3.8	2.5
Total water (litre / kg)	7	6.8	5.5
Filtration area (m^2 / tonne)	2.5	4.5	3.5
Bed depth (mm)	1000	400	50
Bed loading (kg / m^2)	400	200	28
Run-off rate (litre / m^2 / min)	1	0.6	20
Typical extract recovery (%)	97	98	101
Brews / day	5	6 to 12	12+

Cycle times

The efficiency of the mash separation process is measured by:-

- Turn round time, which is the time to process a complete brew from the end of grain out for one brew, to the end of grain out for the next brew. Generally a modern brewhouse would process 8 to 10 brews every 24 hours with a lauter tun; 12 brews per day with a modern mash filter, though 14 can now be achieved.
- Extract efficiency, which is based on a direct comparison of the total extract (gravity x volume) collected in fermentation vessel against the laboratory extract and weight of brewing materials used. Generally a lauter brew house will recover 98% of laboratory extract, but a modern mash filter can achieve greater than 100% extract recovery.

When considering a new brewhouse, or major modifications to an existing system, it is necessary to consider a number of factors before deciding on the most appropriate solution, including the following, not listed in any order of priority:-

- Length of working week.
- Brewlength required (or current constraint where retro fitting).
- Wort clarity required.
- Extract achievable from each system.
- Cleaning cycle times.
- Cleaning frequency.
- Cleaning material costs.
- Engineering maintenance costs (including replacement parts / frequency / downtime).
- Operator maintenance costs (e.g. sheet changing, plate manual cleans).
- Space available.
- Use for spent grains.
- Grain bill (cannot use sorghum for instance in a lauter tun).
- Brewlength variability.
- Utilities requirements (water, electricity).

Wort clarity

Wort separation also aims to achieve consistent wort quality. This can be difficult to measure but typical parameters would be:-

- Wort haze - should be < 50 EBC 10 minutes after the start of run off. This can be measured with an in-line hazemeter.
- Suspended solids - no more than 10 to 15 ml as sediment after 2 hours stand in an Imhoff cone.

High hazes in wort can lead to a number of problems either in the brewhouse, or in the process downstream, including

- Run-off problems.
- Excessive volumes of trub / high hazes.
- Flavour problems.
- Fermentation problems (e.g. due to smothered yeast in extreme circumstances).

- Variable yeast flocculation.
- Poor filterability.
- Potential shortening of shelf life due to haze formation.

Brewhouse manufacturers have placed a lot of emphasis on reducing mash and wort oxidation, and whilst it is generally accepted that undue oxidation is undesirable, it is has not been established that the total elimination of oxygen is beneficial. A small amount of mash oxidation is probably inevitable and may even be desirable.

Spent grains

The waste husk after the wort has been removed is a valuable by-product because it can be utilised as animal food, typically for cattle. Where used as animal feed, it is necessary to maintain hygienic conditions for the storage and handling of the spent grains, and to ensure no contamination by foreign materials such as oils. Traceability is typically also required.

In some breweries, the grain is used as biofuel. To be suitable for this it often has to be further dried using relatively high pressure belt presses and dried further using the hot exhaust gases from the furnaces.

Notes:

Draw a diagram of the mashing system that you are familiar with.

Why was that system chosen?

Draw a diagram of a wort separation system in a brewery that you are familiar with.

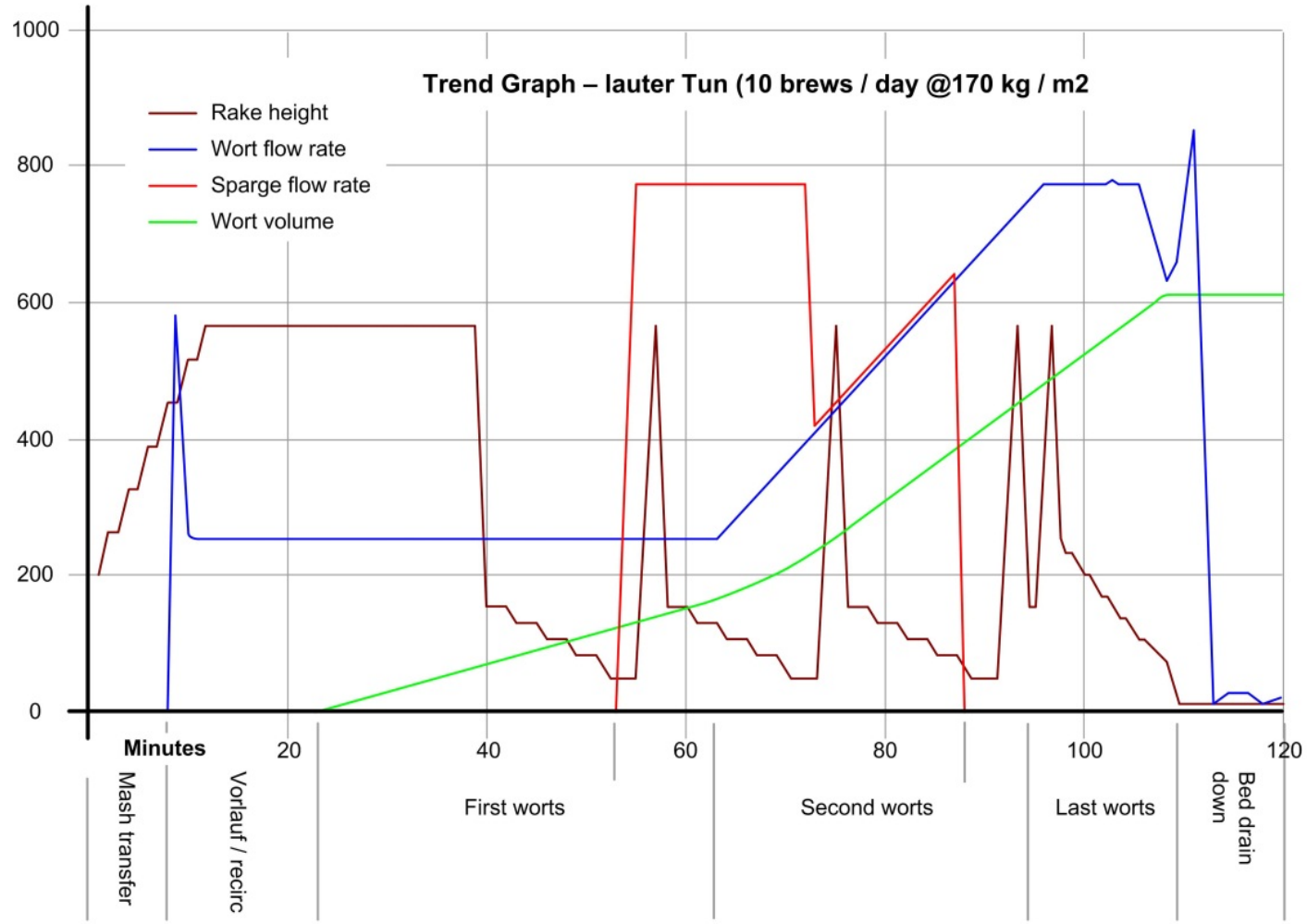
Why was that system chosen in your brewery?

What extract yield is obtained from this system?

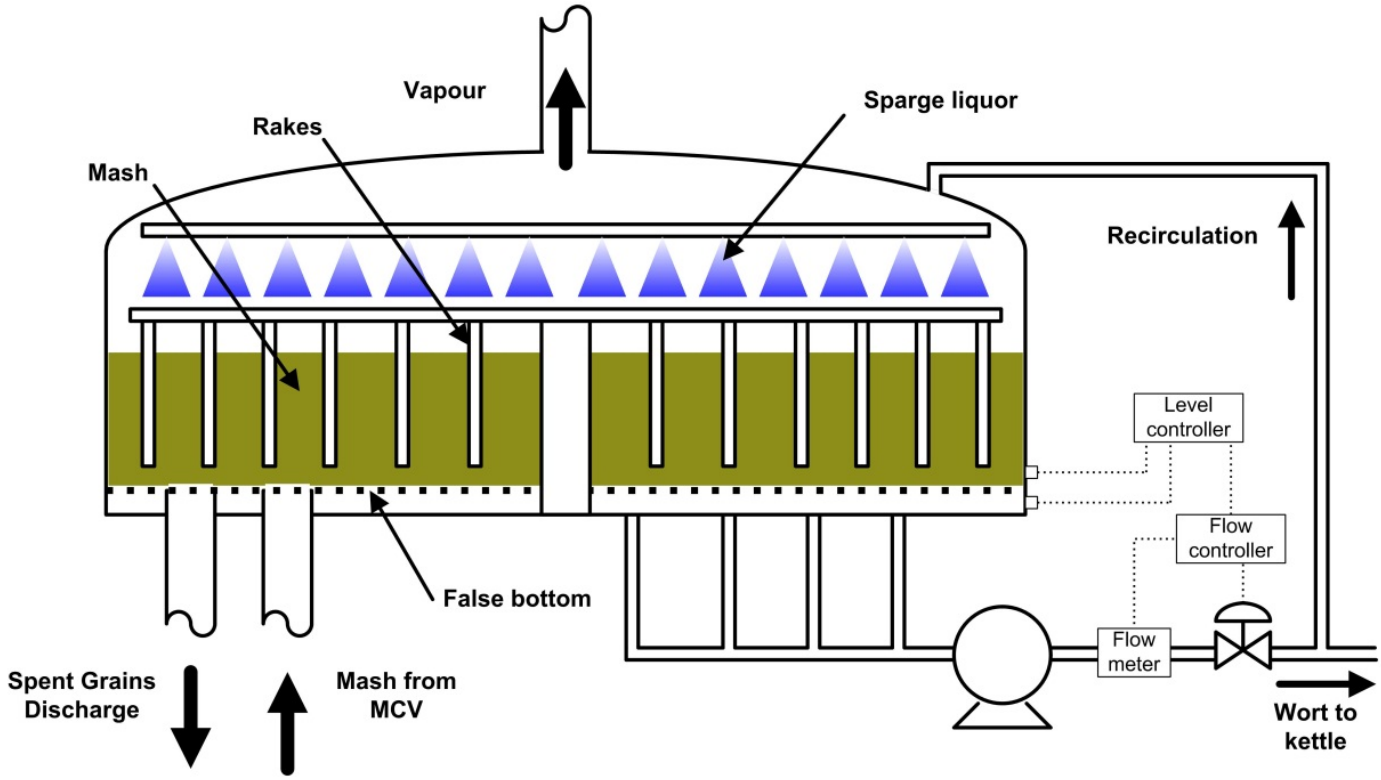
If extract yield is below expectation, how could it be improved?

List the key operational and process parameters relevant to the milling and mashing systems in the brewery that you are familiar with.

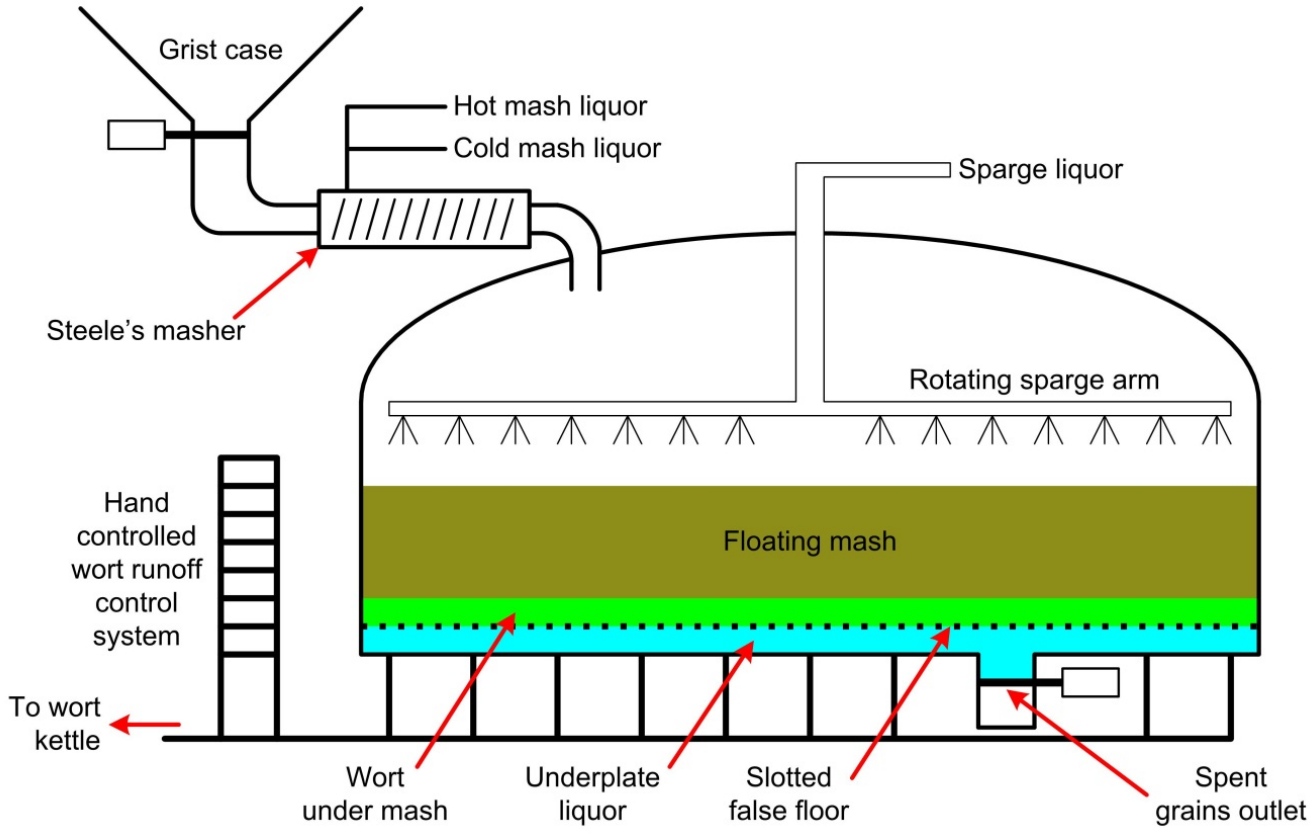
What quality parameters are monitored during milling, mashing and wort separation?



LAUTER TUN



MASH TUN



Qualifications

The General Certificate in Brewing (GCB)

Learning Material © Institute of Brewing and Distilling 2016

Section 3 Wort Boiling

3.1 The purposes of wort boiling

The terms “kettle” and “copper” are used interchangeably throughout this document. Although the term “kettle” is used predominantly, if the user normally uses the term “copper”, then this may be used instead in any answers.

The description of the kettles / coppers has been restricted to “traditional” wort boiling systems, and methods such as wort stripping and high temperature boiling will not be discussed. The underlying principles of the boiling process and desired end results remain the same.

Introduction
When the wort has been separated from the malt husk, it is boiled. There are several reasons for doing this:-

- To **sterilise the wort**. Brewing raw materials such as malt, hops and occasionally brewing water itself are infected by micro-organisms. These contaminants are washed into or added to the wort and remain viable, and therefore have to be killed during the brewing process to prevent wort and beer spoilage.
- To **stabilise the wort**. Above 50 – 80 ^{o}C, enzyme structure is broken down and the enzymes lose their activity. Thus a small quantity of enzymes that converted the starch into sugar and the protein into amino acid may not be fully denatured by the final higher temperature stages of mashing, and sparging. Some brewers add external enzymes, such as thermostable beta-glucanase or alpha amylase, intended to help with wort filtration or adjunct degradation (e.g. rice or maize). These enzymes are more heat stable and are active throughout mashing but will be de-activated during wort boiling. It is important that all enzymes are destroyed by boiling, otherwise they would continue working, which would change the profile of the beer.
- To **evaporate** away unpleasant aromas associated with the wort. DMS, the sulphury character found in lagers is generated on the malt kiln and during boiling. This is volatile and is boiled off in the wort kettle. Aldehydes derived from the malt, substances that give beer an unpleasant straw/grassy aroma are also volatile and evaporated off. Evaporation rates as low as 2% of the initial wort volumes are sufficient to produce good beers after a 60 minute boil.
- To **dissolve the bittering resins** from the hops and to stabilise them. Hops or hop extracts are added because the bitter resins (alpha acids) dissolve better in hot wort. These alpha acids need to be modified by ‘isomerisation’ reactions which are heat induced to stabilise the bitterness that is typical of beer flavour.
- To **dissolve oils** that contribute to hop aroma in the final product, though these generally only remain if the hops are added late, and the oils are not given time to be boiled off.
- To **denature and coagulate** some of the **protein** derived from the malt. Protein has the potential to make packaged beer go cloudy as it ages. Its removal at this stage will help protect the beer’s stability.
- To develop **wort colour and flavour** through the action of heat on sugars and amino acids (the chemical reaction between sugars and amino acids is known as the Maillard Reaction).
- To increase the **strength or concentration of the wort**. Wort concentration is a factor in ensuring that the chemical changes described above actually occur. It is also important in the production of strong beers whose original gravity is higher than that of the wort coming from the wort separation system. The amount of water removed during the boil is directly proportional to the rate of evaporation (and hence the amount of energy supplied). The efficiency is affected by the design of the wort kettle, particularly the heating surface area.
- **Wort pH continues to fall during wort boiling**. The drop in pH is mainly due to the reaction of calcium compounds with phosphates and polypeptides. These form insoluble compounds releasing H^{+} (hydrogen ions) so reducing the pH. This is an extremely important reaction as lowered pH :-
  - Improves protein coagulation.
  - Improves beer flavour stability in particular VDK (diacetyl) reduction.
  - Encourages yeast growth.
  - Inhibits the growth of many other contaminating organisms.
  - Results in less colour formation.
  - Results in poorer hop utilisation.

Other raw materials and process aids may be added to the wort:-

- Sugar can be added here because it needs to be dissolved, thoroughly dispersed and sterilised.
- Kettle finings are additives which enhance the coagulation of proteins during the boil to form ‘break’. These flocs help form the trub which settles out and can be easily removed from the wort. Kettle finings are discussed in more detail in section 4, wort clarification.

Factors affecting wort boiling effectiveness

The principal factors which will affect the evaporation of volatiles include:-

- Duration of the boil.
- The temperature of wort.
- The intensity of boil (the more steam vapour bubbles formed per unit volume of wort the more intense the boil resulting in more evaporation).
- The design of any spreader plate system and spread of wort from it, affecting the surface area for the volatiles to flash off.
- The circulation currents within the wort kettle. Poor circulation (and hence "dead spots") is liable to lead to poor evaporation of the volatiles.
- Condensation of volatiles in the vapour stack if allowed to run back into the boiling wort.

The kettle design will have a major influence. It has been found that more late-hop character persists in poorly agitated wort.

Purposes of solid and liquid sugar addition

There are a number of reasons why sugar adjuncts, in liquid, crystal or block form, may be used. They can affect beer flavour by:

- Diluting the flavour to give a lighter, smoother beer in the case of bland adjuncts.
- Contributing their own distinctive character to the beer in the case of flavoursome adjuncts.
- Altering the carbohydrate and nitrogen ratio of the wort, thus affecting fermentation products in the case of adjuncts low in nitrogen.

Dark coloured sugars and caramels can be used to add colour and or distinctive flavours to a beer. Light coloured sugars will dilute malt colours to produce lighter coloured beers.

Sugar additions can be used to increase kettle gravity as they normally have a very high extract value. There are a number of possible benefits to the brewer:

- Better extract recovery than malt, because there is no loss of extract due to the mashing and separation stages.
- Producing high gravity beers such as barley wines which would otherwise require extended boiling times or non-recovery of weaker worts.
- Production of wort for high gravity brewing, with no changes to the mashing or separation procedures, thus increasing brewery capacity.
- Increased brewhouse output without investing in additional mash vessel and or separation plant
- Lower lauter tun loadings and hence faster run off for the same wort volume.
- They can be added directly to the kettle making additions for any of the above reasons comparatively easy.

Where crystal or block forms are used, special dissolving vessels may be required, whereas syrups can be dosed directly into kettle without further processing.

Sugar additions may be derived from:-

- Malt, in which case the carbohydrate and nitrogen content is like to be similar to the brewhouse wort.
- Other grains such as maize, wheat or barley, typically mixtures of glucose or other simple sugars.
- Sugar cane or beet.

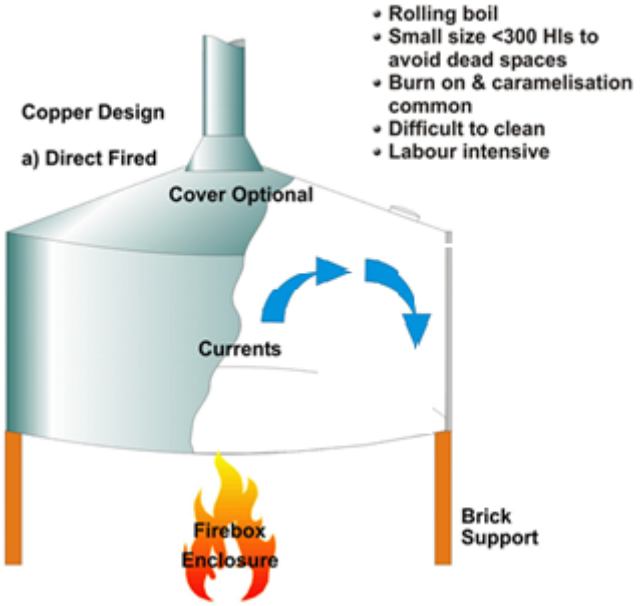
3.2 Wort boiling systems

Operating principles of wort boiling systems

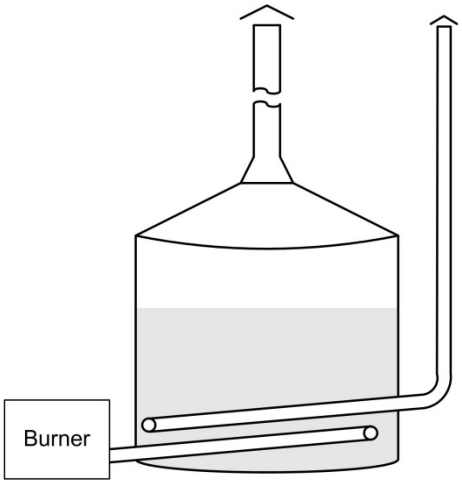
Kettles are designed to provide a vigorous or 'rolling' boil and to be energy efficient. Wort boiling is the most energy intensive part of the brewing process. The main task is to provide sufficient energy input to ensure adequate turbulence and evaporation. A number of different designs have been made to achieve this.

Direct fired

Traditionally, wort was boiled in a direct fired kettle, often made of copper which has particularly good heat transfer properties, hence the widely used term "copper". Because the heat source was localised at the bottom of the vessel, it restricts the volume of wort which can be boiled at any one time with a maximum is around 330 hectolitres. Direct fired kettles are still being installed in the micro brewing industry, though many of them use heating coils near the base of the kettle for improved heat transfer.



The above drawing shows a traditional direct fired copper / kettle – poor recirculation.



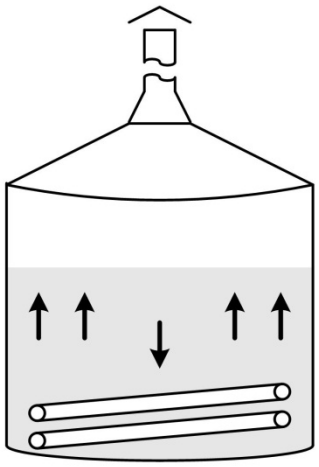
The above drawing shows a typical installation for a small brewery, using a gas or oil burner, with heating via internal heating coils – poor recirculation, but better than traditional direct fired kettles.

The use of steam and internal heating systems enabled the designers to provide a larger heating area, more consistent heating temperature, and use of larger kettles. The heat transfer is more efficient because it was surrounded by the wort (this aspect is also utilised in more recent direct fired kettles, as shown above).

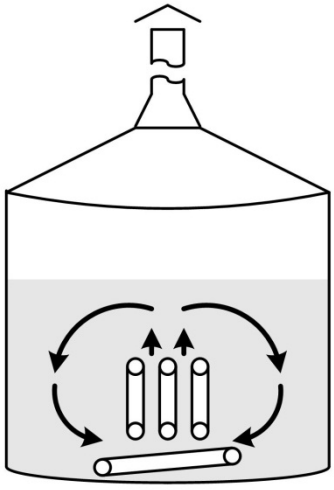
There are two main types, those with the heating element inside the vessel and those with it outside. Internally heated kettles may use simple spiral looped internal heating coils (see drawing (a) below).

In other kettles the heaters were upright and located in the centre to give improved recirculation currents. Some kettles also included base steam coils for preheating the incoming wort, and to minimise dead spots (see drawing (b)). This was developed further by the introduction of a "chimney" and "spreader plate" giving greatly improved recirculation and a greater surface area for evaporation (see drawing (c)).

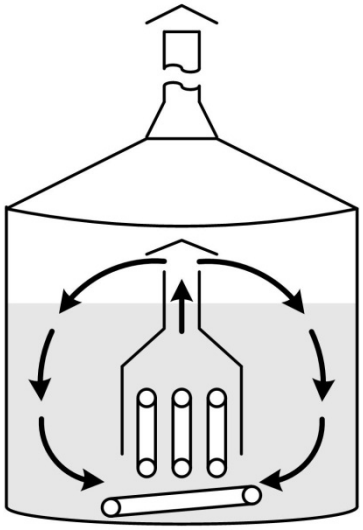
The disadvantage of kettles with internal heating tubes is that the heaters tend to be difficult to clean with conventional CIP due to blind spots and are prone to corrosion. This can result in steam leaks into the boiling wort which are difficult to detect and repair. Wort circulation relies on thermal currents within the kettle and the turbulence over the heating surfaces is limited. This results in high levels of fouling, and will require more frequent cleaning to ensure effective heat transfer is maintained.



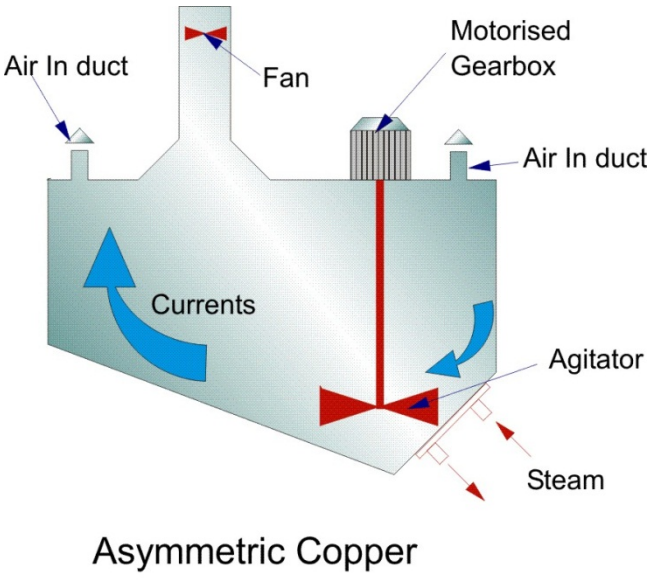
(a) Kettle with "horizontal" internal heating coils – poor recirculation.



(b) Kettle with vertical internal heating coils for improved recirculation



(c) Kettle with vertical internal heating elements, chimney and spreader plate for vigorous recirculation



Asymmetric Copper

The low level of natural turbulence and high fouling is improved by use of forced recirculation.

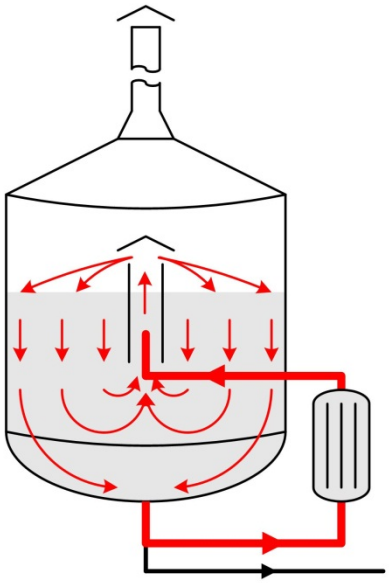
The use of a chimney and spreader plate forms the basis for most modern systems, some of which use pumps to improve the recirculation, at least whilst the wort is heating up, and some without (diagram of example not shown as so similar to (c), but without bottom “horizontal heating coils).

However, heating elements with the wort surrounding the elements have now been superseded by use of shell and tube heat exchangers. In these, the steam supply is contained within the shell, whilst the wort passes through the tubes. This design minimises the problem of the heating surfaces become fouled quickly.

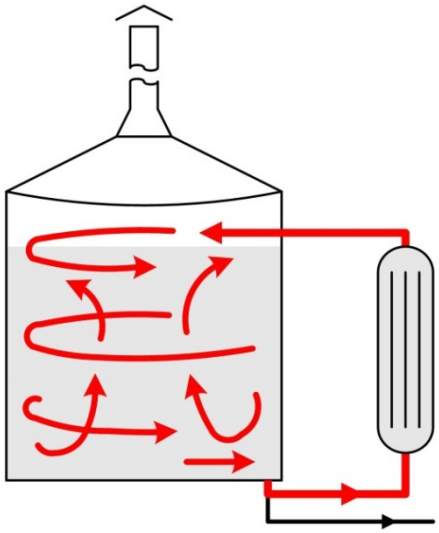
Some of the latest designs use an external heater (external wort boiler). The wort is taken out of the kettle and passed through a shell and tube or plate heat exchanger for heating. The heat exchanger may be primed during the pre-boil stage, using a small circulation pump. In some installations when boiling starts, the circulation pump is by-passed. The wort then circulates using the natural “thermosyphon” effect. Circulation starts because hot liquid rises, cools down and therefore sinks again, etc. Incoming wort to the boiler is at 100^{o}C and the outlet wort and superheated vapour from the boiler is around 105^{o}C. So the hotter liquid rises out of the boiler to the kettle. This saves pumping energy and limits the potential for damage to the "flocs" which would otherwise have to pass through a recirculating pump.

The better heat transfer and turbulent conditions improve self-cleaning of the tubes. This allows between 8 and 16 brews (more in most recent designs) to be processed before a clean.

By reintroducing the wort at a tangent, it is possible to use the vessel as a combined kettle/whirlpool. This eliminates the transfer time between a separate kettle and whirlpool.



External calandria with indicative flows during wort boiling.



Combined kettle/whirlpool with indicative flows during wort boiling.

Energy consumption

The wort boiling process consumes a large proportion of the heat energy used in the brewery and so boiling vessels (kettles/coppers) are designed to be as energy efficient as possible. Features include:-

- Levels of evaporation reduced from traditional levels circa 10% to as low as 4% (with energy recovery) or 2% (without an energy recovery system).
- High levels of insulation.
- Easy to clean and designed to avoid the build-up of soil, particularly the heating surfaces.
- Heat recovery from the vapour evaporated from the wort to generate hot water for brewery use.
- Heat recovery from the vapour evaporated from the wort to preheat wort from the lauter tun or mash filter. Below 4% evaporation energy recovery is not economically viable using current technology.

Typical boiling times and hop addition practices

Boil times

Boil times using the equipment discussed are typically 60 to 90 minutes. Traditionally, boil times were often considerably longer, but with improvements in wort runoff control, particularly with modern lauter tuns and mash filters, long boil times are not normally required specifically for evaporation. Due to the high energy costs, any reduction has a beneficial effect on reduction of energy usage & costs. With improvements in malting and boiling technology, it has also proven less important to boil for long periods to achieve DMS production and evaporation.

It has been demonstrated that extended boil times do not offer improvement to hop isomerization and thus utilization (see section 3.4).

Modern wort boiling systems typically aim for about 4% evaporation, with boil times of 60 minutes or slightly less.

Hop additions

Bitterness hops are generally added at the start of the boil, though where beer is to be packaged in clear (flint) glass, stabilized extracts only may be used to give bitterness, and no hops will be added at all during the boil.

When brewing with whole hops or pelletized whole hops (i.e. not hop extracts), the principal hop volatiles lost during wort boiling are the hop oils. If these are present at too high a concentration they may contribute a bitter, vegetable, grassy flavour to the beer. Most of the hop oil volatiles are lost during the first 20 minutes of a boil.

Where late hop character is required in beer, quantities of selected aroma hops can be added to the kettle shortly before or at the end of the boil. The quantities of hops added and the timing vary from brewer to brewer depending on the desired flavour and aroma characteristics desired. For example, a lager may have:-

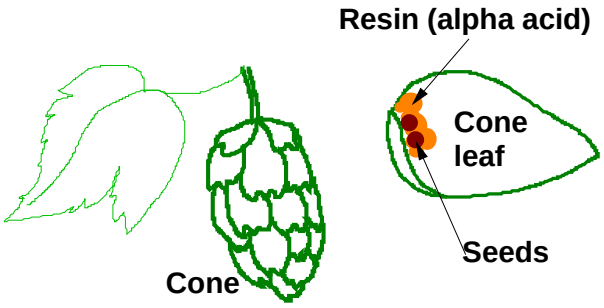
- A first addition of bittering hops made at the start of the boil.
- A second bittering and flavour addition about halfway through the boil.
- A final addition 5 minutes before the end of the boil to impart later hop aroma / flavour.

3.3 The nature of hop bitterness

The nature & origins of hops and hop products

Hops are essential to the brewing process in that they impart both flavour and bitterness to the beer. Up to the years 1400/1500, 'ale' was brewed in England without hops, but often with other herbs as the flavouring ingredient. Hopping of beers grew in popularity, not only because of the flavour but also because of the plant's antiseptic properties. Their use is now almost universal.

The hop develops very bitter resins and oils around the seeds of the cone which is the fruit of the plant. These are seen as the yellow powder obtained when a sample of whole hop cones are broken open, or rubbed between the palms of the hands.



These resins are dissolved when hops are added to the process and remain as a strong flavour component of the finished beer.

The main resin, whose technical name is α-acid (alpha acid), is modified during the boiling process when it is changed to **isomerised-α-acid**, which is both more bitter and more soluble than the original α acid. The isomerised form is more stable and it survives in the finished beer to give the beer its bitter flavour. It can be measured as milligrams per litre (mg/l) of iso-humulone, expressed as an International Bitterness Unit (IBU), internationally recognised as a measure of the beer's bitterness.

Hop oils are the aromatic fraction of the resins and give beer its hoppy 'nose' and character. They are, however very volatile and will be distilled off along with the other volatiles in the kettle unless added late in the boil. Beers with a strong hop aroma are likely to have been late hopped, dry hopped (that is hops added to the FV shortly after completion of fermentation, or into cask beer) or have had hop oil added at an appropriate stage in beer processing.

Hops are generally classified as belonging to one of two main usage groups:-

- Bittering hops.
- Aroma (flavour) hops.

However more recent agronomic developments have developed a number of hop varieties which are considered suitable for either or both uses.

Bittering hops have been bred specifically for high alpha acid content. These can then be used for preparing extracts, when any undesirable aromas are lost, or may be added at the start of the boil, when any undesirable aroma characteristics are boiled off.

Aroma hops have been bred primarily for the desirable hop oil content, though the nature of modern breeding techniques and agronomic practices mean that these often also have quite high alpha acid contents.

Isomerization during wort boiling
Isomerisation is a relatively rapid reaction with production of over 90% of the wort bitterness occurring within the first 30 minutes of boil. Complete extractable bitterness occurs within 60 to 70 minutes.

The isomerisation reaction is faster at higher temperature. Results from high temperature wort boiling show that the rate of isomerisation of alpha acid is directly related to temperature.

Alternative or supplementary hop additions

Hop products
Hops may be obtained from the supplying merchants in a number of forms:-

- Whole hop cones, normally compressed into bales or pockets.
- Whole hop pellets.
- Isomerised hop pellets.
- Non-isomerised kettle extract.
- Isomerised kettle extract.
- Hop oils.
- Post fermentation bittering extracts.

Whole hops
Traditional brewing practice uses whole hop cones, which, after picking, have been dried and then compressed into bales or pockets for transport. However, there are a number of problems associated with using this form of hops.

- The density is low, the bulk high, and transport costs are therefore high.
- Handling in the brewery is difficult, and they cannot easily be used with external calandria and whirlpools for example.
- The entrained air degrades the hop resins rapidly. It is not practical to vacuum pack whole hops. They have to be refrigerated for storage, which adds costs.

Whole hops tend to lose their brewing value during storage, even when dried and kept in cold storage, but extracting the brewing value, either as α-acid or hop oil overcomes this problem.

Non-isomerised hop products
Non isomerised hop products retain the α-acids unchanged after processing, and have to be added at the start of boil. They include

- Pellets from milled and compressed whole hops.
- Pellets from milled and compressed hops after removal of vegetable matter (e.g. hop cone leaves, seeds), concentrating the resins to standard alpha acid values, e.g. type 45 and type 90 pellets.
- Pellets from milled and compressed hops following stabilisation of the hop resins to make them less susceptible to oxidation damage.
- Extracts of the resins, typically extracted using liquid CO_2, concentrated to standard alpha acid values, e.g. 30 %.

Isomerized hop products
Isomerised hop products are made by processing hops or hop extract in a specialised plant so that the isomerisation that normally takes place in the wort kettle during boiling is carried out before the hops are added.

The advantages of using pre-isomerised pellets are the same as those for the use of non-isomerised pellets but with added savings from better hop utilisation. Pre-isomerised hop extracts allow the beer to be hopped at the end of the process avoiding the losses that occur during brewing.

Products include:-

- Isomerised hop pellets.
- Isomerised kettle extracts.
- Isomerised hop extracts for use as post fermentation bittering addition.
- Reduced (stabilised) hop extracts for use as post-fermentation bittering addition, for example in beers to be packaged in clear (flint) glass bottles.

Hop oils
Hop oil products are used to impart hop aroma to beers. The bittering components are not an essential part of these products. These include:-

- Hop oil emulsions
- Pure hop oils

Miscellaneous hop products
There are also some hop products which are not used for bittering beer or adding aroma but used instead to reduce over-foaming in the wort kettle or FV. They are most widely used when brewing beers for package in clear (flint) glass, when foam generation during wort boiling and fermentation is not suppressed by the presence of hops.

Hop pellets - preparation
Hop pellets are made by removing the bulk of the extraneous matter such as stalks and leaves, grinding the hop cones and then pelletizing. The pellets are then vacuum packed, or packed in an inert gas to help preserve the brewing value. Hop pellets contain the essential material from the original hops including the aromatic oils and their use is widespread. The advantages that hop pellets have over whole hops are:-

- The pellets have a known α-acid content so control of bitterness is more accurate.
- Storage is easier and cheaper because the packs are smaller than pockets or bales of whole hops.
- All the brewing value of the hops (α-acid and hop oil) is present after the pelletisation process.
- The hops deteriorate much more slowly during storage.
- Processing to produce pellets is cheaper than extracting.

Hop extract - preparation
Hop extracts are made by dissolving the α-acid in either ethanol or more commonly, liquid carbon dioxide. Bitterness hop extracts may not contain much of the aromatic hop oil. However when added to the wort kettle they the following advantages over whole hops:-

- The extract has a known α-acid content so bitterness control is more accurate.
- Storage is easier because the extract occupies a much smaller space than the large bags (pockets) of whole hops.
- The hop extract does not deteriorate as it gets older.

A disadvantage is that there is no filter bed formed by the spent hops if a hop back is used during wort production.

Pre-isomerised hop extracts
Pre-isomerised hop extracts are prepared from hop extracts and may be used to adjust low beer bitterness after fermentation.

Ultraviolet light normally penetrates clear or green bottles but not those made from brown glass. If beer is to be packaged in clear glass, it is preferable to use only post-fermentation bittering as pre-isomerised extract in a 'reduced' form (for example tetra-hydro iso-α-acid, or 'tetra'), because it is not affected by ultraviolet light. No "normal" hops or non-reduced hops must be allowed to come into contact with the beer in this case – sunlight reacts with the iso-α-acid to produce compounds with a 'skunky' or "light-struck" flavour. An added benefit of beers treated with 'tetra' is that they also exhibit enhanced foam stability.

Hop oils are made by distilling off the aromatics from hops. They are added to fully processed beer to impart a 'hoppy' character.

3.4 Hop calculations

How bitterness is expressed
As discussed earlier, beer bitterness is expressed in the arbitrary unit IBU (International Bitterness Unit). One IBU is usually assumed to be equivalent to 1mg of iso-α-acid in 1 litre of water or beer in the range 15 to 35 IBU, although the isomerised α-acid actually only contributes about 0.7 units per mg/L with the balance being other bittering compounds including β-acids.

Bitterness potential of hops
Both α and β isomerised acids contribute to the perceived bitterness of beer as noted above, and in fresh hops, the potential is based on the α-acid content of the hops only, as expressed in mg α-acid / unit weight – normally as a percentage.

Calculations of hop addition rates
When preparing a recipe for a new beer, it is necessary to consider a number of factors:-

- Target bitterness.
- The type and intensity of hop aroma in the final to be derived from late addition kettle or whirlpool hops. Although the brewer is primarily interested in the aroma obtained from these hops, because they always contain some α-acid, the α-acids contained in these hops must be accounted for, particularly where large amounts of aroma hops are used to obtain an intense hop character.
- The length of boil after each addition.
- The length of time after the boil is completed that the hops remain in contact with hot wort.
- The likely utilisation of each addition.

As an example, we wish to brew 500 hl beer with a final bitterness of 35 IBU, using a single addition of bittering hops with an α-acid content of 8%.

500 hl of beer is 500 x 100 = 50,000 litres.

Weight of alpha acid required in the final beer = 50,000 litres x 35 mg per litre = 1,750,000 mg.

The hops contain 8 % α-acid, i.e. 1 kg hops contains 80,000 mg α-acid

Therefore, assuming 100 % of the α-acid is converted to iso-α-acid, we require

1,750,000 / 80,000 kg hops = 21.9 kg hops.

However, because only approximately 30 % is expected to be isomerised and pass through to the final beer (30% Utilisation), we need 21.9 x 100 /30 = 72.9 kg of hops to achieve our target bitterness.

Note:-

1,000 mg = 1 g
1,000g = 1 kg
1 kg = 1,000,000 mg

Calculation of hop utilization

Hop utilisation is a measure of the efficiency of hop use. The calculation is made by comparing the amount of α-acid added to the beer in mg/L to the level of measured bitterness in the final product in IBU (mg/L of isohumulone).

Hop utilisation in the brewery is affected by a number of factors, including:-

- The timing of the hop addition. Additions at the start of the boil will have much higher hop utilizations than those added later in the boil, getting progressively less the later the addition, and thus the less the contact time.
- The pH of the wort or beer. Isomerisation and solubility are greater at higher (more alkaline) pH values.
- The vigour of the boil and the type of boiling system.
- The amount of bitterness absorbed by the trub. The higher the protein & carbohydrate trub volume, the lower the utilization.
- Particularly for late hop additions, the length of time the boiled wort stays in contact with the hops in the hop separation system (e.g. whirlpool).
- The amount of bitterness absorbed by the yeast. Different yeasts adsorb different levels of bitterness, though these variations are quite minor compared to the variation due to time of addition. More yeast (from yeast growth) will absorb more bitterness.

Again, as an example, if hops are added :-

- At the start of a **60 minute** boil might typically give 30% utilisation.
- **45 minutes** before the end of the boil might give 29% utilisation.
- **30 minutes** before the end of the boil might give 27% utilisation.
- **15 minutes** before the end of the boil might give 15% utilisation.
- **5 minutes** before the end of the boil might give 8% utilisation.

The higher the concentration of α-acid in the hops added, the poorer the hop utilisation.

The higher the strength, or SG, of the wort, the poorer the hop utilisation.

Different types of hop products will give different utilisations, with pre-isomerised hops having the better utilisation values.

Hop Type	**Typical Utilisation**
Whole hops	25 – 30%
Pelletised hops	25 – 30%
Isomerised pellets	50 – 60%
Isomerised kettle extract	50 – 60%
Isomerised post-fermentation extract	70 – 85%

In the following example, α-acid is added from hops which contain 8% α-acid. Only a proportion of the added α-acid ends up in the beer as iso-α-acid.

500 hl of wort is boiled with 35 kg of hops with an α-acid content of 8 %.

The available α-acid is = 35 kg x 8% = 2.8 kg = **2,800,000 mg**

The laboratory analysed the beer, finding it has a bitterness value of 15 IBU.

500 hl beer at 15 IBU means that the beer contains

500 x 100 = 50,000 litres

50,000 litres at 15 mg/l = **750,000 mg iso α-acid**

Therefore the hop utilisation =

(750,000 / 2,800,000) x100 %

= **26.8 % Utilisation**

Knowing the likely **hop utilisation** value from your boiling system it is possible to make a good calculation of a **hop addition rate** (above).

Notes

- *Draw a diagram of the copper / kettle in a brewhouse that you are familiar with.*
- *What type of heater does it have?*
- *What raw materials are added to the kettle in the brewhouse that you are familiar with?*
- *What effect do they have on the wort and beer produced?*
- *What process aids are added to the wort in your brewery? At what stage are they added and why?*
- *What effect do these process aids have on the worts and beers produced?*
- *What types of hops or hop products are used in the brewery that you are familiar with?*
- *At what stage of the boiling process are they added?*
- *What level of hop utilisation is achieved in the brewery that you are familiar with?*

Qualifications

The General Certificate in Brewing (GCB)

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Section 4 Wort clarification, cooling and oxygenation (aeration)

4.1 Wort clarification

Introduction

At the end of the boil, the wort will be bright but there will be large particles floating in it. These particles or flocs contain:-

- Coagulated protein or 'break'.
- Tannin material from the malt husk and from the hops.
- Lipids or fatty material, mainly from the malt.
- Spent hops or debris from hop pellets.

These can all have a deleterious effect on finished beer quality, and as much as possible must be removed prior to transfer to the Fermentation Vessel (FV).

The quantity of hot break formed (not including hop vegetable matter) is around 0.2 - 0.4 % of the hot wort. The difference of the density of hot break and hot wort is very low.

Cold break is formed at temperatures lower than 70 - 80 °C. The composition of cold break is around 52 % proteins, 21 % carbohydrates and 25 % polyphenols. At lower temperatures there is more cold break formation.

Effect of 'break' on wort quality

- The coagulated protein, forming the bulk of the hot and cold "break" will, if allowed to remain, cause haze and may also result flavour problems in the finished beer.
- The tannin materials are very astringent and if allowed to remain in large quantities can pass this character on to the beer. Tannins also combine with proteins, causing haze and, in sufficient quantities, sediments.
- Lipids or fatty material will destroy the head stability of the beer. It also makes the beer taste stale (often described as papery or cardboard) as it gets older.
- Spent hops or hop pellet debris, which can simply smother yeast and prevent it fermenting as well, but if not separated, can make it difficult to achieve the optimal pitching rate. Large quantities can also adversely affect the flavour of the beer and the haze stability by allowing additional flavour and haze forming materials to dissolve during fermentation.

Kettle finings

Malt contains some protein material. Most of this protein material is not wanted as it can cause haze in the final product. It is considered desirable to remove as much protein as possible at each stage of the brewing process. During boiling, much of the larger protein molecules clump together, or coagulate in the same way that the white of an egg curdles when it is heated. This coagulation can be seen by taking a sample of hot wort (hot break sample) and allowing it to cool below 80ºC. The flocs can be seen forming and settling out.

The more vigorous the boil, the better the coagulation. Because the protein is no longer dissolved it can be removed fairly easily by physical methods.

Many brewers simply rely on the use of wort separation procedures such as whirlpools to remove the haze forming proteins. However, where permitted, many brewers add kettle finings to improve the formation of cold break.

Kettle finings are made from seaweeds (often known, not always correctly as "Irish moss"), the active fining ingredient being known as carrageenan. The use of this material also improves the effectiveness of isinglass finings, where used post fermentation, and helps reduce the amount of protein material to be removed during beer filtration.

The principal fining action is the result of direct electrostatic interaction of negatively charged carrageenan molecules with positively charged protein flocs, making them bigger so they settle faster.

The use of pellets of refined seaweed, rather than powder eases handling of the product and dispersion in boiling worts. Kettle finings of this type contain approximately 50% of their weight as a dispersant, usually as sodium bicarbonate and a suitable acid, (e.g. citric acid), to make them self-effervescent.

New materials are semi refined seaweeds of the genus *Eucheuma*. The seaweed is simply harvested and washed in alkali to slightly purify and clean it without major refinement and turned into dust free granules, so reducing the cost of refinement and pelletisation.

The clarity of the wort produced is affected by a number of factors including:-

- Finings addition rate.
- Time of addition.
- Wort pH.
- Malt variety and degree of modification.
- Wort gravity.

Although added to hot wort, kettle finings have no significant effect on hot wort clarity, their main effect being

the production of bright cold wort. The sole reason for adding kettle finings to hot wort (normally the kettle shortly before casting) is to solubilize the carrageenan which does not dissolve below 60 °C. The kettle finings must therefore be added early enough to be fully dissolved, although sufficiently late to avoid thermal denaturation. The actual time and rate of addition will depend upon the type of product chosen and the process conditions. The rate in particular should be optimised on a regular basis.

Break & hops removal

It is necessary to remove this 'break' to protect the beer's quality. There are four main ways of doing this depending on the type of hops used and the requirement for absolute wort clarity:-

- Filtration through the spent hops typically using a hop back.
- Separation of whole hops using a hop separator.
- Sedimentation in a whirlpool.
- Centrifugation.
- Filtration using kieselguhr or other filter aid, though this method will not be discussed further as it is so rarely used.
- The break and spent hops collected from any of these processes are waste material that has to be disposed of.

Wort clarification

Cool ship

For many years the cool ship was the principal means of cooling wort. It provides almost complete removal of hot break and partial removal of cold break. It is a flat open vessel and the wort is pumped into it directly after boiling with a temperature of nearly 100 °C. The height of the wort is only around 15 cm so there is a large surface area, the wort cools down very quickly and the break particles have a short distance to fall.

The main disadvantage is the microbiological risk. The wort is without any yeast in an open vessel for some hours. There may be fans to circulate the air over it. It is possible to install sterile filters, but the risk of contamination is much higher than in closed vessels. Another disadvantage is the size of a cool ship because most other systems need less space.

Sedimentation tank

The traditional sedimentation tank is a simple open or closed vessel where the wort is pumped in after boiling, to a depth of around 1 – 1.5 metres. After a rest of at least one hour the hot break and the spent hops settle down and the wort can then be pumped to the cooler. There is little cooling in the tank itself, so the disadvantages of long stand times at high temperatures occur.

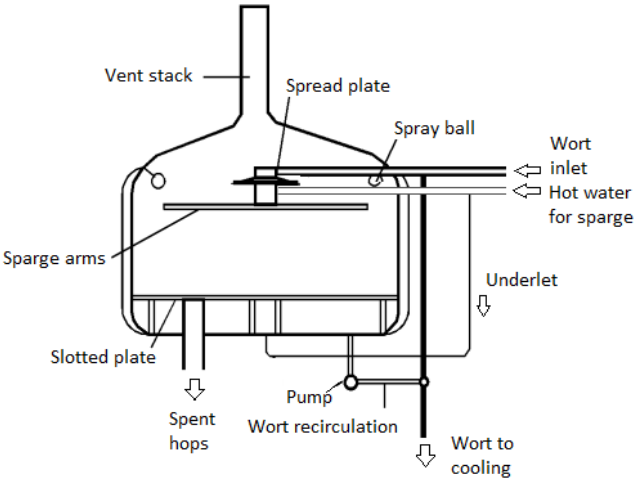
Start of wort transfer to a coolship.

Wort kettle hold back

The hot break may be sedimented in the wort kettle (copper). If a thimble or strainer is installed in the casting outlet, when wort boiling is stopped, the hot break can be allowed to settle down. After that, the wort can be pumped to the wort cooler system.

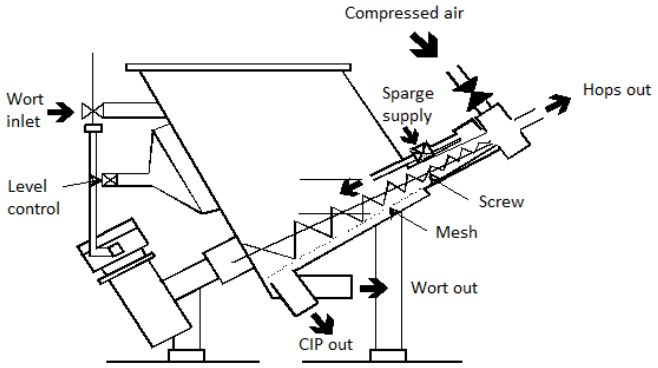
Hop Back

Hop backs are used by traditional brewers who still use whole hops. Hot wort is transferred to the hop back either onto a bed of fresh whole hops used for late addition of hop aroma, or simply to the hop back. The wort is then recirculated so that a hop bed is formed from kettle hop additions. The protein solids are retained in the hop bed and the clear wort runs off for cooling. When drained, the hop bed is usually sparged with fresh hot water to recover any residual extract.



Hop separator (or strainer)

Whole hops can also be removed using a hop strainer. The wort containing the kettle hops is transferred to the strainer. The hops are conveyed by a screw conveyor to a waste tank, whilst the wort drains into a wort receiver. The strainer is often used in combination with a whirlpool tank.



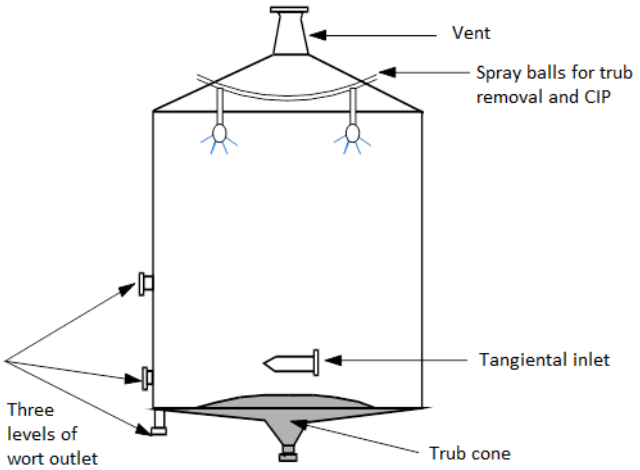
Whirlpool

The whirlpool is probably the most widely used process for hot break separation. Whirlpools are used with hop pellets and extracts and not whole hop cones. It is a cylindrical vessel with a flat bottom into which wort, while still hot, is pumped through an inlet, laterally and tangentially. The inlet pipe is tapered so that the velocity of the wort increases. This configuration puts the wort in the whirlpool into rotation. The rotational movement causes the so-called "teacup effect", i.e. the same effect that can be observed when one stirs a cup of tea that still contains residues of tea leaves. The tea residues collect in the middle of the cup. The same phenomenon is observed in the whirlpool. After some time, a break cone forms in the middle of the whirlpool. After the whole wort has been pumped into the whirlpool, a whirlpool rest takes place, usually taking 10 to 15 minutes, depending on the whirlpool design. The whirlpool rest should not be prolonged too much as the stability of the break cone might suffer. Disintegration of the break cone might be promoted. When the rotational movement has died down, the clarified wort can be removed from the whirlpool and sent to wort cooling. Whirlpools are used with hop pellets and extracts, but not with whole hops.

The difference between the inflow velocity of the wort and the peripheral velocity should not be too high. Traditionally, velocities of 12 - 15 m/s, sometimes 20 m/s were used. Nowadays, the inflow velocity is not generally higher than 5 m/s. Some breweries work with only 2.5 m/s. The disadvantages of high values are high turbulence and high shear forces which adversely affect particle coagulation and settlement.

Different bottoms have been used to try to improve the compaction of the cone and thus losses of entrained wort, but the most common nowadays is flat bottomed with a gentle slope towards the floor outlet.

A number of outlets at different levels are normally used to runoff the wort, starting at the highest, to reduce the amount of tub carried over into the FV.

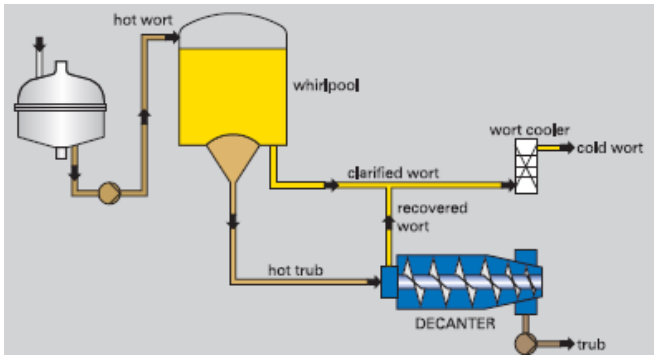


In some breweries, the functions of the wort kettle and the whirlpool are combined into a single tank system. On completion of boiling, the wort is recirculated through a pump to create a whirlpool, and thus settling effect in the kettle.

Centrifugation

A disc or decanter centrifuge can be used to remove hops and break from hot wort. The centrifuge is also often used to recover the wort from settled break in the whirlpool to be added back into the brew.

Please see section 7, yeast handling for a brief description of the flow through a centrifuge.



Typical decanter centrifuge operation

4.2 Wort cooling

Purpose of wort cooling

The wort ex clarification system, e.g. whirlpool is typically at a temperature circa 97 °C, which is too hot to support brewery yeasts. The optimum temperature for the start of fermentation, depending on the yeast strain, will be between 6°C and 20°C. The clarified wort must therefore be cooled to the fermentation temperature before the yeast can be added.

It would be uneconomic to use glycol or similar refrigerant on its own to cool the wort. The wort contains

considerable excess thermal energy, much of which can be recovered to produce hot water, usable for a number of purposes including:-

- Mashing and sparging
- Cleaning
- Preheat wort from the mash separation plant to close to boiling point, so less heat energy is required to boil the wort.

As part of the wort cooling process, the wort is invariably oxygenated, either by addition of pure sterile oxygen, pure sterile air, or sometimes a mixture of both. This is discussed in more detail later in this section.

Effects of cooling on wort constituents

On cooling, wort proteins interact with polyphenols to precipitate as cold break. This material consists of very fine particles that are slow to settle and consequently are likely to survive into maturing beer. In combination, boiling and wort cooling remove 17 - 35% of the total protein content, depending upon the malt variety and hop product/variety used. Cold break formation is temperature dependent, only forming in significant quantities below 20-30^{o}C, and increasing dramatically in quantity as the temperature is further decreased. The removal of cold break can be enhanced by use of kettle finings.

Wort cooling methods

The traditional form of wort cooler was the coolship followed by a trickling cooler. Cold water passed through horizontal pipes and wort was fed over the pipes from the top. The wort was cooled by the cold water and, in addition, more water evaporated from the wort film after the coolship, again contributing to cooling. An open collection tank was placed at the bottom end of the series of pipes, allowing the wort to be runoff to FV and pitching. The large surface area allowed considerable wort oxygenation, but this system is prone to contamination pickup.

Nowadays the plate heat exchanger is almost exclusively used for wort cooling. This is because:-

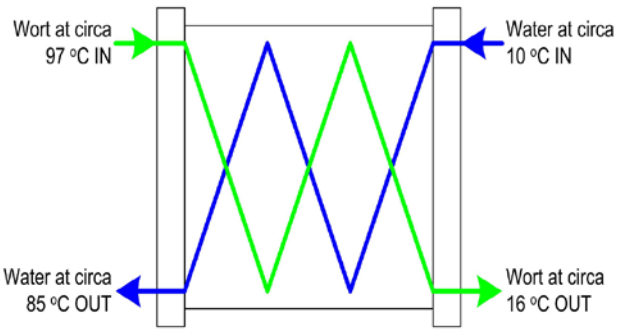
- Plate heat exchangers are very efficient and can cool the wort down in a short time. There is a large plate surface area for wort/coolant and the thin films of water / wort, and high levels of turbulence mean the heat transfer is very rapid.

- Nearly all the excess heat from the wort can be recovered to generate hot water for brewing and other production uses.

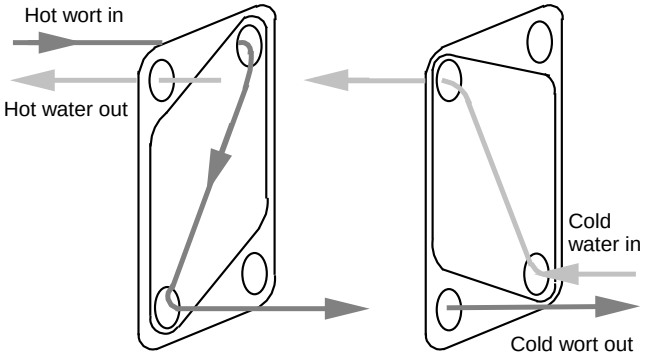
- They are enclosed and are easy to clean in line. Therefore they maintain heat transfer efficiency and keep the wort sterile.

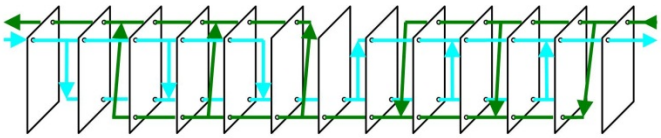
Operating principles of plate heat exchanger wort coolers

The principles of how the plate heat exchanger works are illustrated in the diagrams below. The hot wort is cooled in a counter current direction against the brewing liquor.



Normally, the flow is diagonally across the plates, as follows:-





- In general 100 hl of hot wort at around 98 C will be cooled to say 16 C by around 110 hl of incoming brewing water at 10 C which in turn will be heated to around 85°C.

- This makes wort cooling a very efficient process recovering most of the excess heat from wort boiling which can be used for brewing.

- In ale breweries with relatively high pitching temperatures above 15°C, cold well or town's supply water may be used as the coolant. The hot water generated is then used for brewing and cleaning.

- For lager brewing, with lower pitching temperatures of typically 8 - 12°C, an additional cooling stage is usually added. The coolant in this stage is a refrigerant such as brine, ethanol solution, glycol etc. Some breweries chill the cooling liquor, so that only a single cold water stage is required.

- The plates of the heat exchanger are as thin stainless steel as possible (0.5 mm) to maximise heat transfer. Surface area and turbulence are increased by embossing or rippling the plates.

4.3 Wort oxygenation / aeration

Purpose of wort oxygenation

The absence of sufficient oxygen in the wort for the yeast to make these sterols and fatty acids can lead to number of problems including:-

- Sluggish fermentations - high final pH and other flavour changes.
- Early finish to fermentations resulting in high final gravities.
- Poor yeast growth – insufficient for repitching.
- Unhealthy yeast (normally seen as low viability) which is not suitable for repitching.
- Possible ability of contaminating bacteria to grow faster than the yeast and spoil the beer.

Different yeasts and/or differing wort gravity require different amounts of oxygen. Wort oxygen levels of between 8ppm (air saturated wort) and 30 ppm (oxygen saturated wort) may be required depending on the wort gravity and yeast type used.

Wort oxygenation methods

The wort cooling stage has proven to be the best time for controlling dissolving oxygen. This can be achieved through the use of air or from pure oxygen to a repeatable and measurable level.

It is usual to inject air or oxygen into the wort stream in-line. The amount of dissolved oxygen in the wort affects yeast growth so much that some form of control is required to guarantee consistency. The control can be achieved in a number of ways as discussed later.

The accuracy and repeatability of the control can be measured by using a dissolved oxygen meter. However, particularly in older breweries, wort may be aerated only once the wort is in the FV, where accuracy of addition (and measurement) is much less well controlled.

Aeration can take place before or after cooling on wort transfer, or whilst the pitched wort is in the FV. The main advantages and disadvantages of each choice are listed in the following table:-

System	Advantages	Disadvantages
Hot wort aeration / oxygenation (in-line)	Air is sterilised by the hot wort. Air is dissolved effectively as it passes through the cooler.	Wort colour increase. Flavour change.
Cold wort aeration (in-line)	Virtually no effect on wort quality.	Need to provide sterile air / oxygen and injection system. Need to increase solubility by injecting small bubbles or ensuring vigorous mixing and injecting when wort pressure is high.
Pumped rousing via “fishtail” over top of fermenting wort	Can be used to disperse flocculent yeasts. Can be used to add additional oxygen from the atmosphere if the fermentation starts to slow.	Prone to pick up contamination from atmosphere. FVs have to be built with this facility to allow effective cleaning etc. Cannot be used on enclosed vessels, particularly conicals. No accurate control over amount of oxygen dissolved.
Pumped rousing with air / oxygen injection	Can be used to disperse flocculent yeasts. Can be used to add additional oxygen from the atmosphere if the fermentation starts to slow. Can be used on enclosed vessels, including conicals. In deep vessels, rousing part way through fermentation may result in excessive CO2 breakout and “boiling over”.	Gas used must be sterile, otherwise liable to pick up contamination. FVs have to be built with this facility to allow effective cleaning etc. Difficult to clean. Poor / difficult to control amount of oxygen dissolved.
Bubbled aeration / oxygenation	Can be used to disperse flocculent yeasts (though this is not main purpose) Can be used to add additional oxygen from the atmosphere if the fermentation starts to slow. Can be used on enclosed vessels, including conicals. In deep vessels, rousing part way through fermentation may result in excessive CO2 breakout and “boiling over”.	Gas used must be sterile, otherwise liable to pickup contamination. FVs have to be built with this facility to allow effective cleaning etc. Difficult to clean. Poor / difficult to control amount of oxygen dissolved.

Aeration versus oxygenation

Use of aeration or oxygenation is generally dictated by the level of dissolved oxygen required in the unpitched wort.

It is not possible to dissolve more than about 10 ppm oxygen in cold wort when using air as the gas supply in a simple aeration system. However, it is possible to dissolve up to approximately 30 ppm oxygen in cold wort if using pure oxygen. Both these values are affected slightly by the cold wort temperature and wort gravity. The higher the wort specific gravity, the less oxygen will be dissolved. The higher the cold wort temperature, the less oxygen will be dissolved.

Typically, sales gravity beers need no more than air saturation i.e. about 9 ppm dissolved oxygen. High gravity beers may need oxygenation, up to 30 ppm. Very high gravity beers (e.g. SG of 80° +) may require additional oxygenation / aeration during fermentation to allow the wort to be fermented successfully.

Different yeasts need different levels of oxygen for adequate yeast growth. Since yeast growth has a direct effect on the level of higher alcohols and esters produced during fermentation, different beers will need different levels of dissolved oxygen to provide the correct (desired) amount of esters and alcohols. Some brewers use additional oxygenation / rousing during early fermentation to suppress the production of excessive levels of esters.

In practice, levels of dissolved oxygen are finely tuned by each brewery for each quality to give fermentations that ferment on profile, give an acceptable flavour match and minimise excessive yeast growth and losses.

Air injection - advantages	Air injection - disadvantages
Compressed air is inexpensive. It will saturate to approximately the level required by many yeasts, although dissolved oxygen should still be measured to ensure consistent fermentations.	Air must be sterilised. The large volume of N2 introduced with the air is very difficult to fully dissolve and will pass through the fermenter, causing thick top foams. Aromatic flavour compounds can be sparged from the wort by these bubbles.

O2 injection - advantages	O2 injection - disadvantages
Cylinder oxygen is free from microbes. Only the quantity of oxygen required for the fermentation needs to be injected, to reduce costs. No large "nitrogen foams" will be created in the fermenter. Concentration levels are adjusted easily and accurately. Since oxygen is very soluble, usage costs are very low.	Extremely high levels of dissolved oxygen are possible unless a feedback control system from a dissolved oxygen analyser is used.

Example maximum dissolved oxygen levels in water and 40° SG wort whilst **air** in contact with water at atmospheric pressure.

Temperature	Max DO2 in water	Max DO2 in wort
10 ^{O}C	11.3 ppm	9.8 ppm
15 ^{O}C	10.1 ppm	8.8 ppm
20 ^{O}C	9.1 ppm	7.9 ppm

In theory, it should be possible to achieve the following dissolved oxygen levels if using **pure oxygen** instead of air, though brewers do not normally require these levels in a single dose. However, a number of breweries use DO2 levels around the 30 ppm in cold wort.

Temperature	Max DO2 in water	Max DO2 in wort
10 ^{O}C	53.8 ppm	46.7 ppm
15 ^{O}C	48.1 ppm	41.7 ppm
20 ^{O}C	43.3 ppm	37.6 ppm

Operating principles of wort oxygenation systems

The following discussion only relates to in-line wort oxygenation / aeration.

Factors that promote gas absorption include:-

- Low temperature.
- High pressure (e.g. by use of a back pressure control valve).
- Small gas bubbles at point of injection, to give very high surface area by using, for example, a venturi system or a sintered stainless steel candle.
- High levels of turbulence, which can be achieved by high flow rates, in-line mixers or plate heat exchangers.

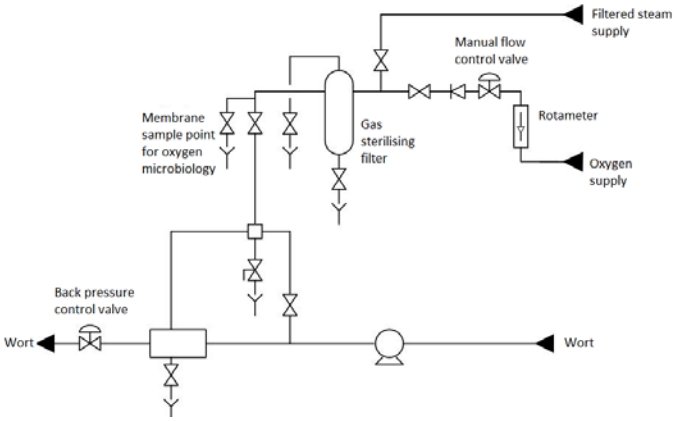
Brewers using air may add it to the hot side of the wort cooler thus ensuring sterility, without the complication of additional gas sterilisation equipment. Because aeration on the hot side of the wort cooler may cause some colour pick up due to oxidative browning reactions with wort hot side aeration is predominantly used by ale brewers, where a slight colour pickup is less noticeable than in say a pale coloured lager. Brewers adding it to the cold side must ensure the air is adequately sterile-filtered, usually by a

membrane cartridge filter system which can be steamed sterilised as part of the entire injection system. There is no point in having a sterile filter if the rest of the gas injection system is not equally sterile.

Brewers using oxygen invariably add it to the cold side of the wort cooler. The mass of pure oxygen required is only approximately one fifth of the mass of air required, and so the risk of it not dissolving is much lower than the equivalent mass of oxygen added as air.

In order to dissolve oxygen up to about 10 ppm, a slight excess of air needs to be added. Shallow FVs in particular will allow the excess to flash off, but with the risk of creating considerable foam.

If using oxygen, or requiring a very accurate DO2 of less than about 10 ppm when using air, then it is necessary to introduce some form of control system such as that shown below:-

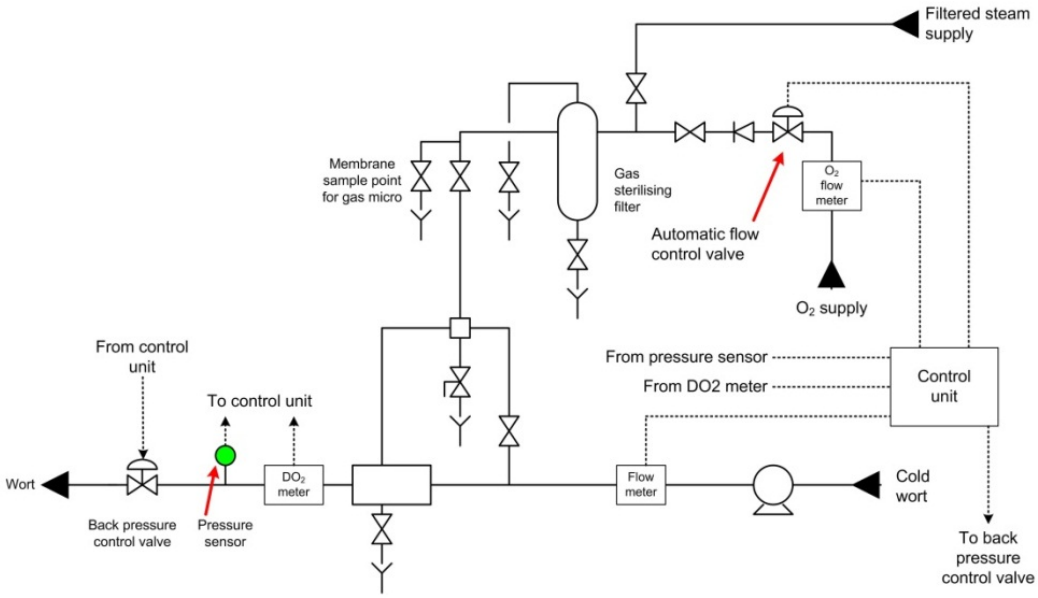


Here, the gas is being injected after the wort chiller. The wort flow rate is known. In simple systems this will simply be as a result of using a fixed speed pump. More sophisticated systems will have a flow meter in the wort main (not shown). The wort flow rate is controlled to a setpoint, and the gas injection rate set according to a fixed flow rate.

A more sophisticated system (shown at the bottom of this page) will incorporate computer control of the gas injection to be able to achieve a constant addition rate in response to the measured wort flow rate. The back pressure control valve will maintain the pressure at a suitable constant value, say 4 bar to increase the rate at which the gas dissolves. Finally, a dissolved oxygen sensor can be used to monitor the actual dissolved oxygen levels. The system can then incorporate alarm handling to warn the operator the process is out of control, or to shut it down, and to provide management information to allow validation of oxygen addition compared to fermentation performance.

Notes

- *What type of cooling system is used in the brewery that you are familiar with?*
- *How is the wort aerated?*



Qualifications

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Section 5 The basic principles of yeast fermentation

5.1 Brewing yeast

The relationship to other organisms

Yeasts are eukaryotic (cells containing complex structures enclosed within membranes) microorganisms (organisms too small for the individual cell to be seen with the naked eye) which form part of the kingdom Fungi.

Yeast is a single celled fungus. It is capable of growing anaerobically (i.e. in the absence of air) and breaks down sugars to release energy, producing carbon dioxide, alcohol and water.

Top & bottom fermenting yeasts

Brewing yeasts may be classed as "top-cropping" (or "top-fermenting") and "bottom-cropping" (or "bottom-fermenting"). Top-cropping yeasts are so called because they form a foam at the top of the wort during fermentation. An example of a top-cropping yeast is *Saccharomyces cerevisiae*, sometimes called an "ale yeast"

Bottom-cropping yeasts are typically used to produce lager-type beers, though they can also produce ale-type beers. These yeasts ferment well at low temperatures. An example of bottom-cropping yeast is *Saccharomyces pastorianus*, (known as *S. carlsbergensis* in the 1970's).

In addition to behaving differently and producing different beer types, ale and lager yeast are genetically very different. *S.pastorianus* is unusual in being a natural hybrid of two yeasts, S. cerevisiae and a low temperature wine yeast, *S. Eubayanus*.

Top- and bottom-cropping and cold- and warm-fermenting distinctions are largely generalizations used by non-brewers to communicate to the general public.

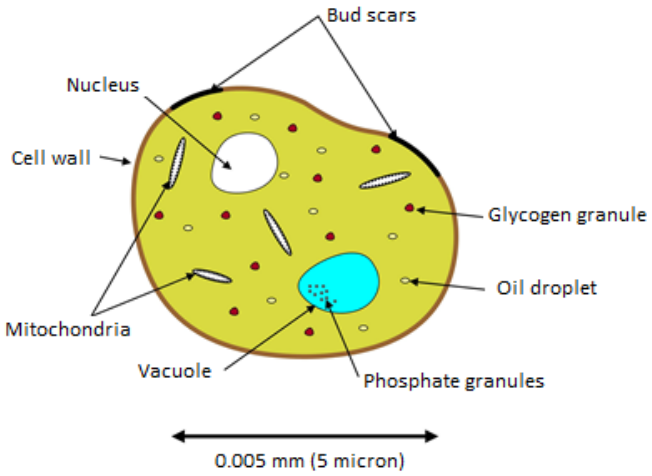
Within each type of yeast there are numerous strains, with each strain performing differently in terms of which sugars it can ferment, how effectively it settles out after fermentation, and what flavours it produces. There are numerous strains of yeast used in brewing, many having characteristics that create unique flavours during fermentation.

For this reason, many beer brands have their own specific pitching yeast. Some breweries deliberately have more than one strain in their pitching yeast in order to provide characteristics that just one of the yeasts alone would not provide.

Saccharomyces cerevisiae **or** **Ale Yeast**	***Saccharomyces pastorianus*** **or** **Lager Yeast**
The 'top' yeast used for fermenting ales.	The 'bottom' yeast used for fermenting lagers.
It floats to the top of the vessel at the end of fermentation because the carbon dioxide bubbles stick to the yeast's cell walls.	It sinks to the base of the vessel at the end of fermentation because it has a different kind of cell wall.
It thrives on relatively high fermentation temperatures, for example 20°C and consequently fermentations are fast, for example 3 days.	It likes low fermentation temperatures, for example 10 °C and fermentations are slower, for example 7 days.
Ale strains cannot grow above 37 °C.	Lager strains cannot grow above 34 °C.
The system used for cropping the yeast at the end of fermentation, that is skimming the yeast off the top of the beer, naturally selects the best yeast for repitching.	The system used for cropping the yeast at the end of fermentation, that is collecting from the base of the vessel is not selective and usually a pure culturing system is in use to maintain yeast purity.
Beer containing this yeast can be clarified by the addition of finings.	Beer containing this yeast cannot usually be clarified by finings.
It cannot ferment a sugar called 'melibiose'.	It can ferment a sugar called 'melibiose'.

Microscopic appearance

Yeast is a single celled micro-organism, which is larger than any bacteria.



Yeast cells normally reproduce asexually. That means that they do not "mate" with another cell. They bud new daughter cells from a mother cell. Bud scars occur when daughter cells separate from their parents. The greater the number of scars, the higher the number of generations, and the older the parent cell. There is a limit on the number of daughters a yeast cell can have and hence the age of a yeast cell.

(It is possible to induce most yeasts to reproduce sexually. They normally only do this under stressful conditions. It seems to be a survival mechanism. The resulting spores are very tough and can survive long periods without suitable growth conditions, but these conditions are never met within brewery operations).

Under the microscope, the appearance of the cells gives information about the yeast.

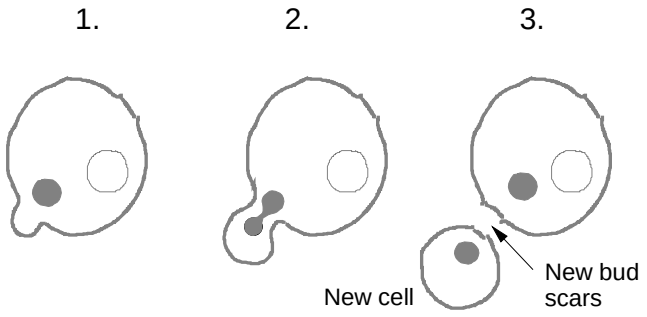
- Bud scars indicate its age; older cells have produced more buds.
- The shape and size of the vacuole changes with age. It becomes bigger as the cell ages. This is strain dependent.
- The size of the cell gives an indication of the strain. They generally grow larger as they grow older.
- The presence of chains of cells indicates the class of yeast. These chains encourage flocculation and forms one of the methods of classifying yeast.
- Yeast is classified depending on how it performs during the fermentation, including flocculation as noted above.

Subcellular structures

- Each yeast cell is bounded by a rigid cell wall (made of protein and polysaccharides).
- The cell wall encloses the cell membrane (plasmalemma), which regulates the wort materials that are taken into the cell.
- Inside the cell membrane lies the cell cytoplasm which is permeated by internal membranes such as the endoplasmic reticulum (which is involved in protein synthesis) and Golgi body.
- Within the cytoplasm are:
    - the nucleus, which contains all the cell's genetic material as DNA; the nucleus divides each time the cell buds, so that the bud has the same genetic material as the mother cell.
    - the vacuole, which is a main storage organelle.
    - the mitochondria, which are involved in many enzyme reactions, especially energy production during aerobic respiration (which does NOT operate during fermentation) and synthesis of key lipid compounds (fatty acids and sterols).
    - the cytoplasm itself contains many enzymes, including all enzymes involved in fermentation.

Bud formation

Yeast cells multiply by 'budding' as shown in the diagrams below:-



Nutritional requirements of yeast

When oxygen is available (aerobic conditions) to the yeast sugars are mainly converted into carbon dioxide and energy is created to produce new cells. Some unpleasant by-products are also produced.

When there is no oxygen available (anaerobic conditions), the yeast primarily utilises the sugar to produce alcohol (ethanol), carbon dioxide and a range of aromatic substances (esters and higher alcohols). While under anaerobic conditions new cells are not produced in large numbers.

Yeast has nutritional requirements other than just sugar including:-

- Protein or nitrogenous compounds in the form of amino acids. These are derived from the barley protein during malting and mash conversion.
- Lipids or fatty material. This is also supplied by the malt.
- Vitamins from the malt.
- Trace metals. Calcium is usually present in the brewing water, if not it must be added as described in module 6.1. Zinc may be present in hop products, if not it can be added to the wort. Copper may also be present in hop products, but if stainless brewing plant is used, may have to be added to the wort.
- Oxygen is usually dosed into the wort. Oxygen is essential for healthy yeast growth and a large yeast population is required to ensure that the fermentation is healthy and fast.

5.2 Fermentation theory

The production of alcohol & CO_2

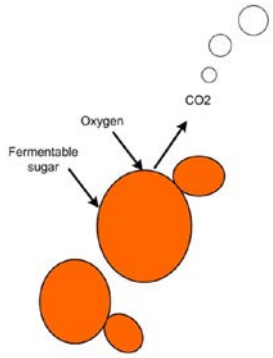
Most living organisms respire aerobically. They use oxygen to convert sugars to carbon dioxide and water. This releases the energy. Some micro-organisms, including yeast, are able to metabolise anaerobically. They do not need to use oxygen to breakdown carbohydrate. However the process, known as fermentation is inefficient and instead of CO_2, water and energy, it converts those sugars into alcohol and carbon dioxide plus considerably less energy.

The process starts when yeast is pitched into the wort and finishes when most of the sugar has been converted into alcohol and carbon dioxide.

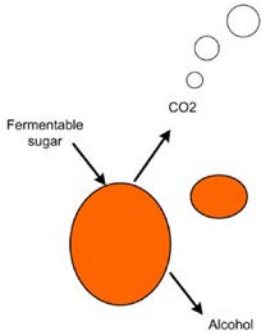
The overall reaction for fermentation is:

$C_6H_{12}O_6$ ------► $2(C_2H_5OH)$ + $2(CO_2)$ + Energy

Glucose (sugar) — Ethanol (alcohol) — Carbon Dioxide



Aerobic conditions – increased growth rate.

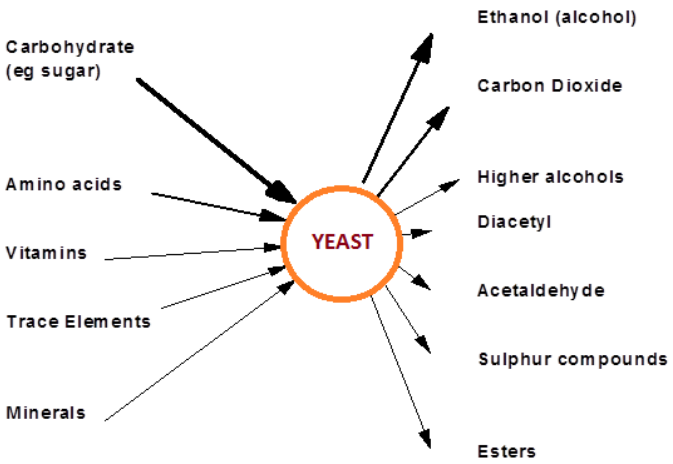


Anaerobic conditions – increased alcohol production.

This equation summarises the many metabolic reactions occurring during fermentation, all controlled by a variety of different enzymes in the yeast cell. The main purpose of the breakdown of glucose to alcohol and carbon dioxide is to generate energy necessary for the yeast cells to survive and grow. However, many of the metabolic reactions carried out by the yeast, such as making proteins and fats for new cells, also produce by products, which can be very important to beer flavour. (see section 11 – flavour, for further details)

These by products, such as esters, higher alcohols, diacetyl and sulphur compounds, can make major contributions to beer flavour and various fermentation conditions can influence the amounts of these compounds.

Beer Flavour Compounds



Not all of these flavours are desirable. Ethanol (alcohol) itself only makes a minor contribution to beer flavour, other than having a warming effect.

Esters

Esters are very important beer flavour compounds and several hundred different compounds can be found in beer, although only a few are present in sufficient amount to contribute significantly to beer. The flavours generated by esters are described as “fruity” and “tropical fruit”. These compounds are essentially formed by combination of alcohols with organic acids, so that those present in the

highest quantity, such as ethyl acetate (which contributes "boiled sweet", almost "solvent" flavour character), are derived from ethanol (since this is by far the most abundant alcohol). Another very flavour active ester is iso-amyl acetate, which is usually present in high enough levels to taste (i.e. above its "flavour threshold") and tastes of "bananas" or "pear drops".

Esters are formed during fermentation by esterification of fatty acids with alcohols. The amounts of individual esters and the total produced are affected mainly by the same fermentation factors that affect yeast growth.

Especially important is the strength of the original wort (i.e. wort gravity). Stronger worts usually produce very high levels of esters and so, strong beers taste very fruity. In fact, it is the proportion of fermentable sugars to the amount of assimilable nitrogen (mainly amino acids derived from malt proteins during mash conversion) that is the main driving force in determining the levels of ester production.

Other factors that encourage yeast growth, such as increased dissolved oxygen at the start of fermentation, reduce ester formation.

Increased fermentation temperature encourages ester production.

However increased pressure during fermentation tends to decrease yeast growth and thus reduces ester formation. This means that fermentations in very tall vessels produce lower levels of esters, because of the increased hydrostatic pressures.

Higher alcohols

Higher alcohols (also known as Fusel Alcohols) are produced as by products from protein synthesis and have aroma and flavour effects such as "alcohol" and "winey". The main examples are iso-butanol and iso-amyl alcohol.

The total concentration of higher alcohols produced during fermentation is directly related to amount of yeast growth, so that factors increases yeast growth also favour increased production of higher alcohols:-

- Increased level of wort oxygen.
- Higher levels of wort FAN (free amino nitrogen).
- Increased fermentation temperature.

Increased pressure during fermentation tends to decrease yeast growth and thus reduces higher alcohol formation (like ester synthesis), so that fermentations in very tall vessels produce lower levels of higher alcohols, because of the increased hydrostatic pressures.

Diacetyl

Diacetyl gives a "toffee" or "butterscotch" flavour to beer.

This character is often acceptable, and may even be considered desirable in ales at low levels, but is usually unpleasant in lagers. Lager processing is designed to reduce the level of diacetyl to below its flavour threshold of approximately 25 ppb or micrograms / litre (µgm/ litre).

Diacetyl is produced during fermentation, but yeast will reabsorb it (and so convert the diacetyl to less flavoursome compounds) during a warm conditioning stage. Consequently, it is very important (especially for lager brewing) to monitor, by chemical analysis, the level of diacetyl towards the end of fermentation and during maturation to ensure that the beer is not chilled before the level of diacetyl has reduced to achieve the final beer specification.

The desired beer diacetyl specification determines when the beer may be moved from fermentation vessel to the conditioning phase, or chilled, or centrifuged or filtered.

Factors affecting diacetyl production (and removal by yeast) are:-

- The yeast strain.
- Wort composition.
- The type of fermentation vessel (open or closed).
- Fermentation conditions favouring yeast growth rate, such as high temperatures and pitching rates, and an increased level of wort oxygen.

Sulphur compounds

Sulphur compounds make a significant contribution to beer flavour. When in excess, they can give rise to unpleasant off-flavours. The fermentation should be managed with the measures described below to make sure the amount remaining in the final beer is below the flavour threshold. This is especially important for the more volatile compounds such as hydrogen sulphide (H_2S), which smells of bad eggs and sulphur dioxide (SO_2) which smells of burnt matches. Both of these sulphur compounds are produced by yeast from sulphate and are by-products in the synthesis of sulphur-containing amino acids.

The control procedures include:-

- Ensuring sufficient evolution of CO_2 to purge these volatile compounds from the beer.
- Extended maturation time (to allow these sulphur compounds to escape).
- More vigorous fermentation processes result in lower levels of the volatile sulphur compounds.
- Not allowing settled yeast to remain the fermentation vessel for too long. If settled for too long yeast may break down and release other unpleasant sulphur flavours ("cooked meat", "autolysed yeast").

One other sulphur compound often found in beer, but principally derived from malt is Dimethyl Sulphide (DMS), which smells and tastes of “cooked vegetables” or “tinned sweetcorn”.

This compound is rarely detectable in ales, because it is usually removed during kilning to produce ale malts, but may be intentionally present at tasteable levels in some lagers, although others are designed to have specification levels of DMS below flavour threshold (approximately 30 ppb or micrograms /litre or µgm /litre).

The level of DMS surviving into beer is very much determined by the amount of DMS (and its precursor) surviving in malt after kilning and then how much remains after wort boiling. Those lager brewers who specify a tasteable level of DMS in the finished beer will specify desired levels in malt and will design the wort boiling conditions so that a controlled level of DMS will remain in the finished beer. Otherwise malt specifications and boiling conditions will be designed to ensure sufficient removal of DMS to achieve the required low level in beer.

One important point is that some yeasts can produce a small amount of DMS during fermentation, which may be significant, although it is usual to control DMS levels in beer by malt specification and boiling conditions.

Main phases of a fermentation
Four different stages of fermentation are normally described.

Lag phase
Nothing happens to the wort specific gravity until the yeast has been pitched in. Yeast growth/ reproduction and fermentation do not start immediately. The yeast cells metabolism becomes active following a period of relative inactivity during storage. The length of this phase depends on the type of yeast, the pitching rate, its health, in many cases including the age (number of times it has previously be repitched), and the conditions within the wort. The lag phase is caused by the yeast re-adjusting to the new environment and beginning to absorb and combine the nutrients and oxygen to give them everything required for growth and reproduction. The phase ends with the first cell division.

Growth (logarithmic or exponential) phase
The lag phase is followed by a rapid growth phase, starting between 6 and 12 hours after pitching. During the first part of this phase, the rate of cell division continuously increases. The specific gravity drops slowly at first whilst the yeast is growing and dividing. How long the accelerating growth lasts largely depends on the temperature. After about 24 hours the growth rate is constant and at a maximum. The cell numbers can double every 90 to 120 minutes.

Growth is only limited by physical parameters such as temperature and the availability of nutrients such as amino acids and by the amount of oxygen added to the wort. The specific gravity drops rapidly during the fermentation phase. The fermentable sugars are quickly converted into alcohol, large volumes of carbon dioxide are produced and heat is generated. The pH of the beer also drops during fermentation.
Because specific gravity drops so rapidly and alcohol content increases so rapidly, this phase of the fermentation is often referred to as the Logarithmic (Log) or Exponential phase.

Retardation phase
The growth phase is followed by a retardation (late fermentation) phase which is limited by one or more of the following:-

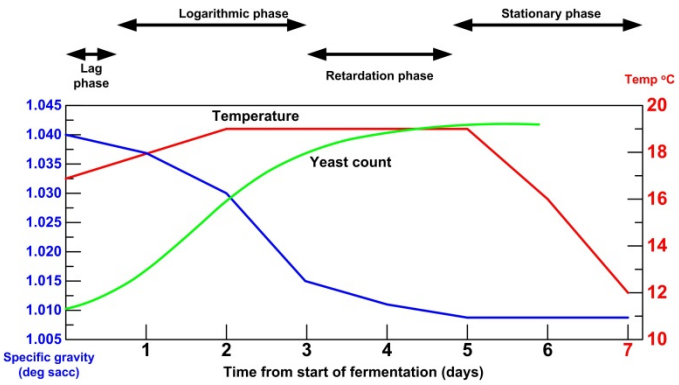
- Available fermentable sugars.
- Free nitrogen (amino acids).
- The increase in alcohol level.
- Settling or flocculation of the yeast.

and to a certain degree, by lack of recirculation currents keeping the yeast in suspension.

Stationary phase
There is a balance between the number of newly formed cells and the cells which die. In the latter stages, sometimes called the declining phase, the rate of cell death exceeds the rate of new cell formation.

The final stages of fermentation are slow and it is where the yeast tends to "mop up" available nutrients that are available. Other biochemical reactions continue, the most important being the removal of diacetyl. Top fermenting yeast may be cropped at this stage. The beer may be reduced in temperature.

Example of an ale fermentation profile



The conversion of sugars into alcohol can be tracked by measuring the specific gravity of the liquid. Alcohol is less dense (lighter) than sugar and CO_2 is lost, so specific gravity drops as the fermentation progresses.

The significance of oxygen

Oxygen is required in sufficient quantities to allow the yeast to synthesise sterols and unsaturated fatty acids which are not available in the wort, and which cannot be synthesised in anaerobic conditions. Under anaerobic conditions brewers yeast strains require both pre-formed sterols and unsaturated fatty acids as they are critical for cell membrane function and integrity.

Inadequate growth of a brewery yeast culture will result in poor attenuation, altered beer flavour, inconsistent fermentation times and recovered pitching yeasts which are undesirable for subsequent fermentations.

Perhaps unexpectedly, over-vigorous aeration of fermenting worts can lead to increasingly sluggish fermentations characterised by longer lag phases, a slower fermentations and/or residual sugar remaining in the final beer.

Factors affecting the phases of fermentations

As noted before, the key factors are:-

- The pitching rate of yeast.
- The yeast strain – including flocculation characteristics.
- The age of the yeast – older yeasts tend to produce more sluggish / abnormal fermentations.
- The wort oxygenation level.
- The wort temperature – including the control of the temperature rise.
- The wort composition in terms of nutrients – minerals, vitamins, amino acids.
- The sugar concentration.
- The amount of alcohol produced associated with the alcohol tolerance of the yeast strain used.
- The vigour of mixing in the FV.

Factors affecting the speed of fermentations

The yeast used for brewing beer is carefully selected because it influences fermentation performance and the beer's eventual flavour, by influencing the amounts of various flavour compounds.

The various fermentation conditions that are important in this respect include:-

- Selection of pitching yeast.
- Pitching rate (the amount of yeast added to the wort). The amount of yeast in suspension can be measured by 'yeast count'.
  - Ales are typically pitched at approximately 9 million cells per ml.
  - Lagers (typically) at 14 million cells per ml, but possibly higher when beers are high gravity brewed.
- Wort dissolved oxygen (the amount of air/oxygen added to the wort).
- Initial temperature (wort temperature before the yeast is added).
- The rate of temperature increase during the growth phase.
- Top heat (the maximum temperature during fermentation).
- Final temperature (what temperature the beer is reduced to at the end).
- Fermentation vessel design / shape.

Consistent application and tight control of these parameters is required to produce a fermentation of consistent speed so that the beer produced has consistent quality and flavour characteristics.

Notes

- *Describe the yeast used in the fermentation of a beer that you are familiar with.*
- *Observe your brewery's pitching yeast under the microscope and draw a diagram.*
- *Draw the temperature profile of fermentation you are familiar with, and identify the key parameters of temperature, gravity against time.*
- *Identify when key processes take place (e.g. cooling, yeast cropping) and relate to the stage of yeast growth.*

Qualifications

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Section 6 Fermentation Practice

6.1 Fermentation vessels and their control

The basic requirements of fermenting vessels

A fermentation vessel has a large number of functions, including those listed below:-

- Its prime function is to contain the fermenting wort.
- It must protect the fermenting wort against ingress of foreign micro-organisms which could contaminate the fermentation.
- It must allow fermentation of wort at a controlled temperature by having provision for cooling.
- Sometimes it is considered essential to ferment at a constant pressure to control production of esters and to a lesser extent foam.
- It must allow CO_2 produced during fermentation to escape or be collected sufficiently pure for re-use.
- It must allow, and preferably actively encourage mixing of the vessel contents to avoid layering and to disperse the yeast.
- It must be insulated (either directly or indirectly in a constant temperature atmosphere) to minimise influence of the ambient temperature affecting the wort temperature.
- The control must allow for elevation of the temperature of the fermenting wort to a desired value for warm maturation to allow effective use of the heat generated during the latter stages of the fermentation (free-rise, mainly for diacetyl control).
- It must uniformly chill the contents to 1-3 ºC for maturation and/or yeast sedimentation.
- The design and control must allow / encourage sedimentation of the yeast and easy removal from the vessel while it is full.
- It is normally required to allow / encourage the solution of CO_2 produced during fermentation in the beer, but not to excess.
- It must be easy to clean, preferably using CIP techniques.
- It must retain sterility after cleaning, normally by enclosing.

Some brewers may also require the following:-

- Gas washing to remove unwanted volatiles (purging).
- Wort aeration / oxygenation during fermentation (e.g. for barley wine production).
- Storage of yeast (under beer) for pitching subsequent fermentations.
- The use of the fermenter for cold conditioning of beer at temperatures of 0 ºC or below (Unitank or dual purpose operations).
- Final culture stages of yeast.
- The use of a vessel for a number of somewhat different brewlengths, to suit the sales of different beers.

In all cases the materials should ideally be:-

- Non-toxic or staining.
- Easily sanitised.
- Corrosion resistant.
- Easily fabricated using a wide range of forming & welding techniques.
- Readily available.
- Cost effective.
- Strong over a broad range of conditions (pressures / temperatures).
- Pleasing appearance.
- Scratch proof.
- Non porous.
- Finished internally allowing high standards of hygiene, being free from crevices or surface roughness which could harbour micro-organisms.

Vessels have been made of the following materials, and generally, where they do not meet the above criteria have been superseded by materials and construction that do:-

- Wood.
- Copper.
- Carbon steel lined with an epoxy resin.
- Plastic, either as a lining or in small vessels, as standalone tanks.
- Fibre impregnated resin, either as a lining or in small vessels, as standalone tanks.
- Aluminium.
- Stainless Steel.

Modern large vessels are invariably made of stainless steel due to the strength, hygiene factors (scratch resistant, chemical resistance, non porous etc.), though some small brewers use plastic or fibre impregnated resin tanks, mainly due to purchase costs.

Operating principles and diagrammatic representation of FVs, reasons for choice, advantages & disadvantages

Older vessels were often rectangular, usually not enclosed, and made of wood or copper. They typically had internal pipes to carry cooling liquids. Control was simple and very variable, generally manually controlled.

Improvements were made by enclosing vessels to improve sterility, combined with basic in-place cleaning systems. Ultimately the conical fermenter was developed.

Current systems in use

- Traditional ale fermentations are carried out in shallow open vessels (wood, slate, stainless steel, copper or epoxy lined) with top cropping of yeast - "squares".
- Burton Unions and Yorkshire stone squares are elaborate ways of collecting pitching yeast and regulating the amount of yeast left for cask conditioned beer.
- Flat/sloped (12^{o} angle)-bottomed rectangular, enclosed vessels, usually stainless steel or mild steel with an epoxy lining, sometimes known as Asahi tanks. These were developed in Japan and the United States. Sizes can range from 300 hl to 3,000 hl. They are used normally as fermenters, but sometimes as maturation vessels, occasionally as combination vessels for fermentation, maturation and cold conditioning (unitanking).
- Spherical fermenters. Optimum geometry in terms of surface area to volume. In 1970 large numbers of vessels were installed in Spain with 3,000/5,000 hl capacity each. They may also be used as unitanks. However for good yeast settlement and cropping, it is necessary to fit them with conical bottoms.
- Continuous fermentation. This method followed considerable R&D in 1960's and early 70's. The process was discontinued except in New Zealand. There was renewed interest with immobilised systems in the 1990's.
- Cylindro-conical vessels for use as fermenters, maturation vessels or unitanks. Probably the most popular vessel currently employed in brewing world-wide.

The major influence on the design of a fermenting vessel is the behaviour of the yeast, whether it is top or bottom cropping and whether or not it settles out (flocculates) readily. It has proven possible to use bottom cropping yeasts in covered squares and other flat bottomed vessels though cropping only the best portion of the yeast for repitching is not possible.

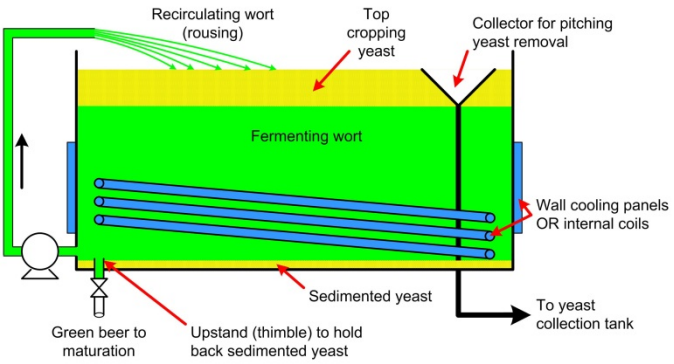
Fermentation – key activities

All fermentations, irrespective of FV design, or the yeast used have a number of key activities:-

- Collection (transfer of wort at the correct temperature, gravity and wort oxygen level in the FV).
- Pitching (either into the transferring wort, or directly into the FV).
- Attemperation (cooling to a specified temperature profile).
- Rousing (if required).
- Gravity monitoring to ensure fermentation is proceeding to specification).
- VDK (diacetyl) control - mainly by a period of warm maturation / late fermentation.
- Cooling to transfer temperature.
- Yeast removal (may follow beer transfer in some vessel designs).
- Green beer transfer.
- Cleaning / sterilisation.

Open & closed squares

These are the traditional fermentation vessels, though recent ones, as shown in some of the following photos are manufactured using stainless steel. Note that "squares" come in all sorts of different shapes and sizes, including round and oval FVs. Insulation is not shown on the drawings.

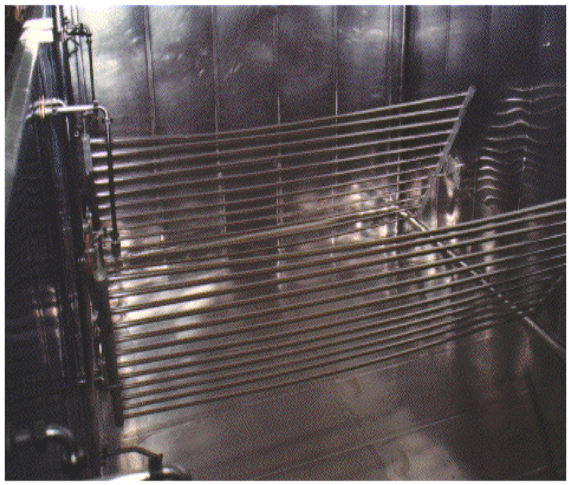


The yeast may be pitched into the wort stream, but is commonly pitched in as slurry or as pressed yeast cake directly into the FV.

The wort is allowed to rise to top temperature and is then cooled using wall cooling panels, or internal coils or suspended panels. The formation of a yeast head largely prevents contamination by non-brewing yeast and bacteria.

Wort rousing

Example of internal cooling coils



If necessary, the wort is roused to mix the wort, to re-suspend settled yeast and or to introduce additional air to ensure the fermentation progresses as required.

An upstand (thimble) is frequently fitted in the outlet to retain the yeast and trub which has settled on the bottom of the vessel, preventing it being dragged into the beer as it is transferred. The thimble is then removed for yeast recovery and vessel cleaning.

Enclosed vessels are fitted with equipment for CIP rather than manual cleaning. Removable covers and portable CIP equipment can be used to clean older vessels rather than cleaning manually.

The following section identifies some of the advantages and disadvantages of "squares", both open and closed.

Advantages

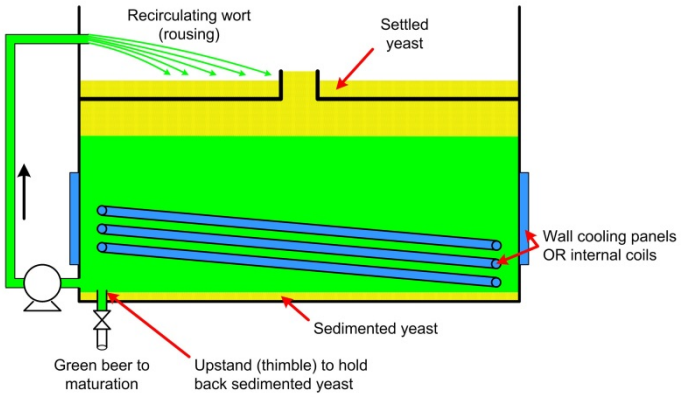
- Shallow, so low retained CO_2 content and thus suitable for cask beer without degassing.
- Can be used for a multiple of different brewlengths when low level internal coils are fitted. Less flexibility with cooling panels.
- Top cropping yeast tends to be self-selecting, so many brewers do not regularly culture new yeast.
- Great for PR purposes.

Disadvantages

- Risk of airborne infection pickup (or other organisms such as flies).
- Difficult to clean and sterilise – especially if open vessels. Open vessels usually cleaned manually – safety implications due to confined working space. Closed-in vessels can be fitted with CIP.
- High labour costs, particularly where vessels are manually cleaned.
- Poor CO_2 recovery / extraction – safety concern and potential increased costs due to purchased CO_2.
- Flat bottoms can lead to high losses from settled yeast. Difficulty recovering yeast settled on bottom due to lack of access and normally virtually horizontal bottom.
- Generally small volume, with large footprint, so space / cost considerations.

Yorkshire squares

A Yorkshire Square vessel consists of a shallow fermenting vessel above which is a walled deck. The wort is fermented in the lower part of the FV, while the yeast head is collected on the deck above. During the first stage of fermentation, the fermenting wort is periodically pumped from the bottom of the FV over the top deck, to keep the yeast mixed in with the wort. Later, the mixing is stopped and the green beer in the lower FV allowed to settle and to cool gently. Most of the yeast rises onto the deck, and is left behind when the beer is drained from the lower FV.



The advantages and disadvantages are virtually identical to those of conventional "square" FVs.

Modern vessels are fitted with equipment for CIP rather than manual cleaning.

Burton union

Wort is half fermented in conventional squares, and then transferred to casks (8-10hl each) for further fermentation. Yeast is forced through swan necks to a yeast back where it separates naturally from the associated beer. The beer is allowed to flow back into the casks. The yeast is a non-flocculent strain.

Advantages

- Full flavoured beers can be produced.
- The beer when racked off has a comparatively low yeast cell count and is suitable for cask racking without further settlement.
- Great for PR purposes.

Disadvantages

- Requires conventional fermenter for first stage, and union system for second. Expensive.
- The union is complex, and difficult to clean.
- The casks cannot be cleaned with detergents or sterilants – hot water only. The large number of casks and the open trough create a significant microbiological risk.
- The casks require a cooper to maintain in good condition.
- High losses due to large numbers of small vessels.

Spherical tanks

The vessels are used as unitanks, and use highly flocculent yeast.

Because it would be difficult to crop yeast from an entire sphere, a conical base is fitted. Cooling is provided by wall jackets arranged in four rings around the spherical part of the vessel, plus a cone cooling jacket. These are large vessels, the ones installed having a capacity of 5,000 hl each. The diameter is 10 metres, height 12 metres.

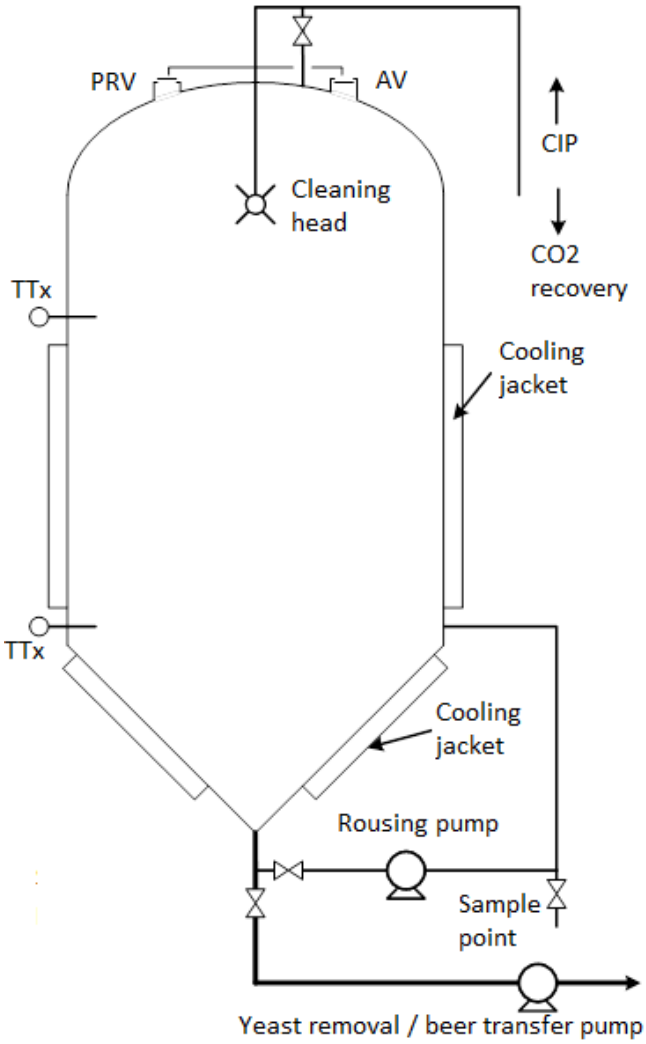
None have been installed recently due to construction costs, and the foot print required, which is considerably higher than similar volume cylindroconical vessels.

Cylindroconicals (conicals)

The vessels are stronger and lighter, and require a smaller footprint than rectangular vessels of the same capacity. The shape of the vessel causes a vigorous fermentation. Fermentation is completed more quickly than in shallower rectangular vessels.

The advantage of the conical fermenter is primarily economic. A large volume of wort can be stored in a relatively low ground surface area. Bottom cropping yeasts which settle after fermentation is complete and the vessel has been cooled are used.

All the yeast is removed before the beer is transferred, unlike square FVs.



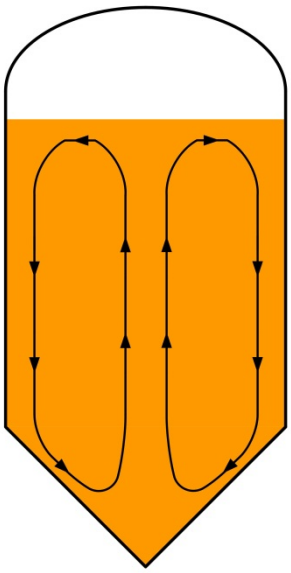
Typical layout of cylindroconical FV

Key

PRV = pressure relief valve
AV = anti vacuum valve
TTx = temperature transmitter

In the majority of breweries the attemperation is via wall and cone cooling jackets, which are surrounded by thermal insulation. A number of breweries have the vessels installed in a thermally insulated room which is cooled using dried air. The vessels have individual cooling jackets, but do not have individual thermal insulation. Adequate insulation is provided by the air. Some breweries use insulated vessels and rousing loops containing in-line chillers instead of wall jackets. The loops may also contain facilities for post collect aeration / oxygenation or carbonation.

CO_2 bubbles generated during fermentation cause strong circulation currents. This ensures consistent yeast concentration throughout the wort, and improves the growth rate of yeast. It also gives more effective cooling as the wort passes over the cooling surfaces.



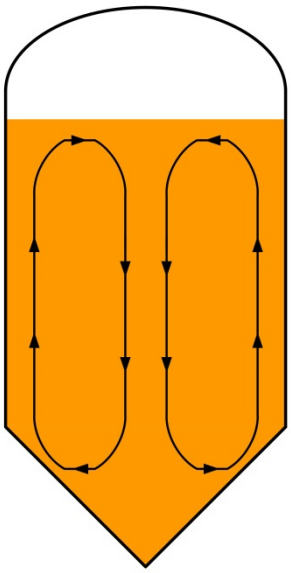
Cylindroconical FV – circulation currents during fermentation (simplified)

The conical fermenter is ideal for bottom cropping yeast. The cone makes it easy to collect yeast. There is also a small, but significant saving in the "loss" of bittering materials by yeast adsorption with bottom settling yeasts.

The totally enclosed design makes it easy to incorporate in place cleaning using either sprayballs or high pressure cleaning heads. However enclosure also makes it necessary to incorporate pressure and vacuum relief devices. These are essential to prevent explosion or collapse. The design of the vessel, the quantity of CO_2 remaining after emptying, and the type of cleaning reagents and temperatures used for cleaning must all be considered when preparing a cleaning regime. See the sections 15 & 16 for further details.

CO_2 from the fermentation can easily be collected with minimal wastage of impure gas due to the effective headspace purging.

Thermometers are required at different heights, to accommodate the different density of wort / beer at different temperatures. During fermentation, convection currents are created in the FV, with the wort in contact with the cooling panels becoming denser, and falling, with the warmer beer in the centre rising. So the coldest wort is towards the bottom of the vessel. The temperature probe therefore measures wort at its coldest, and will stop cooling if below the temperature setpoint. At the end of fermentation, when cooling to less than 4°C, when the beer is colder than 3.5°C, the density decreases, and the cold beer rises to the top of the vessel alongside the cooling jackets, and back down the centre of the FV. A high level probe is therefore required to prevent ice formation at the top of the vessel.



Cylindroconical FV – circulation currents cooling below approx. 4°C (simplified)

Advantages

- Stronger/lighter than rectangular vessels.
- Slender shape occupies little ground area, reduced capital costs.
- Fermentation completes faster than rectangular fermenters.
- CO_2 emission causes strong circulation currents resulting from long bubble path.
- This improves the growth rate of yeast and thus faster fermentation.
- It also gives more effective cooling.
- Ideal for bottom fermenting yeast (cone collection)
- Easy to collect CO_2.
- Greater hop utilisation (absence of top crop which absorbs hop resins).
- Improved cleaning and reduced beer losses resulting from the excellent draining and rinsing characteristics of the vessel.
- Improved product flexibility (lagers and ales can be produced in the same vessel) and consistency.
- Low cross sectional area at the top of the vessel makes it easier to apply a top pressure in order to contain the fermentation head, assist in the purging of air prior to CO_2 collection and venting during maturation/ageing (unitank operation).

The reasons for temperature control

Under brewery conditions yeast metabolises sugar by fermentation:

$C_6H_{12}O_6 \rightarrow 2(C_2H_5OH) + 2(CO_2) + Energy$

Glucose ethanol carbon dioxide

When an energy rich substance, such as glucose, is broken down to form a compound with a lower energy content (for example, ethanol), the excess energy (originally derived from photosynthesis when the barley grew) is released. Depending on whether the glucose is respired or fermented the amount of energy released is different. Approximately 25 times more energy is released during the respiration of glucose than during the fermentation of glucose by yeast.

During fermentation under production brewing conditions, the amount of heat is approximately 586.6 KJ/kg of fermentable sugar.

Wort is usually 70% fermentable. One hl of wort may contain 12 kg (12^{o}P or 1048) of extract. Of this, 8.4 kg is fermented during the primary fermentation. Consequently 586.6 x 8.4 = 4927 kJ are produced by every hl of wort. This heat generated must be removed during fermentation by cooling in order to:-

- Ensure that the fermentation temperature is maintained at the set level which prevents the formation of unwanted flavours.
- Ensure yeast viability.
- Reduce fobbing.

Key criteria include:-

- If cooling is applied early, the yeast will be unable to grow and the fermentation will stick.
- If cooling is not put on whilst yeast is actively fermenting the fermentation temperature will rise to an unacceptable level causing damage to the yeast.
- Crash cooling during the active stage of yeast growth tends to stop the fermentation.
- Attemperation should be carried out gently using feedback control.
- The process today is normally controlled automatically by setting the required temperature, measuring the beer temperature with a probe in the vessel, and allowing this to control the flow of coolant to the vessel.
- Where an automatic system is not used, the checks (thermometer reading) must be carried out frequently and regularly, and the coolant applied by manually opening a valve.

The fermentation conditions determine many of the flavour characteristics of the final beer:-

- The initial temperature and 'top temperature' of the fermentation affect the amount of aromatic volatile substances produced. For example, more esters are produced at high temperature. Fermentation itself generates a lot of heat which must be removed to avoid production of excessive quantities of esters.
- The temperature of the fermentation affects the time taken, which in turn affects the pH of the beer. Slow (perhaps due to being cold) fermentations produce beer with high pH's. Time also affects flavour because sluggish yeasts can release unpleasant sulphur compounds into the beer, especially at warmer temperatures.

It is important therefore, that the following temperature related elements of the fermentation are under strict control:-

- Initial temperature (wort temperature before the yeast is added).
- The rate of temperature increase during the growth phase (phase two).
- Top heat (the maximum temperature during fermentation).
- Final temperature (the temperature that the beer is reduced to at the end).

Consistent application of these parameters will help produce a fermentation of consistent speed and a beer with consistent quality and flavour characteristics.

Temperature has an effect on the metabolism of yeast (as in any organism). Simply put, the higher the temperature the faster the reactions and vice versa. However this effect on the rate of yeast respiration has other effects, such as high ester production and the pattern of yeast growth. Thus it is essential to control the temperature curve so that it complies as closely as possible with your standard fermentation as set by your local specification.

Procedures for the temperature control of fermentations

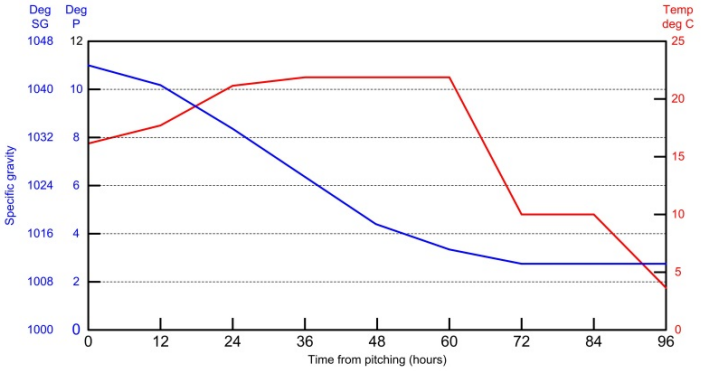
The supply of coolant, e.g. chilled liquor, I.M.S. (Industrial Methylated Spirit) or glycol, is important and frequent checks should be made on the supply and temperature. Slowing or insufficiently fermented brews may be revived by allowing a higher temperature before the end of fermentation. This may however create undesirable by-products.

This stops any further fermentation and also prevents any potential yeast autolysis (yeast break down). The green beer is typically cooled by 1°C per hour, so preventing ice formation on the cooling jackets / coils, and ensuring the beer is cooled consistently. There is also less risk of thermal shock to the yeast, which might lead to autolysis.

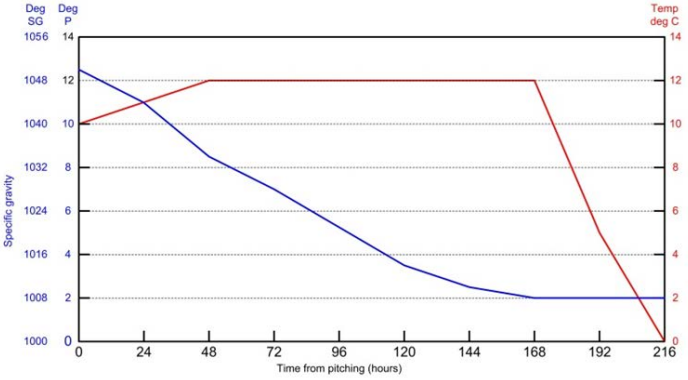
Cooling too early can result in green acetaldehyde and diacetyl flavours. Cooling too late can result in yeasty off flavours from yeast autolysins. The end of fermentation is decided by the specific gravity reaching the preset attenuation value for the brand. Other indicators are a drop in CO_2 production and the flocculation of the yeast. In many breweries the start of cooling is initiated after analysis has confirmed that diacetyl levels have dropped below the level stipulated as maximum for the brand.

Typical maximum levels for diacetyl are 25 ppb or micrograms / litre (µgm/ litre) for lager, or 100 ppb or (µgm/ litre) for some ales.

Example of a top fermenting ale fermentation profile



Example of a bottom fermenting lager fermentation profile



The progress of fermentation is measured by the fall in the value of the specific gravity using a Saccharometer. Since alcohol is less dense than the sugars which have been fermented its production results in falling gravity.

The gravity of the fermenting wort should be measured regularly, typically at least every 12 hours. This gravity is measured using a saccharometer/hydrometer or densitometer. The gravity readings (Present Gravity or PG), and the temperatures are best plotted on a graph and compared to a standard profile to monitor the progress of the fermentation, and to help determine if cooling needs to be started or stopped.

Automation allows the cooling to be applied to maintain the temperature of the wort / green beer, typically to within 0.5 deg C of the setpoint. The use of a target attemperation (temperature / time) profile reduces the amount of manual input required. Automated sampling for specific gravity may also be used, though is not common due to complexity of design and difficulty in maintaining good hygiene. The simpler method is to use two pressure transmitters a known vertical distance apart and calculate the gravity according to the apparent distance apart – the greater the apparent distance, the greater the density.

6.2 Health & safety

The evolution of CO_2 from fermentations

During fermentation CO_2 gas is produced. However, in FVs, virtually all CO_2 is produced as a result of fermentation.

$C_6H_{12}O_6 \rightarrow 2(C_2H_5OH) + 2(CO_2) + Energy$
Glucose ethanol carbon dioxide

Some of the CO_2 remains dissolved in solution, but most is released as gas bubbles, also helping the mixing of the fermenting wort. The FV must be designed to allow the release of the gas into the atmosphere, or in larger plants, into a collection system where it may be recovered for re-use in the brewery.

The hazards associated with CO_2

During fermentation CO_2 gas is given off as noted previously. Breweries produce large volumes of the gas.

CO_2 concentration by volume of air	Effects and Symptoms
1 %	Slight and unnoticeable increase in breathing rate – this is the level commonly used to evacuate an area.
2 %	Breathing rate increases (increase to 1.5 times normal rate), and prolonged exposure over several hours may cause headache and feeling of exhaustion
3 %	Breathing becomes deeper (increase to twice normal rate). Hearing ability reduced, headache experienced with increase in blood pressure and pulse rate
4 – 5 %	Breathing becomes deeper and more rapid (increase to four times normal rate). Signs of intoxication after exposure for half an hour, with slight choking feeling.
5 – 10 %	Characteristic pungent odour noticeable. Breathing very laboured leading to physical exhaustion. Headache, visual disturbance, ringing in the ears and confusion, probably leading to loss of consciousness within minutes.
10 – 100 %	Loss of consciousness more rapid, with risk of death from respiratory failure. Hazard to life increases with the percentage concentration, even if there is no oxygen depletion.

- It is toxic over 5% v/v.
- When pure, it is odourless – the smells normally noted being the result of impurities and the tingle as CO_2 dissolves in the nasal passages etc. to form irritating dilute carbonic acid.
- It is heavier than air and can accumulate in a fermentation room if inadequately ventilated.
- Large amounts remain in the vessel itself after it has been emptied.
- It kills by asphyxiation rather than poisoning.
- It is moderately difficult to detect, special electronic equipment or calibrated chemical reaction tubes being required for accurate assessment.
- The first evidence of high atmospheric levels is shortness of breath.

CO_2 rapidly dissolves in caustic CIP solutions.

$2\ NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

Sodium hydroxide — Sodium Carbonate

$Na_2CO_3 + CO_2 + H_2O \rightarrow 2\ NaHCO_3$

Sodium Carbonate — Sodium Bicarbonate

This creates two problems:-

- Firstly, the reaction can cause the caustic detergent to be significantly reduced in strength and effectiveness.

  For every hectolitre of pure CO_2 remaining, this will react with approximately 200 g sodium hydroxide. Assuming a 2% w/w solution, this is approximately 10 litres. A 2,000 hl FV, with 400 hl head space as pure CO_2 could completely neutralise approximately 40 hl of detergent.

- Secondly, if the vessel is closed in, but is not fitted with adequate anti vacuum devices, as can be seen from the volumes of CO2 that could be mopped up by the caustic, this could cause a sealed vessel to implode.

The monitoring / checking of atmospheres for safe working.

The following are typical figures quoted. Note that although this section refers mainly to CO_2, it is necessary to check for other gases. In a fermenting vessel or room, this is normally limited to oxygen and, by implication, the nitrogen level.

	Carbon dioxide	Oxygen	
Long term exposure	0.5 %	Minimum oxygen level – 19 %	Maximum level – 23.5 %
Short term exposure	1.5 %	Minimum oxygen level – 19 %	Maximum level – 23.5 %

Continuously running gas detectors linked to alarm systems with audible and visual alarms should be installed wherever possible in the FV rooms as there is a risk of CO_2 accumulation.

Where this is not possible, then regular checks should be made and recorded using hand held devices. These may be chemical reaction tubes, or more usually nowadays, portable electronic devices, capable of measuring both CO_2 and oxygen content simultaneously.

All monitoring equipment must be regularly serviced and calibrated.

Note that all sample points must be at low level, because CO_2 is denser than air and will settle under calm conditions.

Fermenting vessels and maturation vessels are classed as confined working spaces and CO_2 and oxygen levels must be checked as being OK before anyone can enter the vessel. The atmosphere must then be continuously checked whilst anyone is in the vessel. See below for further details.

Safe working practices for fermenting room operations

Large amounts of carbon dioxide are produced during fermentation. Many fermenting rooms have facilities for the safe extraction of CO_2 out of the working area and in some breweries the gas is collected directly from the FVs for further use. Because CO_2 is heavier than air and can accumulate in a fermenting room or in the base of a tank this creates a safety hazard.

Precautions for fermenting rooms include:-

- CO_2 collection from fermentations – to remove the CO_2 safely.
- Gas detection systems, with associated alarm handling. It is essential to be familiar with your own sites emergency and evacuation procedures. If the alarms (normally set to => 0.5% CO2 and <19% O2) are set off **leave the area at once**, open windows and doors if possible, switch on extraction fans if necessary.
- Low level CO_2 extraction systems. These are often linked to the gas detection system, so the fans are only run when CO_2 is detected, or less likely, high oxygen levels, thus saving energy (particularly environmental heating). Therefore it is crucial that the ventilation equipment is kept in good working order.

Confined working space – vessel entry

Confined working spaces are areas not intended for continuous occupancy and where there is a risk of serious personal injury from: Asphyxiation by gas (including CO_2 & nitrogen), flowing solids (e.g. grain), drowning, fire / explosion, unconsciousness from heat stress.

Confined spaces also have limited access / egress making entry / exit difficult. In the event of emergency, rescuing is therefore made more difficult.

Beer fermentation / maturation vessels, and enclosed rooms following a gas leak are classified as confined spaces.

All confined space entry must be covered using a permit system or robust Safe System of Work (SSoW).

- The confined space must only be entered if it is not reasonably practicable to complete the task without entry, e.g. manual FV cleaning where no CIP exists.
- If entry must be made, a risk assessment is required, with the key points detailed in a comprehensive SSoW.
- Adequate emergency arrangements must be put in place before entry.
- The space should be ventilated to ensure the gases are maintained at safe levels.
- The space must be tested for appropriate gas levels before entry. Personal monitors and emergency escape sets to be used at all times whilst inside confined space.
- Personnel working in the confined space should wear a personal gas meter & escape set.
- The standby person must remain outside confined space while person inside.
- The main role is to observe activities carried out within confined space.
- If an emergency situation occurs, the standby man raises alarm to summon assistance - first aid / ambulance / rescue team – as identified in risk assessment.
- The stand-by man must not enter confined space.

And finally, when the work is completed.

- Ensure the permit to enter is signed off.

Vessel CIP

If using acid detergents and sterilants, it is not normally necessary to remove any residual CO_2. However, if using caustic based detergents exclusively:-

- it is necessary to ensure that the vessel has sufficient ventilation to deal with any vacuum or sudden expansion that might occur during the CIP.

or

- The vessel must be purged to remove CO_2 before CIP.

Notes

- *Draw a diagram of the type of fermenting vessel used in a plant that you are familiar with.*
- *How is fermentation temperature controlled?*
- *Why was that type of vessel chosen?*
- *Describe the fermentation of a beer that you are familiar with.*
- *Draw a graph of the fermentation profile including*
  - *Collection temperature.*
  - *Top heat temperature.*
  - *Duration of fermentation.*
- *What problems occur and what action is taken to resolve problem fermentations?*

Qualifications

The General Certificate in Brewing (GCB)

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Section 7 Yeast Management

7.1 Yeast propagation, storage and handling

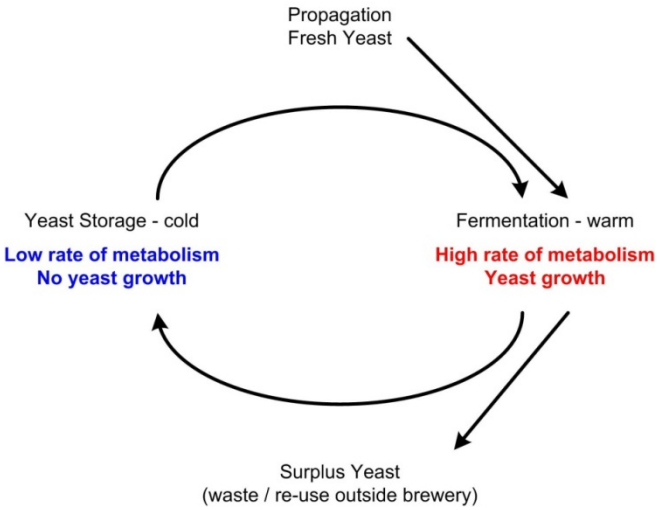
Introduction

The yeast population grows by about five times during the fermentation process and a large proportion is cropped from the beer at the end of the fermentation.

The yeast crop has to be carefully looked after otherwise its health and performance will deteriorate with each successive generation.

A healthy crop is maintained by aerating the wort, by always selecting the best of the yeast crop for re-pitching and in most breweries, by periodically generating a new pure yeast culture using specialised plant.

Brewery yeast cycle



Yeast must be stored carefully under hygienic cold conditions to keep it healthy and reduce the risk of growth of microbiological contamination.

Requirements of yeast handling

Yeast is the only living organism which should be found in most beers (there are a few notable exceptions which are not covered by these notes).

At the start of the fermentation it has to be added and mixed with wort which is at a suitable temperature for the strain of yeast & style of beer, is sterile, and has been oxygenated or aerated sufficiently to allow the yeast to grow.

At the end of fermentation sufficient yeast must be separated using hygienic processes from the fermented wort (green beer), allowing the yeast to be re-pitched if necessary. The excess yeast (i.e. yeast not required for re-pitching) may be disposed of in a number of ways.

Periodically, normally defined by the number of times the yeast has been re-pitched, the yeast is to be replaced with a fresh batch of yeast grown from a single yeast cell (a new culture).

Brewing yeast must be cultured, cropped and stored in such a way to ensure:-

- The use of the correct strain.
- The consistency of the characteristics of the selected strain, e.g. flocculation, metabolism, age (generations).
- Freedom from contamination by wild yeast, other brewing yeasts and bacteria.
- High viability.
- The fermentation performance is “normal”.
- The yeast cropping is “normal”.
- Ensuring the yeast is fed OK (micro-nutrients, oxygen).

Main processes involved in yeast handling

- Introduction of replacement yeast strains – yeast propagation.
- Addition to wort – yeast pitching.
- Separation from fermented wort (green beer) – yeast cropping, including centrifugation and beer recovery from yeast slurries.
- Storage of pitching yeast between brews.
- If required, yeast sanitisation (acid washing).
- Disposal of surplus yeast – waste yeast handling. Excess yeast is typically sold on for yeast extract, health tablets, animal feed or the biochemicals industry, though of course it may simply be sent to liquid effluent systems or landfill.
- Effective cleaning and sterilisation of all yeast handling plant.

Reasons for yeast propagation

Yeast is usually collected at the end of a brew for subsequent re-use in the following brew(s). It is essential to use a supply of good healthy yeast in order to:-

- Maintain consistently good fermentation performance.
- Maintain consistent beer quality.
- Ensure the economics are maintained.

The quality of pitching yeast can deteriorate for a number of reasons, including:-

- Contamination by bacteria.
- Contamination by other brewing yeast strains (e.g. an ale yeast with a lager yeast used in the same brewery).
- Storage for excessively long periods without re-pitching, allowing autolysis or general loss of viability.
- "Contamination" with an enzyme used for "lite" beer fermentation. The yeast slurry is then not suitable for normal beers, as it almost certainly contains some residual enzymatic activity, is liable to cause over attenuation.
- If the yeast is required for production of light struck flavour resistant beers because it will be packaged in clear glass bottles, the beer must only contain suitable stabilized pre-isomerized hop extracts. The slurry of "normal" beers contains normal hop isomers from whole or pellet hops. "Contamination" with the normal hops are likely to lead to the development of the undesirable light struck flavour in the beer, thus must be strictly avoided. However, it is possible to use yeast from a "light struck resistant" beer in non-light struck resistant beers.
- Changes in performance, e.g. sedimentation or cropping characteristics, fermentation speed, growth rate and mass, beer flavour changes. Yeasts do suffer increasing levels of contamination over time and it is usual to not keep yeast over 8 to 15 generations, particularly in bottom cropping yeasts where the distinction between desirable and non-desirable portions of the yeast mass is not easy to determine.
- Loss of fermentability – particularly maltotriose, one of the principal fermentable sugars.
- Yeast cropped from high gravity fermentations (circa 8% +) is generally not considered suitable for re-pitching as it tends to have reduced viability and vitality, and so is best discarded.
- Changes in nature (e.g. flocculation characteristics) due to mutation.
- Changes in proportions of mixed strain yeasts.

The way that the yeast is cropped will often influence the degree of deterioration. Top cropping can be very selective, based on the condition of the yeast head at the time of cropping, whilst bottom cropping is far less. For this reason lager breweries invariably operate yeast propagation plants with frequent yeast propagation cycles. Increasing numbers of ale breweries now do as well.

However, some brewers have used the "same" yeast for years and have little idea of its provenance. Any catastrophic failure in the past would have been accounted by another delivery from the same source. Typically, even these breweries have backup in the form of dried or deep frozen cultures maintained at specialist culture centres.

Pure yeast culturing procedures

In most modern breweries, to maintain the yeast purity and the consistency of fermentations, yeast is typically propagated from a starter culture every 8 to 12 generations. Propagation starts in the lab and continues in special vessels with yeast count increasing between 5 and 10 times at each stage. Finally the yeast is pitched directly into the fermentation vessel.

The principle of culturing yeast is to grow up a population of yeast from a single yeast cell. Because of the way that yeast multiplies (cells forming buds which break off and develop into new cells) each cell is a 'clone' of its parent.

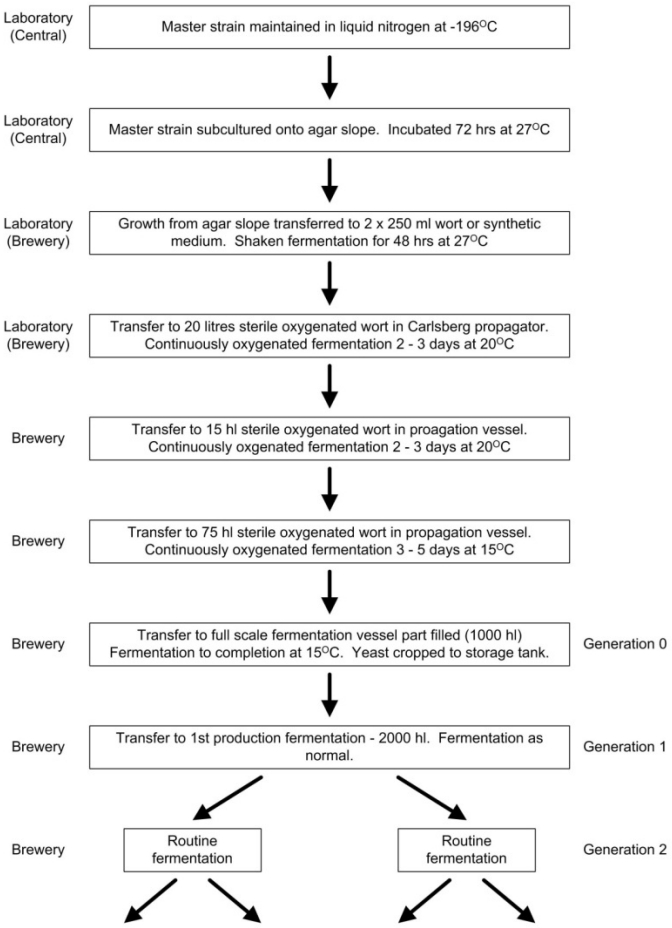
Consequently, a population grown from a single cell consists of identical cells known as a 'pure culture'. Yeast only grows well when it is in the presence of the sister cells, and so culturing is carried out in stages where the volume is increased at each stage.

The key guidelines for yeast propagation are as follows:-

- Stepped volume increase.
- Stepped temperature decrease – avoidance of temperature shocks.
- Oxygenation / aeration level and method according to the step.
- Transfer to the next stage during the yeast growth phase.
- Avoidance of contamination by other yeasts or bacteria.

Yeast culture sequence

The following diagram shows a typical lager culture sequence in a large brewery using cylindroconical vessels.

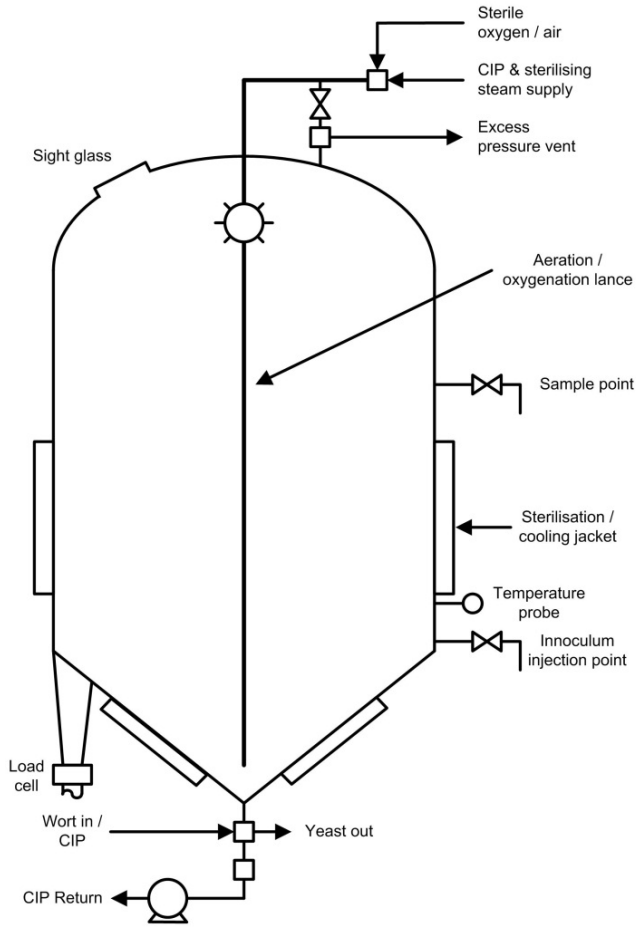


Yeast propagation plant

Yeast culture plants typically have the following features:-

- Hygienic design and build, close to pharmaceutical standards.
- Provision for sterilising the medium, usually wort boiling, though this is increasingly not required providing the quality of the CIP and sterilisation sequences can be shown to be adequate and hot wort is transferred to the vessels.
- Provision for very accurate cooling control.
- Provision for intense aeration or oxygenation.
- Provision for efficient but gentle agitation to ensure the yeast does not settle to the propagation tank bottom. Some systems rely on the oxygenation / aeration system to achieve the rousing rather than having a separate stirrer or recirculation system.
- A number of tanks for the different stages, each one being a larger volume than the previous one.

The diagram illustrates a yeast propagation tank with steam/cooling jackets. In this design, the air or oxygen is injected into the culture through a long lance extending through the spray head to the bottom of the tank. This allows effective cleaning, (no shadows) and steam sterilisation of the air injection lance and the vessel. Other designs of oxygenation / aeration system use recirculation loops or simple sinters in the base of the vessel.



The basic design of both small and large tanks is the same. The plant is steam sterilised prior to addition of wort. The wort is re-boiled in the plant to ensure sterility. After cooling sterile air or oxygen is injected. The plant is then inoculated with a pure yeast culture. The yeast grows over 1-2 days when it is transferred to the next stage. Following this stage the yeast culture is pitched into wort in a FV. Note that in some modern systems, the quality of the CIP and the incoming wort is such that the sterility of the cooled wort can be assured without steam sterilisation of the vessel or boiling the wort.

The yeast mass requires vigorous oxygenation / aeration to increase the mass. The formation of alcohol is much lower than in an anaerobic fermentation.

Wort must have sufficient nutrients to build the required cell mass. Yeast must be fully viable and give a yeast count

at pitching as normal. Lower cell counts will lead to slower fermentations and perhaps the need to blend away with beer from 'normal' fermentations.

Each stage is carried out under sterile conditions thus ensuring contaminant free yeast.

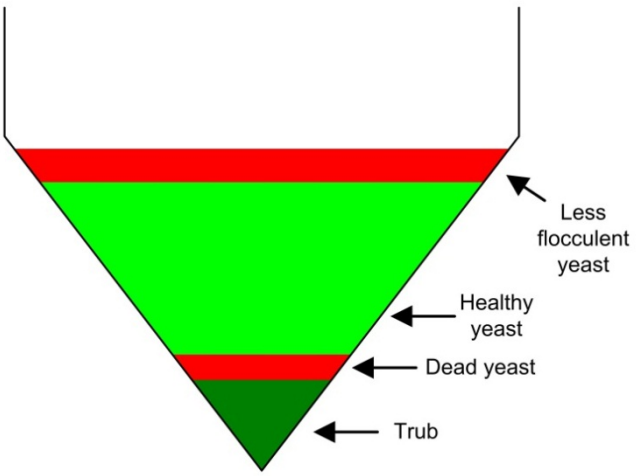
When the yeast population at each stage of propagation has grown and the wort proteins and fermentable sugars have been depleted to the point where further growth is about to be inhibited, the yeast and wort is transferred to the next stage.

Yeast cropping – reasons & times

During the growth phase of fermentation the yeast population grows approximately five fold. This additional yeast can be cropped and the best portions used for pitching into subsequent brews. Yeasts of different strains have different growth rates and this factor needs to be considered when selecting suitable pitching yeast.

With top fermentations, the time of cropping can be used to select the best yeast for re-pitching. For example the first and last skimming can be discarded and the middle crop re-used. Yeast selection like this has enabled some ale brewers to maintain the same yeast strain for many years without culturing.

With bottom fermentations, yeast selection is more difficult, although selection of the most suitable yeast is possible by careful cropping processes. For example, the first purge from the cone can be discarded because it contains trub and a large proportion of dead yeast, and the final purge discarded because it contains some dead cells and particularly low flocculence yeast.



Note that particularly with bottom cropping yeasts, if yeast is allowed to remain in a large mass without movement, the yeast mass is liable to start autolysing, and heat up excessively. This will produce yeast of low viability and vitality, and any beer recovered from the slurry is liable to have distinct off flavours, typically described as "meaty", which may be considered unfit for blending back into the main beer stream – with associated loss of revenue and an increase in effluent & disposal costs.

The timing of yeast cropping is therefore to a large extent dependent upon the resistance of the yeast to autolyse when in a settled mass. Cone cooling in itself is of little use as the yeast is a very poor conductor of heat and will not allow the centre of the yeast mass to be cooled.

Yeast removal processes

Yeast for re-pitching must be cropped only from fermentations which meet specification for attenuation profile and diacetyl reduction. Wherever possible, microbiological status of fermentations should be available in time to prevent reuse of contaminated or cross-contaminated yeast.

At the end of fermentation in a cylindroconical vessel, the FV is typically cooled to around 4°C and the yeast settles out. The first portion of cropped yeast contains break and dead yeast cells and should go to waste / beer recovery.

The next portion can be recovered if required for subsequent re-pitching. Yeast can be stored as a slurry in beer or pressed to recover the beer, and then either stored "dry", as a cake, or re-slurried with water. Some breweries store the yeast in the cones of the FV and pitch "cone to cone".

Yeast can also be recovered from beer on transfer from FV to MV using a centrifuge, though normally the yeast recovered is not used for re-pitching, but is sent to waste. This recovery process is discussed later.

Yeast cropping procedures must be optimised to target a consistent ratio of yeast to liquid (beer) (% solids) as possible.

The following storage conditions are important:-

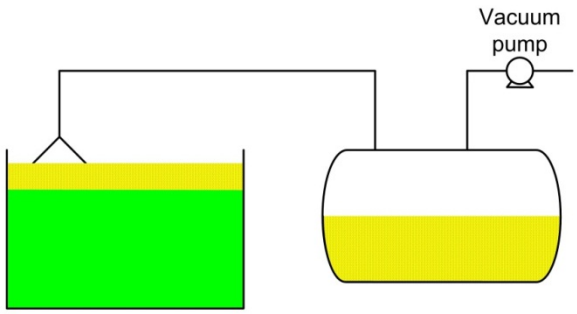
- Low temperature, at say 2-4°C, with gentle agitation of slurries to ensure the temperature is consistent. Yeast deteriorates or autolyses when inactive, but low temperatures slow this process down.
- Good hygiene. Micro-organisms will feed on the medium surrounding the yeast. Contamination during cropping or storage must be avoided.
- Time. Even in the best conditions, yeast will deteriorate with time, so a storage limit of 2 to 5 days is normally imposed.

Before yeast is re-pitched, it should be checked:-

- The storage temperature must have remained consistent.

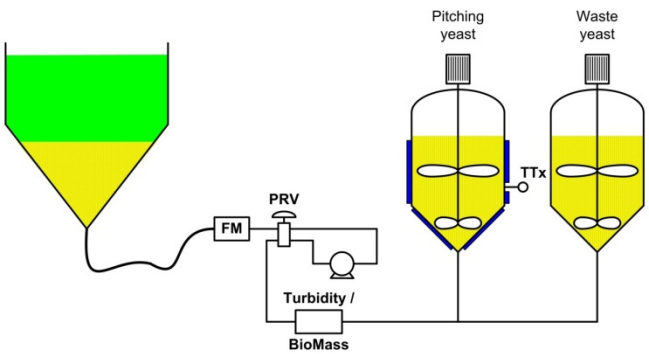
- The yeast must be free from microbial contamination.
- The yeast concentration, for instance, the number of cells per ml of slurry, or per gram of pressed yeast.
- Yeast viability – (% live cells).

Top fermenting yeast cropping – vacuum & parachute system



Top fermenting yeast cropping – vacuum & overflow system

Bottom fermenting yeast cropping



Centrifugation

Centrifugation is a method of dramatically increasing the rate of sedimentation, by artificially increasing the gravitational force applied to the beer. This particularly affects the rate of settlement of yeast, trub and large compact protein particles.

There are two types of centrifuge used, disc bowl, and decanter, which both artificially increase the gravitation force, and particularly in the case of disc bowl centrifuges, decrease the distance particles have to settle.

Decanter centrifuges tend to be used for separation of larger particles such as trub from whirlpool residues, and sometimes for beer recovery from yeast slurries.

Disc bowl centrifuges may be used to clarify green beer on transfer from FV to MV and to remove solids from matured beer immediately prior to filtration because they can remove solids in seconds that would take weeks to settle out naturally.

For a centrifuge to remove yeast and other particles, the beer must have sufficient residence time in the machine for cells and flocs to fall through the path length under the applied "g" force. When smaller particle sizes are considered, the flow rate through, the residence time, or centrifuge speed become more critical.

Disc Bowl Centrifuges contain numerous conical discs plates on which the deposited particles collect and then slide into the solids holding area. They are spaced only a few millimetres apart (compared to perhaps a few metres in a tall cylindroconical vessel), so dramatically reducing the distance the particles, particularly the yeast, have to travel before settling out.

There are some drawbacks to the use of centrifuges that must be considered when using them:-

- The beer may be subject to shearing, which can break up suspended particles (typically protein) into smaller particles, making subsequent clarification more difficult. This is the main reason that centrifuges are not used for recovering yeast to be used for re-pitching.
- Beer temperature rises during the clarification.
- Unless well designed and maintained, the beer is liable to pick up oxygen via leaking seals.
- Centrifuging is rarely sufficient to completely clarify beer and is normally followed by filtration.

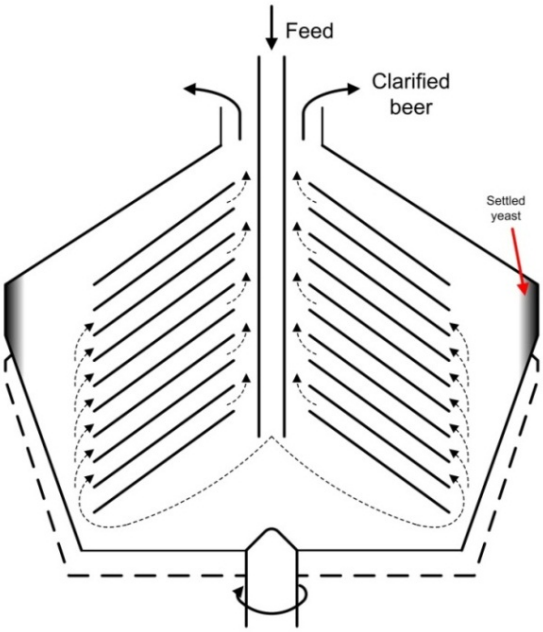
Beer must be kept separate from the atmosphere to prevent oxygen pick-up by use of sophisticated seals.

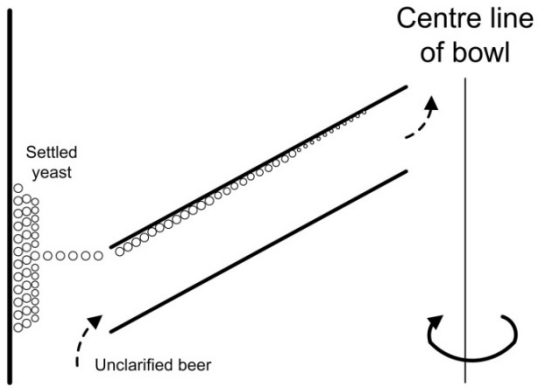
The rate of feed of beer into the centrifuge must be matched to the capacity of the machine and the solids load in the beer. Usually, higher yeast counts are encountered at the start and end of beer transfers. To allow the centrifuge to handle the high yeast load, beer is fed to the centrifuge slowly at first until a consistent feed is obtained. The supply rate can then normally be increased. The supply rate is often slowed towards the end of the transfer as yeast slides off the cone walls.

Modern centrifuge discharge frequency, i.e. the removal of settled yeast from the solids holding area, is controlled by the turbidity of the beer being discharged, with time overrides. The consistency of the supply beer solids content is improved by use of pre-centrifuge buffer tanks to mix in "slugs" of high solids.

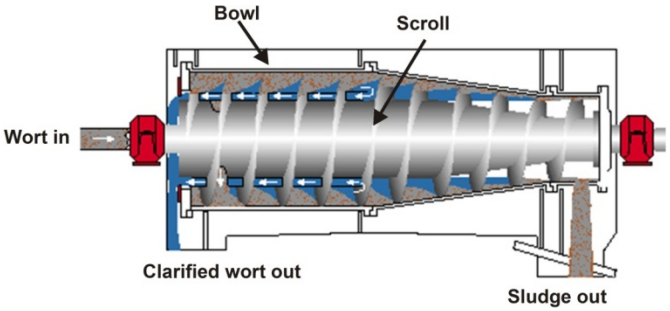
Infrequent discharge allows yeast cell damage to occur (risking poorer beer quality and increased filtration difficulty), whereas too frequent discharging increases losses.

Flow through a disc bowl centrifuge





Decanter centrifuge



Separation takes place in a horizontal cylindrical bowl equipped with a screw conveyor. The product is fed into the bowl through a stationary inlet tube and is accelerated by an inlet rotor. Centrifugal forces cause sedimentation of the solids on the wall of the bowl. The screw conveyor rotates in the same direction as the bowl, but at a different speed, thus scraping the solids off the wall and towards the conical end of the bowl. Separation takes place throughout the total length of the cylindrical part of the bowl, and the clarified liquid leaves the bowl by flowing over adjustable plate dams into the casing. (Drawing courtesy of Flottweg, description courtesy of Alfa Laval & Westfalia).

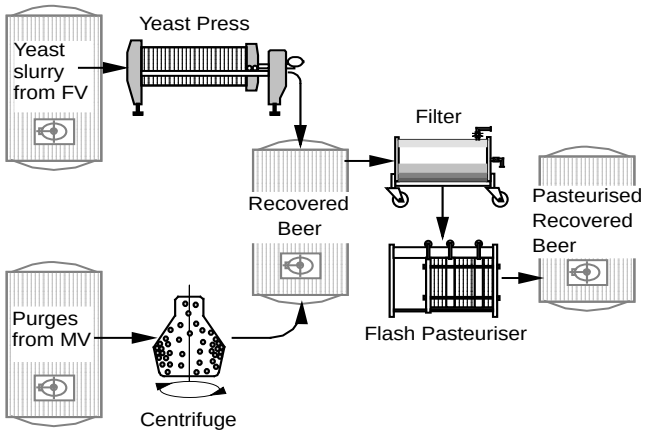
Beer Recovery

The yeast slurry skimmed off top fermentations or purged from bottom fermentations contains around 50% usable beer. Purges from maturation tanks may contain as much as 80%. Many breweries have plants designed to recover this beer, process it and return it to the mainstream product.

The benefits of doing this are a reduction in beer losses along with the avoidance of effluent charges from running the waste beer to drain.

There are associated quality considerations because the recovered beer may have a yeasty flavour and it may be contaminated. However plant design and quality control procedures can overcome these concerns.

The diagram below shows a beer recovery plant installed in a large brewery.

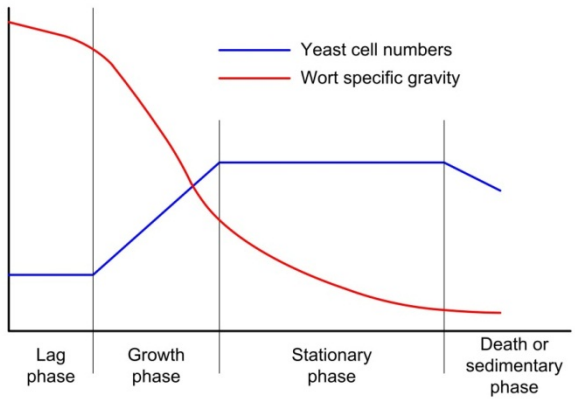


Monitoring yeast growth

Methods for measuring yeast concentration or numbers include plate count, haemocytometer, turbidity, biomass measurement by electronic sensors (such as the Aber Instruments yeast monitor), or more commonly for quick checks, the weight of yeast cells per unit of volume of liquid slurry. The average weight of individual yeast cells varies throughout the course of fermentation, and so using the weight to calculate the number of cells is not strictly accurate, but discrepancy is slight and for most purposes can be ignored.

For less accurate determinations, it is convenient to measure the volume of packed yeast separated from a known volume (e.g. 15ml) of suspension in a calibrated centrifuge tube.

Another means of monitoring yeast growth is the measurement of the specific gravity of the fermenting wort. If the conditions are the same as previous fermentations, including wort oxygenation, specific gravity vs. time, yeast pitching rate, fermentation temperature profile, then the yeast growth will be very similar to previous fermentations. The chart below shows typical profiles of apparent specific gravity and viable yeast mass during fermentation.



Yeast storage conditions

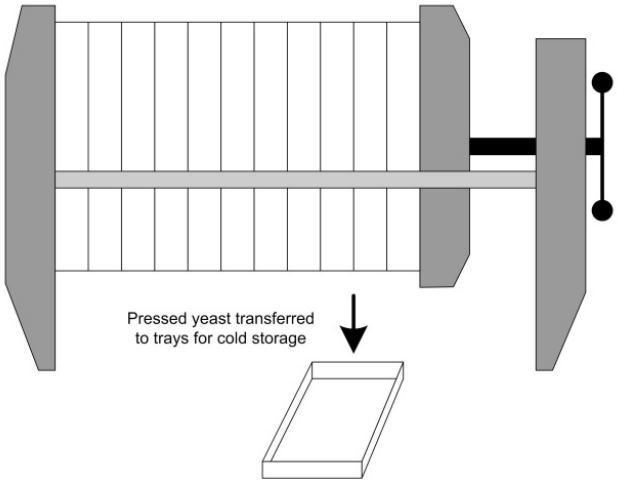
Yeast may be stored as a fairly dry cake of pressed yeast, in a cold room. There are risks of cross contamination with different generations of yeast, or with other yeast strains in use, or contamination with bacteria. The stored yeast tends to suffer from viability and vitality issues more rapidly than slurried yeast.

Yeast is more commonly stored with the entrained beer residues that it was cropped with, but sometimes may be pressed and re-slurried with water. The vessels are either individually cooled and insulated, or may be in a common refrigerated room. The vessels must be fitted with low shear mixers, and may be at atmospheric pressure, or pressurised with sterile gas.

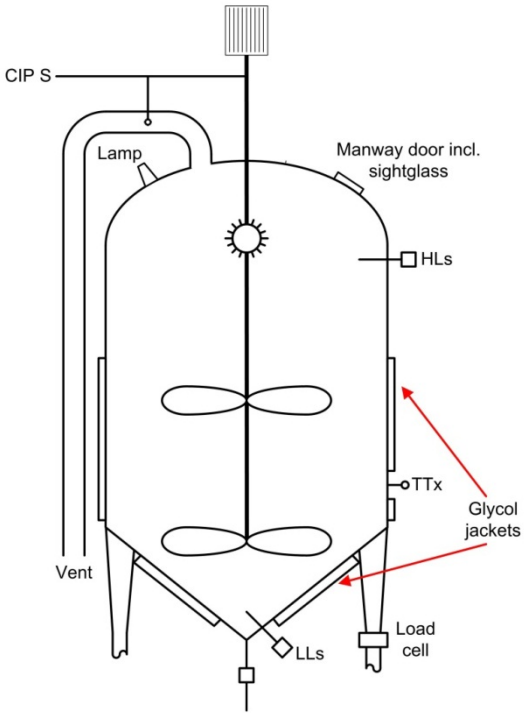
Good practices for storage include:-

- Maintaining the temperature at 2 – 4 °C.
- Chilling to storage temperature rapidly.
- Mixing to ensure homogeneous yeast slurries.
- Avoiding aeration.
- Minimising storage times – 5 days maximum is a typical specification.
- Hygienic vessel and pipework design.
- Efficient and effective CIP regimes.
- Thorough sampling & inspection regimes.

Yeast pressing for storage



Yeast storage vessel



7.2 Yeast selection, treatment & pitching

Pitching yeast selection
Pitching is the term used for adding yeast to the wort to start the fermentation.

The choice of pitching yeast has a major influence on the performance of the fermentation and its outcome. The aims of selecting the correct pitching yeast are to:-

- Ferment the wort to the desired temperature and gravity profile.
- To achieve the desired flavour profile in the final beer.
- To obtain sufficient healthy yeast for re-pitching, typically
  - Lager 15 – 20 million cells / ml
  - Ales 5 – 15 million cells / ml

The criteria used to assess the suitability of a batch of yeast include:-

- Is this the correct strain for the beer to be fermented?
- Is the yeast of the appropriate generation (i.e. less than the maximum specified generation, typically somewhere between 8 and 12 generations)?
- The previous history and fermentation performance of the yeast. Yeasts selected from a slow or sticking fermentation are likely to repeat the problem.
- Growth rate / mass in previous fermentations.
- Is the yeast contaminated by any bacteria or wild yeast?
- Separation behaviour – was the flocculation true to type?
- The previous wort gravity – very high gravity worts commonly produce low viability / vitality / mutated yeasts.
- Viability is ideally >95%, preferably >90%
- The storage time, temperature, etc.

Pitching yeast characteristics and assessment

Pitching yeast has a number of key characteristics. A key one is the ability or otherwise to flocculate. The flocculation ability has greatly influenced the design of the FV, and the cropping system associated with that FV. One definition of the flocculation characteristics is that of Gilliland, as follows:-

- C1 Permanently non flocculent - not commonly used in breweries.
- C2 Reversible loose flocs, head formers – used in top cropping systems.
- C3 Reversible large, tight flocs – no head – typical bottom cropping yeast.
- C4 Permanently flocculent, chain formers.

Yeast types are determined by a range of tests, including the following:-

- Morphology – what it looks like under the microscope.
- The growth medium the yeast will grow in.
- The flocculation characteristics.
- The fining ability.
- Heat resistance - autolysis due to heat.
- Fermentation by-products (e.g. esters, diacetyl).
- Whether spore forming or not.
- DNA fingerprinting.

Acid washing

Bacterial contamination of brewer's pitching yeast may lead to undesirable off-flavours as well as potential increased levels of ATNC (nitrosamines) in the beer. It is therefore good practice to minimise the numbers of bacteria in pitching yeast.

This can be achieved by one of two methods:-

- Very high standards of brewery hygiene to minimise pickup and growth of bacteria, associated normally with regular introduction of fresh, contamination free yeast cultures, discarding contaminated (or potentially contaminated) yeast.
- Acid washing, normally with phosphoric acid, though tartaric and citric acids have also been used.

Acid washing is the carefully controlled addition of an acid, typically phosphoric acid, to the yeast and mixing continuously at, typically, 2-4^{o}C to prevent excessively low and high pH portions of the slurry. The acid preferentially destroys bacteria but the yeast remains relatively unaffected. Acid washing will not destroy wild yeasts so cannot be a substitute for good hygiene. Thus, in spite of regular acid washing, regular introduction of new pure yeast cultures may still be required.

Acid washing may be carried out every pitching cycle, or as determined necessary on an irregular basis due to high bacterial counts. Most breweries, if they carry it out, will carry it out every cycle as it can be very difficult to distinguish using microscope examination between low contamination levels and higher contamination levels, and plating takes too long to be useful as a means of control.

Do

- Ensure the yeast is adequately "diluted" in beer or water to allow good dispersion.
- Use food grade acid, either phosphoric, citric or tartaric acid.
- Chill the yeast slurry to < 4^{o}C prior to addition of the acid.
- Stir constantly whilst adding acid to eliminate variation in pH, and regularly / constantly during stand.
- Ensure pH is in specification (typically 2.2 – 2.4) immediately after acid addition.
- Pitch as soon as stand complete.
- Regularly check the yeast micro and viability both pre and post acid wash.

Don't

- Exceed 5^{o}C at any time.
- Treat (stand) for more than 2 hours.
- Treat unhealthy yeast.
- Expect it to remove wild yeasts or mutated culture yeasts.
- Store acid washed yeast.
- Use yeast from high gravity fermentations (> 8% ABV ethanol). However, if all brewing is at high gravity, the yeast slurry should be diluted with sterile water prior to storage to reduce the effect on the yeast.

The acid washing tank (AWT) should be:-

- Insulated.
- Temperature controlled 3 – 5^{o}C.
- Agitated.
- Calibrated.
- Large enough to contain all the yeast required to pitch all the wort to be transferred into a single FV.
- Only one AWT per FV should be used.

Pitching methods

Whichever pitching method is used, the systems must ensure that:-

- Only the correct yeast strain is used.
- The yeast is free from contamination.
- The appropriate pitch rate of viable and vital yeast is achieved.
- The yeast is even dispersed throughout the wort in the FV.

Dried yeast

Fresh quantities of dried yeast are used by many microbrewers to pitch directly into the FV, and sometimes by larger (international) brewers for either pitching directly into FV or further growth in a propagation plant.

In the case of microbrewers, typically the yeast is mixed with a small quantity (a few litres) of warm wort or water (commonly circa 25 ^{o}C) and allowed to disperse evenly for 30 to 60 minutes, until no dried yeast "pellets" remain, and

the yeast is starting to produce gas. The yeast slurry is then simply poured into the wort in the FV, and allowed to ferment as required.

In the case of the larger brewers, they will have their own defined methods of "liquefying" the dried yeast, but the basic principal of initial mixing as noted above remains.

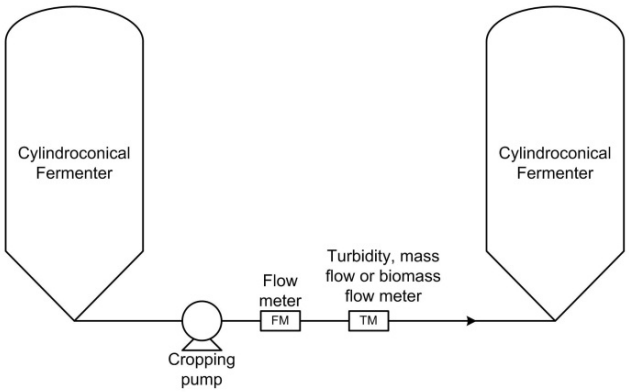
Recovered pressed yeast

Recovered yeast suitable for re-pitching may be pressed in a sterile yeast press, and the yeast stored in trays in a refrigerated room, or less commonly, re-slurried immediately with sterile water and stored as slurry in sterile refrigerated, stirred tanks.

If the yeast is stored as pressed yeast cake, it may simply be weighed out and tipped into the FV whilst the wort is filling the FV – a common method with older breweries with open or covered square FVs.

If the yeast is re-slurried it may be acid washed or pitched directly into the wort without washing.

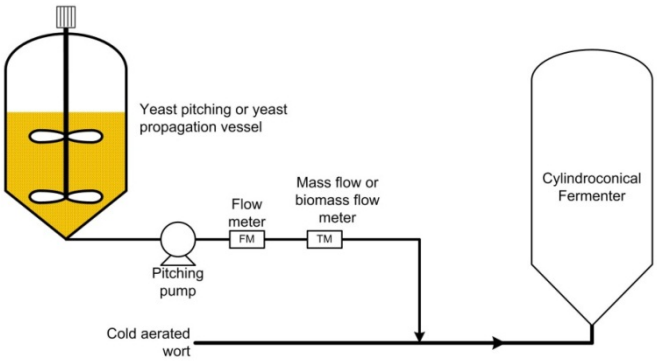
FV cone to cone



- This system has comparatively low capital costs – no separate yeast tanks and mains.
- Yeast may be transferred before or after wort transfer.
- The lack of additional tanks and mains means there is comparatively low risk of contamination pickup as the mains, pump and meter systems can be sterilised without breaking joints etc.
- Equipment used includes:-
  - Positive displacement pumps for accurate transfer of high viscosity slurry.
  - Flow meters for simple volume measurement, or
  - Mass flow meters for taking into account the mass of yeast.
  - Viable biomass meters (e.g. Aber yeast monitor) for measuring viable yeast mass.
  - Turbidity meters etc. used with simple flow rate measurement to guard against yeast running out.
- If suitable instruments are not used, then the pitching rate control can be poor due to variability in yeast slurry consistency.
- FV utilisation is not considered efficient as yeast must remain in cone until required, and excess can only be removed after pitching complete.
- Process is complex due to need to dispose of trub and dead cell portion at bottom of cone.
- Non ideal yeast storage – not stirred, so may have high levels of autolysis.
- Unable to acid wash effectively.

Yeast pitching tank to FV

Yeast from storage or propagation is pitched, in line into the cooled oxygenated wort, or less commonly, directly into the FV.



- Additional capital and revenue costs.
- Yeast is normally transferred during wort transfer.
- Equipment used includes:-
  - Positive displacement pumps for accurate transfer of high viscosity slurry.
  - Load cells on pitching or propagation vessels.
  - Flow meters for simple volume measurement, or
  - Mass flow meters for taking into account the mass of yeast.
  - Viable biomass meters (e.g. Aber) for measuring viable yeast mass.
- Allows acid washing if required.
- Greater accuracy of pitching rate.
- Improves FV utilisation.

Pitching rate calculations

Typical pitching rates are

- Lager 15 – 20 million cells / ml
- Ales 5 – 15 million cells / ml

Pitching yeast is checked before use for viability & contamination.

- Only viable yeast will ferment wort, so the mass of non viable yeast cells only must be accounted for.

- If pitching is carried out on a weight basis the proportion of entrained beer must be accounted for.

The viability is normally checked by mixing thin yeast slurry with methylene blue stain. The viable cells metabolise the dye to colourless compounds. Dead cells are stained blue. It is assumed under normal brewery conditions that the yeast vitality is 100%, though the variation in required pitching rates of different yeasts will allow for any consistent reduction. It is not good practice to use yeast that has a viability of < 90%.

To assess the solids content of yeast slurry, a small portion is spun down in a laboratory centrifuge.

These two factors can then be used to calculate the mass or volume of slurry that has to be pitched into a specified volume of wort to enable its subsequent fermentation to the required specification.

Normally, rather than convert back to cells / ml or wort, the calculation keeps to a more practical level, for example, kg yeast / hl wort. For example, the standard pitch rate for a lager wort is defined thus:-

- Wort is to be pitched with **0.7 kg pressed yeast per hl**.
- Actual volume of wort to be pitched is 500 hL
- The yeast slurry to be used contains 65% solids (as determined by laboratory test)
- 96% viable yeast (methylene blue)

The mass of yeast to be pitched $= \frac{(500 \times 0.7) \times 100 \times 100}{(65 \times 96)}$

$= \frac{(500 \times 0.7)}{(0.65 \times 0.96)}$

$=$ **560kg**

Yeast as a co-product.

With an increase in the yeast stock with each fermentation, a surplus is inevitable. Yeast is rich in vitamin B and is very flavoursome after processing so it is commonly sold as a co-product to food manufacturers or to pharmaceutical companies.

Alternatively, surplus yeast can be used as a food for livestock.

Qualifications

The General Certificate in Brewing (GCB)

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Section 8 Beer Maturation and Cold Storage

Introduction

The biochemical, chemical and physical mechanisms involved in flavour changes occurring during maturation are intricate and complex. Maturation includes all transformations between the end of primary fermentation and the final filtration of the beer[#]. Classically fermentation and maturation are considered separate steps in brewing but in practice there is significant overlap.

The main difference between *traditional* maturation systems in ale and lager brewing is that ales are conditioned by warm storage, holding the beer at 12 - 18°C, whilst lagers are conditioned at much lower temperatures (3 - 6°C). There are, of course, always exceptions to this traditional view.

Under warm maturation conditions, residual sugars are rapidly metabolized and removal of "green" flavours is completed in 1-2 weeks (normally far less) depending on the type of beer, yeast strain, wort composition and primary fermentation conditions.

Maturation of lagers, particularly at low temperature, is significantly dependent upon the length of the lagering (ageing) period, the amount of yeast in suspension and the quantity of fermentable sugar in the young beer or added in the form of actively fermenting wort (kräusening).

Brewery conditioned and filtered beers, i.e. most keg, can and bottle beers, are matured in tanks where flavours improve, the yeast is sedimented out (so aiding filtration), the beer is stabilised to ensure that it stays bright, and oxygen is purged / mopped up by the yeast to very low levels.

[#]Cask and bottle conditioned beers are matured in cask or bottle and are unfiltered. Here, the yeast settles out, sometimes assisted by use of finings, flavour is improved and CO_2 levels are increased.

8.1 Warm maturation

The purpose of warm maturation, and beer flavour changes post-fermentation

Beer at the completion of primary fermentation, sometimes termed 'green beer', contains:-

- Unpleasant flavour compounds, for example – acetaldehyde (green apples) and sulphur compounds (bad eggs) and vicinal diketones (VDK's) such as diacetyl (rancid butter, butterscotch).
- Many particles in suspension, mainly yeast, which make it cloudy or turbid.
- Constituents which have the potential to make the beer go cloudy after packaging, known as haze precursors.
- Usually, lower levels of carbon dioxide than those specified for the final product.

The "off" flavours are largely result of poor yeast growth due to poor oxidation, yeast viability or vitality, temperature, nutrient status etc. The vicinal diketones, hydrogen sulphide and acetaldehyde are primarily responsible for "green beer" flavour and an important feature of maturation is adjustment of their concentration. The adjustment (normally a considerable reduction) is primarily completed by the remaining yeast, which acts to reduce the "green beer" flavours.

During the maturation period, VDK (principally diacetyl) is reduced by the yeast to acetoin and 2,3 butanediol. Both of these compounds have far higher taste thresholds than diacetyl and do not contribute adverse flavours to beer. The rate of diacetyl removal is temperature dependent, the rate being much higher at higher temperatures and higher yeast concentrations – hence the increase in temperature at the end of fermentation during some lager fermentations. Because the rate is dependent on the temperature and viable yeast cell concentration, maturation takes place before chilling of the beer and sedimentation of the yeast.

The removal of aldehydes is favoured by:-

- Measures to promote vigorous secondary fermentation & maturation.
- Higher temperature maturation.
- High yeast concentration during warm maturation.

Hydrogen sulphide is very volatile, and much is removed by the stripping effect of CO_2 during late fermentation and early warm maturation, particularly in shallow vessels.

During this maturation, the levels of carbon dioxide dissolved in the beer will increase, especially if the beer is held under pressure. The evolution of CO_2 bubbles will also help to purge out any unwanted substances like oxygen or unpleasant flavour compounds, though the effectiveness of the CO_2 "purge" is doubtful.

Typical times & temperatures

Ales are typically held at 12 – 18°C for 1 to 4 days, though may be up to a week.

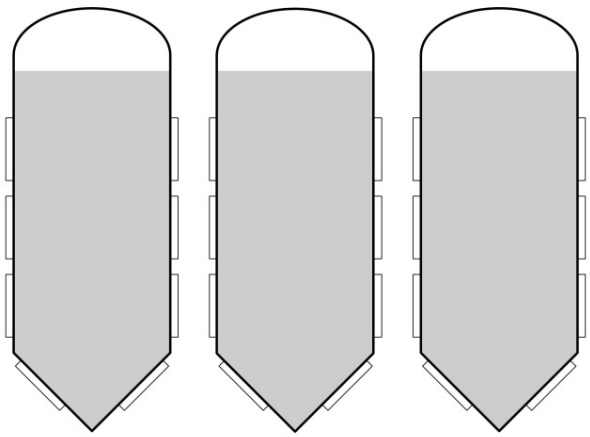
Lagers are typically held at 3 to 6°C for 4 days up to a few weeks. Sometimes the warm maturation process involves a slow reduction in temperature over a period of days or even weeks, rather than a single rapid cool. There may even be a temperature rise towards the end of fermentation for diacetyl removal followed by gradual cooling to 0°C or below.

Maturation systems

There are different types of maturation system. In a uni-tank system, beer is matured in the same tank that it was fermented in (FV). In a dual tank system, the beer is transferred into a maturation tank (MV) and either cooled in that tank or more usually, is chilled on transfer into the tank. Some brewers use a three tank system, using a fermenter, a warm maturation tank followed then by a cold conditioning tank.

Maturation tanks can be cooled by external jackets or they can be sited in a cold room as illustrated in the diagrams below:-

Vertical maturation tanks with side wall and cone cooling

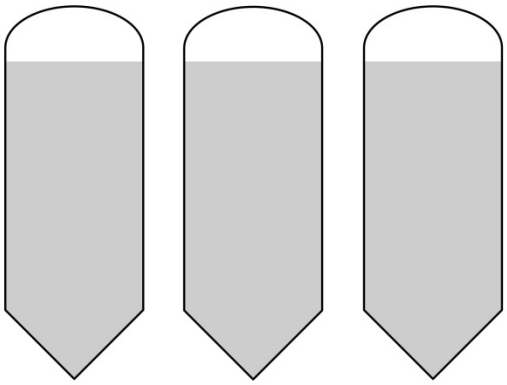


Each tank is individually cooled and lagged.

May be used as uni-tanks or dual purpose, or as pure cold store vessel.

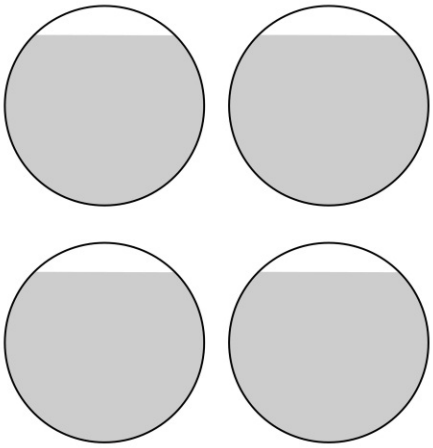
When used as non uni-tank MV, for best results, the beer is cooled on transfer to the vessel to -1°C.

Vertical maturation tanks in a cold room



Tanks have no cooling or lagging. Kept in refrigerated room. For best results, the beer is cooled on transfer to the vessel to -1°C.

Horizontal maturation tanks in a cold room



Tanks have no cooling or lagging. Kept in refrigerated room. For best results, the beer is cooled on transfer to the vessel to -1°C.

8.2 Cold storage & stabilization

The purpose of cold storage

Improvements in beer flavour are achieved in two stages, warm maturation and cold storage. Yeast must be present for the improvements to occur. Cold storage takes place at 0°C or below and beer flavour continues to improve as the unpleasant compounds are reduced, though the rate of reduction is very much slower than at warm maturation temperatures.

The raw materials from which beer is made, especially malt, contain protein material and tannins, which can combine together to form particles large enough to create hazes. This haze is termed non-biological haze because it is not caused by microbiological activity.

Non-biological haze can also be formed after filtration and packaging especially as the beer ages and in the presence of oxygen. A 'chill haze' can be formed if inadequately stabilized beer is stored in a cold place like a refrigerator because the remaining haze particles are less soluble at low temperature.

Other functions of cold storage include:-

- Oxygen reduction – by allowing residual yeast to mop up oxygen.
- Carbonation - by action of the residual yeast on any fermentable sugars, producing CO_2.
- Stock holding – providing a buffer for periods of high demand.
- Blending – to improve consistency of final flavour etc. Ideally to be a routine operation, rather than as a need to bring out of specification beer into specification.
- Process aid reaction time – to allow sufficient time for reactions and settlement to take place.

Typical times & temperatures

Ales typically -1°C for 1 to 4 days, though may be up to a week, particularly for small pack beers. Shorter residence times are most easily obtainable when using beer stabilisers such as silica gels or PVPP.

Lagers -1°C for 4 days up to a few weeks, particularly dependent upon the origins of the beer. Traditional style beers are more likely to use longer times than modern recipes. Again, shorter residence times are most easily obtainable when using beer stabilisers such as silica gels or PVPP (where permitted).

General principles of stabilization

On transfer from FV (or MV) to cold maturation/storage vessel, the beer contains high levels of suspended solids, mainly of yeast and proteins. However, it also contains large amounts of protein and polyphenol precursors. These need to be largely removed before filtration to allow efficient filtration and the required shelf life. The period of cold maturation allows much of the suspended yeast and proteins to settle out. The settlement / removal may be aided by use of centrifuges (see section 7 – yeast handling) or processing aids, as described later in this topic.

At 0 to -2°C there is little yeast activity (although lager yeast can grow very slowly at this temperature). The principal changes are physical. Beer haze is formed during cold storage due to the combination of proteins and polyphenols, which either settle out in the storage tank or are removed during filtration. This occurs principally during cold storage and takes around 12 to 36 hours to form. However the bonds are very fragile and almost instantly break if the beer is warmed up.

Particles, for example yeast and insoluble protein particles, will sediment out as long as they are heavier than the beer. The rate of clarification depends on the size of the particles, how dense the particles are and how far they have to fall.

The simplest but lengthiest way of removing the yeast and haze particles remaining in the beer is to allow suspended matter to settle. Stoke's Law tells us the essential features of settling, namely that the rate of sedimentation is increased by:-

- Increasing the diameter of particles.
- Increasing the density of particles.
- Increasing the gravitational force.
- Decreasing the liquid viscosity.
- Decreasing the distance the particles must settle.

Thus:-

- Larger particles settle very much quicker (the rate increases by the particle diameter squared). The means of doing this are described under finings
- Denser particles settle more rapidly.
- Liquids that are less dense and less viscous permit more rapid settling.
- Shallow vessels rather than deep vessels encourage more rapid settling.
- Increasing gravitational force (by centrifuging) achieves rapid settling.
- Decreasing liquid viscosity. However, this is not a practical option, since this means allowing the beer to warm up, which would allow potential haze material to re-dissolve (the decrease in viscosity is minimal anyway).

The factors that the brewer can influence that will have the greatest effect on time to clarify are:

- Particle diameter, which can be increased by causing particles to agglomerate, for instance by the use of finings.
- Gravitational force, which can be increased by centrifugation.

Haze precursors and their removal

The most common hazes are derived from protein fractions, chiefly polypeptides derived from the malt protein.

The polypeptide material may be polymerised to form visible haze particles by polyphenols or tannins, also derived from malt (but also possibly from hops). These polyphenols easily oxidise to become highly reactive so that the level of dissolved oxygen in the beer is important in this context. Heavy metals (such as iron and copper, from untreated brewing water) are also important as they link oxidised polyphenols and polypeptides.

Thus the building up of visible haze particles is particularly rapid in the presence of dissolved oxygen and / or heavy metals.

When beer from the primary fermenter is chilled to 0°C, it usually becomes hazy due to the precipitation of material which typically is mainly a complex of protein and polyphenols plus a small amount of inorganic substances.

When beer is warmed, the bulk of the haze disappears. The portion of haze that has re-dissolved is called chill haze. The beer may be subject to a succession of alternating periods (through transport and warehousing) of chilling and warming, with the beer becoming hazy and then clearing again. Gradually, however, the haze formation ceases to be reversible. That which is stable at 20°C is called permanent haze.

Chill haze represents such reversible association, the material coming out of solution because of the decreased solubility at low temperature. Permanent haze is the irreversible association, characterised by the more durable covalent linkages.

Not all hazes are associated with protein and tannins. Other hazes include those from:-

- calcium oxalate crystals, although these are unlikely if there is excess calcium present during wort production, particularly during the mashing process.
- carbohydrates, especially β-glucan material, and less commonly, residual unconverted starch.
- filter powders (e.g. kieselguhr) or cellulose fibres which have passed through the filter systems.
- collapsed foam particles. Poor beer handling or over carbonation, particularly when using reduced hop compounds, can result in particulates due to collapsed foam floating in the beer.
- undissolved propylene glycol alginate foam enhancer (PGA) if used.

To produce stable beer, it is also necessary to ensure the other processes associated with beer brewing and packaging minimise the risk of producing hazes.

Typical ways of reducing the protein content of a beer are:-

- Selecting low nitrogen malts (typically 1.6 to 1.8% nitrogen), to give comparatively low nitrogen worts.
- Using adjuncts which are low or free from nitrogen e.g. maize flakes or brewing syrups.
- Using under-modified malts thereby reducing the amount of protein extracted.
- Promoting proteolytic action during mashing where necessary, such as stands in the range 45-55°C.
- Adding additional enzymes – proteases or glucanases to the mash.
- In the brewhouse, efficient separation and removal of proteins with the spent grains and as hot or cold break after wort boiling, during cooling. The efficiency of separation will depend on the quality of wort, and where appropriate mash boiling, boiling, and performance of the whirlpool.
- Improving the hot and cold breaks by use of kettle finings and if necessary appropriate hops / hop materials. Some hop extracts contain little or no polyphenol. The presence of the vegetable matter in whole or pellet hops also helps produce a more compact trub and clearer wort.

Typical ways of reducing the polyphenol content in beer are:-

- The use of adjuncts to dilute the amount of polyphenols coming from the malt.
- Reducing the extraction of malt polyphenols by avoiding running to a low gravity (less than 1004 or 1^0plato) and keeping the sparge pH low (below 7) (most malt polyphenols are extracted towards the end of the runoff).
- Brewing with proanthocyanidin free malt, which is now commercially available. (“Pro-ant” malt – bred to be free of proanthocyanidins, the most reactive of polyphenol which, in beer, is derived 70-80% from malt, the rest from hops).

Other precautions include:-

- Ensuring adequate levels of calcium ions in the mash and wort boil to ensure oxalates and phosphates which can form haze are precipitated.
- Avoiding contamination of water and raw materials by heavy metals and avoiding their introduction from materials of construction of equipment.
- Removing any brown scum which appears during fermentation (only realistic with suitable top fermenting operations).
- Ensuring strong yeast growth. New cells adsorb protein – polyphenol complexes onto their surfaces.

- Reducing the dissolved oxygen content of the beer post fermentation by carefully processing and possibly the use of reducing agents (e.g. SO_2 plus ascorbic acid – though these are increasing less widely used) or the enzyme glucose oxidase.
- Keeping beer free of dissolved oxygen and heavy metals in packaging.
- Holding packaged beer in cold store.

THE NATURE & ACTION OF STABILIZING AGENTS

Introduction

Stabilisation, other than enhanced removal of yeast by centrifugation, or yeast and protein by long, cold storage time to allow settlement, may be improved by a number of methods.

Other than the use of long cold storage periods, the use of finings is perhaps the most traditional method of reducing storage times and increase beer clarity and shelf life. Comparative recent stabilisation methods are aimed at reduction of the protein or the polyphenols which comprise chill and permanent haze.

Finings

Finings act like electrostatic "glue" having the effect of increasing the diameter of haze particles, so that in accordance with Stoke's law, the particles will settle more rapidly. Brewers may use two different kinds of finings – auxiliary and isinglass finings on transfer from FV to MV.

The use of the correct balance of auxiliary and isinglass finings will rapidly clarify a beer containing:-

- 0.5 to 2.0 million viable yeast cells per ml.
- 1 to 3 million non-biological particles (mainly protein) per ml.

Finings systems will not adequately remove:-

- Colloidal hazes caused by metallic contamination.
- Bacterial contaminations.
- Dead yeast cells.
- Wild yeasts.
- Beers with particle loadings much higher or lower than the optimum.

There are three principle objectives of beer fining:-

- Bright beer – important with unfiltered beer.
- Rapid speed of fining.
- Tight and minimal cask bottoms.

The emphasis that any particular brewer will place on these objectives will determine his assessment of the best type of auxiliary and the optimum usage rate. This is especially important when the beer is not going to be filtered i.e. for cask conditioned.

Finings optimisation should be carried out on a regular basis, and certainly when the new season's malt starts to be used. Usage rates need to be optimised both to ensure economic cost is achieved and in order to gain the best possible results. Over fining can cause hazes just as under fining can leave hazes.

Auxiliary finings

There are a number of different types of auxiliary finings. The most common is based on acidified silicates. Polysaccharides (gums such as acacia, gum arabic) and seaweed extracts - finings based on carrageenan or alginates (carbohydrates from seaweed) and blends of part silicate/part polysaccharide finings are also available.

Isinglass finings

Isinglass finings are made from the swim bladder of specific types of tropical and subtropical estuarine fish. This contains high levels of a protein called collagen which makes the yeast cells clump together by an electrostatic effect.

Proteins removal

Adsorbents – silica gels

Silica gels (acidified sodium silicate) remove proteins by adsorption into pores within the gel structure. The size of the pores can be used selectively to remove proteins in terms of their molecular size (molecular weight). Silica gels are not strictly additives because they are removed during filtration.

Hydrogels contain up to 60% w/w moisture and are easily handled, quick dispersing and fast settling, whereas xerogels (with less than 10% w/w moisture) are more adsorbent, but are more expensive and more difficult to handle due to the very low bulk density.

Silica gels are readily removed as tank sediments or at filtration. Hydrogels can also be used as filter body feed.

Dosing rates are typically 40 – 60 g / hl on transfer from FV to MV, and 40 to 100 g / hl when added at filtration, though generally at the lower end of this range for domestic beers.

Bentonite

Bentonite (an aluminium silicate derived from certain clays) is now rarely used for protein stabilisation in beer (although may still be used in winemaking as a protein adsorbent).

Tannic acid

Tannic acid itself can precipitate protein but tends to produce a lot of loose solid matter which adversely affects losses. It is now rarely used because of this problem. Typical dosage rates are 5 to 8 g / hl of beer. Reaction time is 5 – 10 minutes, but the settlement time can be days.

Proteolytic enzymes

Proteolytic enzymes such as papain, extracted from sap of the papaya plant, hydrolyse proteins, i.e. break them down into smaller compounds which will not produce hazes. It is dosed typically at 2 to 6 ml / hl of beer.

It may be added on transfer from FV to MV though is not common nowadays as it is less effective than adding later at

filtration, when there is less protein left in suspension for the enzyme to act on. It is more commonly added during the filtration process, typically as part of the pre-filtration additions, where the activity is carried through to bright beer and final packaging process. Most enzyme activity will occur during the warm up phase of tunnel pasteurisation (optimum circa 50 ^{O}C), because cold storage temperature is too low. It is far less effective when beer is flash pasteurised because the warm period during which the enzyme is active is too short. It is liable to remain active if the beer has been subjected to less than 20 PUs. The denatured enzyme stays in solution in the final product. Beer foam proteins may be adversely affected by other enzymes in the 'enzyme' preparation.

Polyphenol reduction

PVPP

Polyvinyl polypyrrolidone (PVPP) is a nylon derivative and acts as a synthetic protein and is used to remove polyphenols and polyphenol-protein complexes.

PVPP is expensive and can be used either as single use (by addition to maturation/ cold storage tank, or dosed in on transfer to filter and trapped on a filter mixed with the kieselguhr), or it can be used in a stand-alone recovery filter (where the PVPP slurry is dosed in-line to bright beer after kieselguhr (KG/DE) filtration, and then trapped on a second filter. The powder is then regenerated by hot caustic solution (1 – 2 % at 80°C), neutralised and then recovered for re-use.

Dosing rates are typically 10 – 40 g / hl on transfer from FV to MV, and 20 to 70 g / hl when added at filtration as a single use material or recovered material. Re-use PVPP is considerably more expensive than single use PVPP, but the additional cost of both material, recovery system and regeneration chemicals etc. is outweighed by the reduced usage.

Combination treatment

There is often a synergistic effect when removing both protein and polyphenol. To achieve this, the beer may be treated with silica hydrogel on transfer to maturation vessel, or at the infeed to the filter, and treated with PVPP after filtration. This double treatment can produce a beer which is haze stable up to 18 months.

Notes

Describe the maturation process in a plant that you are familiar with.

- *How long is the cold storage?*
- *What agents (process aids) are added to the beer to improve its stability?*
- *What additional ingredients are added to your beer during processing?*
- *Where are they added and what are the rates of addition?*

Qualifications

The General Certificate in Brewing (GCB)

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Candidates should follow, and will be examined on, either section 9A or 9B.

SECTION 9A – BRIGHT BEER PREPARATION (MAINSTREAM BREWERY)

9.1. Chilling and Carbonation

Beer Chilling

The final stage of beer maturation, prior to filtration and packaging, is cold storage, usually at less than 0°C and usually for several days (see section 8). The most efficient way to chill beer to low temperatures is to use a heat exchanger, either on transfer from FV to MV, or if uni-tanking, by recirculating through a heat exchanger. Most breweries use plate type heat exchangers (PHE) using glycol or brine as the refrigerant, but some use shell and tube types, using ammonia, glycol or brine.

Section 4 of the GCB notes describes how wort can be cooled using a plate heat exchanger. The flow patterns through a heat exchanger can be either counter-current or co-current.

In the previous example of a wort cooler, counter-current heat exchange is used. This is where the two fluids flow in opposite directions to each other, separated by thin stainless steel plates, i.e. the hot wort inlet is adjacent to the hot water outlet. Such an arrangement is used to obtain good recovery of heat and to minimise refrigeration loads.

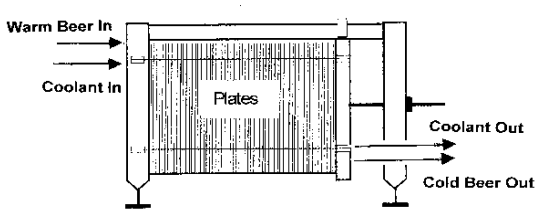
The alternative PHE flow arrangement is co-current where the two fluids flow in the same direction. In the case of the wort cooler, this arrangement would fail to give adequate recovery of heat and consequently would place an unnecessary burden on the refrigeration plant. However a co-current heat exchanger is suitable for chilling beer by only a few degrees, from say 4°C to less than 0 °C, as there is reduced risk of freezing the beer in the heat exchanger.

The beer is cooled to close to its freezing point (typically –1.0 to –2.0°C, depending on the alcohol content) in a heat exchanger, the temperature change coming from the use of secondary refrigerant, such as propylene glycol solution, as the coolant, at approximately -4°C.

In this way, passing beer through the heat exchanger will safely chill the beer to just above the freezing point of the beer.

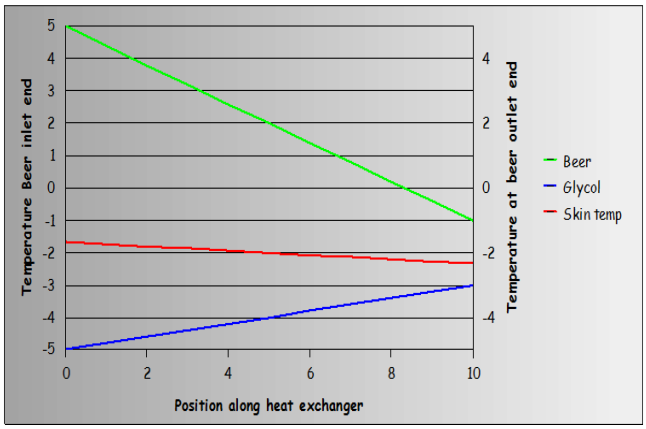
The operating principle of a co-current beer PHE:-

Plate heat exchanger



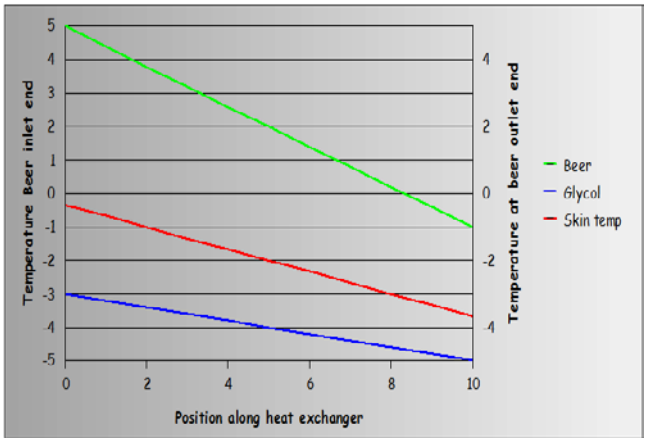
The figure below shows the temperature profile in a beer chiller arranged to have co-current flows. Beer at +5°C and coolant, for example glycol, at -5°C, are shown as entering at the 'Left-hand' side of the diagram. The 'red' line denotes the metal heat exchanger plate skin temperature, which in this case reaches a minimum of –2.3°C and so would not cause the beer to freeze.

Temperature profiles in a co-current beer chiller



By comparison, the next figure shows the same cooling duty if the beer and coolant flows were in a simple counter current arrangement. Again, beer is shown as entering the heat exchanger at the 'left-hand' side of the diagram, but being counter current, this is the position at which the coolant leaves the heat exchanger. This means that the coldest coolant would be directly next to the beer at its coldest.

Temperature profiles in a counter current beer chiller



In this case, the minimum skin temperature is –3.6 °C which is below the freezing point of most beers. With such an arrangement, there is a severe risk of freezing occurring.

Modern beer plate heat exchangers often use a recirculating loop of glycol (or other cooling medium) with small quantities of fresh glycol being fed into the system, displacing the equivalent volume of warmer glycol. This reduces the temperature difference between the glycol and the beer, so reducing risk of freeze ups. Such recirculating glycol systems may be configured as co-current, or counter-current systems.

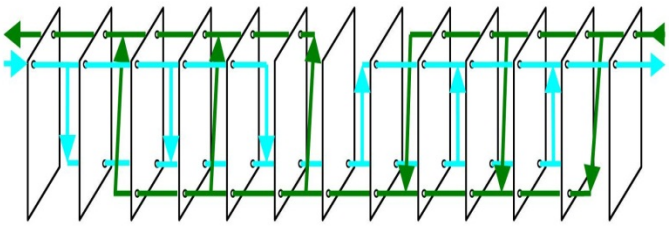
Plate Heat Exchanger (PHE) Design

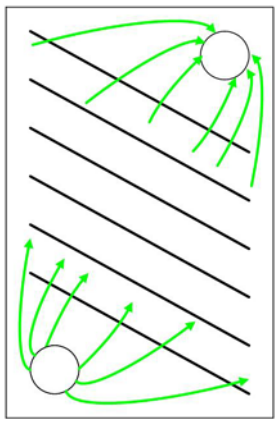
The plate heat exchanger is by far the most widespread type of heat exchanger in the beverage industries. For brewery applications, a stainless steel frame is often preferred to the coated steel frames for reasons of hygiene, maintenance and appearance.

The PHE comprises a collection of plates assembled within a frame. The two process fluids flow in the spaces between the plates and are distributed along the length of the heat exchanger by means of circular passages cut into the corners of the plates. The flow channels between the plates and the distribution passages are sealed by a gasket fixed to the face of each plate. A seal is made between the gasket and the reverse face of the adjacent plate.

There is a high degree of turbulence in the fluids flowing in the narrow passages, created by the high velocities and the pattern embossed into the plates. Very good heat transfer and a degree of 'self-cleaning' are achieved under these conditions.

Example of flows through a counter current PHE:-

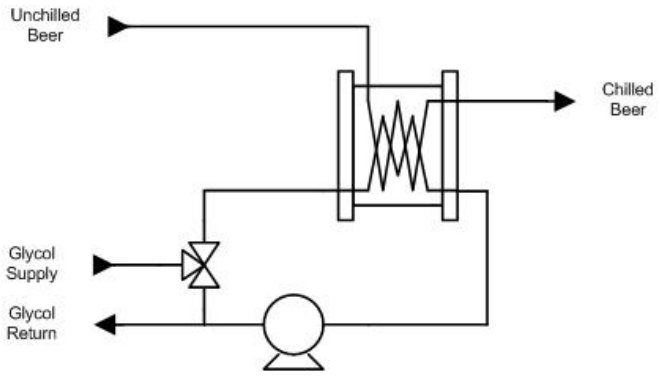




Good flow rate across plate surface

Cross section of plates and counter-current flow:-

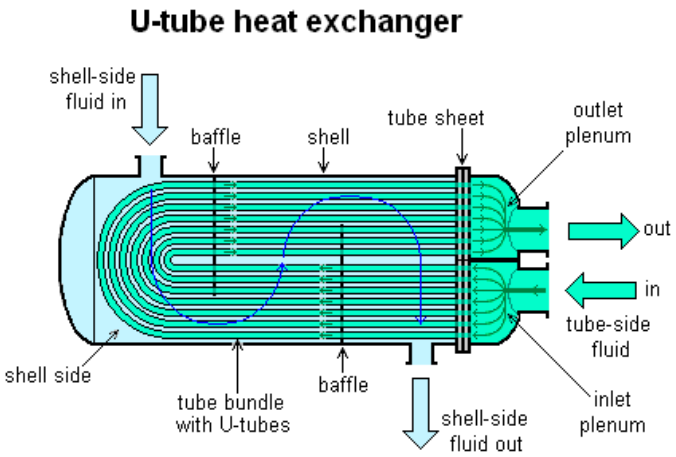
Co-current PHE with partially recirculated coolant for improved temperature control.



Shell and tube heat exchangers

Two fluids, with different supply temperatures (in this case beer and the coolant, typically glycol, brine or ammonia) flow through the heat exchanger. The beer flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from the beer to the coolant through the tube walls. In order to transfer heat efficiently, a large heat transfer area is used, leading to the use of many tubes.

There are a number of different configurations of shell & tube heat exchangers. The following is shown to give the basic principle of such a heat exchanger.



Carbonation

The purpose of carbonation is to increase the level of CO_2 dissolved in the beer to the required level for the next stage of the process.

This is normally determined by the customer palate, and the beer foam required when poured correctly, but the package types may also impose limitations, e.g. if beer CO_2 is too high, then the cans may be damaged during pasteurisation or bottle explode in a pasteuriser; if too low, cans may not be pressurised sufficiently to withstand secondary packaging and transport without damage.

Normally, carbonation is left as late during the beer production process as possible because it improves the accuracy and consistency of the final in package CO_2 content. Where high gravity brewing is practiced, the deaerated dilution liquor normally has quite a low CO_2 content, and carbonation has to be carried out post dilution.

Carbonation is typically measured using one of two units; the first being the metric grams of CO_2 per litre of beer (g/l), the second being the more traditional volume of CO_2 per volume of beer (vol/vol, or vols).

The following ranges are examples of CO_2 (in g/l) content of beer in final package:-

- Keg lager 4.3 – 4.9
- Keg ale 2.8 – 3.2
  2.0 – 2.4 (nitro keg)
- Bottle & can lager 4.8 – 5.4
- Cask ale 1.7 – 2.3

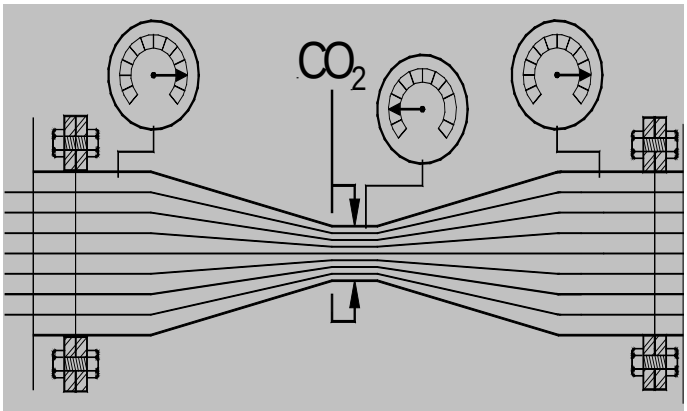
The process of dissolving a gas in a liquid (such as carbon dioxide in beer) is helped by a number of factors:-

- Solubility is increased at low temperatures.
- Solubility is favoured by high pressure.
- Solubility is favoured by a fine dispersal of gas as micro-bubbles which give a very high surface area / volume ratio for rapid solution of the gases.

Generally all 3 factors are observed when designing a carbonation facility of which there are several designs, such as:-

(a) Venturi carbonator

The following is a diagram showing the changes in velocity and pressure through a venturi carbonator. The gas is injected in the low pressure zone in the venturi and the gas dissolves when, because of the increase in the pipe diameter, the pressure increases and the flow velocity reduces.



Venturi is formed by reducing the cross sectional area of pipe.
Low pressure zone created at point of maximum restriction & velocity.
Gas injected into this low pressure zone.
Absorption occurs as the area increases, the velocity decreases and the pressure rebuilds.

The venturi is made, for example, from a section of 100 mm diameter pipe that has been reduced to say 40 mm, with a section having a reduced flow area. As beer passes through the venturi, the velocity increases and there is a corresponding decrease in pressure. Carbon dioxide is injected into the beer at this low pressure zone. Absorption is aided by the high degree of turbulence in this zone and by the increase in pressure in the diffuser section immediately afterwards. In this section, the cross sectional area increases, with a consequent reduction in velocity and increase in pressure.

(b) Sintered diffusers

Sintering is a process where metal or ceramic particles are pressed into a shape then heated to just below their fusion point. Partial fusion takes place to give a mechanically strong yet porous material. For gas diffusion, the sintered material is made into a cylindrical shape, often referred to as a 'candle'. The effect of passing gas through the candle immersed in a liquid is the formation of a very many fine bubbles. Fine bubbles are absorbed readily by the beer.

(c) Nozzles

Many breweries still prefer the simplicity of a simple injection nozzle for carbonation. The gas is forced through a fine hole at the end of a nozzle and the result is a fine stream of bubbles in the liquid. Nozzles have an advantage over sintered diffusers in that they are more easily cleaned.

Location of Carbon Dioxide Injection Points

Typically, carbonation is carried out either prior to filtration, or if after filtration, immediately after dilution to sales gravity (if high gravity brewing is practiced). Many older breweries still carbonate on transfer between FV and MV,

to reduce the work load of the filtration areas carbonator and improve the accuracy of the final carbonation unit in the filter area. It is also possible with modern control systems to adjust CO2 levels at the infeed to a packaging machine, for example, immediately prior to the flash pasteuriser of a keg filler.

In selecting the point in the process at which to inject gas, consideration is given to the factors that promote gas absorption, i.e. low temperature and high pressure.

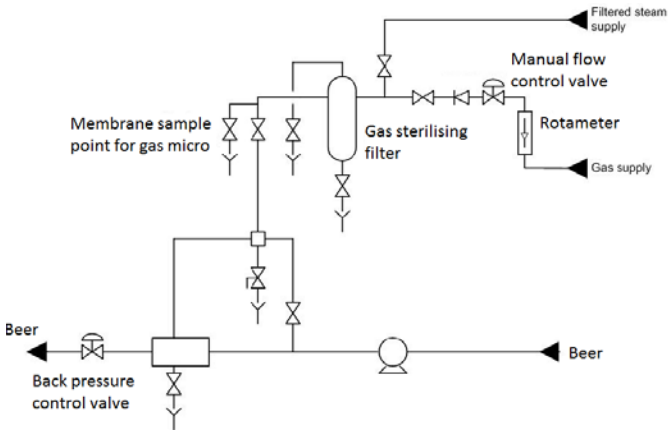
Often a static mixer is incorporated after the injection point to create turbulence and so aid solution.

For carbonating beer, the selection of an injection point is dependent upon the ability of the injection system to dissolve the gas fully. For example, if injection is made immediately before a beer chiller, the turbulence through the chiller will increase the transfer rate and the drop in temperature that occurs through the chiller will also help gas solution. Thus it is less necessary to have a very fine stream of gas bubbles produced by the injector. If the injector is after the chiller, then the gas bubbles need to be much finer, to ensure rapid solution by ensuring a high surface are to volume ratio of each gas bubble.

The figure below shows the arrangement for a typical carbonation point. Note that this particular arrangement is fitted with a sterile filter and a steam sterilisation/CIP connection. Although this may not be considered necessary for gas derived from cryogenic storage or of certified quality, it is necessary to ensure that no microbiological growth can develop in the injection system itself.

Note also that a sight glass is usually included (though not shown here). This gives a visual check on the gas injection.

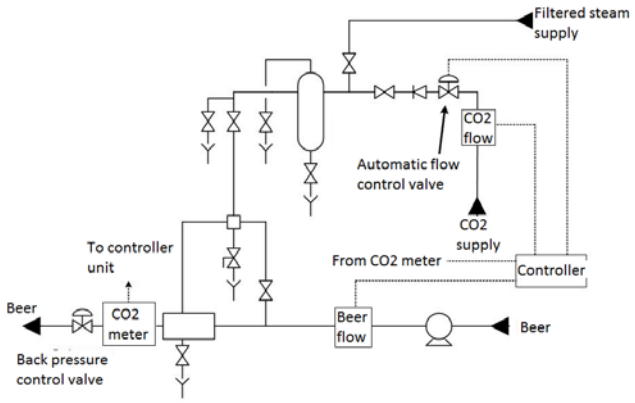
Manually controlled carbonation system



The next figure shows a system for carbonation where the gas flow is controlled automatically by means of a CO_2 in-line sensor, the signal from which is used to vary the gas flow by a standard process control loop. This system also shows a static mixer. This may be included to agitate the beer and un-dissolved gas to accelerate the absorption of gas into the beer.

Modern systems also measure the actual addition rate to give a calculated CO2 value and compare this to the measured value to ensure the control system is working.

Automatically controlled carbonation system



9.2 Beer Filtration

Consumers have come to expect visually clear beer, free of haze.

Beer that is intended to be clear (bright) is often assumed to be of better quality and there is much historical evidence to prove that this is often true. However, unfiltered, intentionally cloudy beer, including wheat beer, is still produced and enjoyed in many countries.

Matured beer will still have particles in suspension, mainly yeast but also smaller particles, mainly protein, unless it has been fined. There are three types of filtration:-

The purpose of **'rough' filtration** is to remove all the particles that would make the beer cloudy.

The purpose of **'polishing' filtration** is to remove all yeast and bacteria so that the beer is sterile.

The purpose of **'stabilising' filtration** is to prevent non-biological haze formation in package, which is the haze formed by the protein/tannin particles described in Section 9.1.

Traditionally, beer has been filtered using filter aids, predominantly kieselguhr (KG). More recently however, new filter aids that are capable of being regenerated have been developed. These reduce powder purchase costs, waste disposal and improve safety aspects, albeit at the additional cost of a regeneration process. However, the underlying physical principles by which beer is filtered remains the same as with KG.

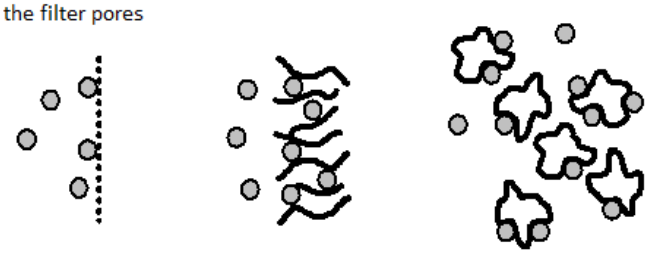
Another more recent development is the use of cross flow membranes to filter beer, which will be discussed later.

Filtration uses one or more of the following three principles:-

Sieving where particles are held back because they are larger than the filter pores

Depth filtration, where the particles are trapped in complex pathways

Adsorption, where particles adhere to the pores of filter powder granules

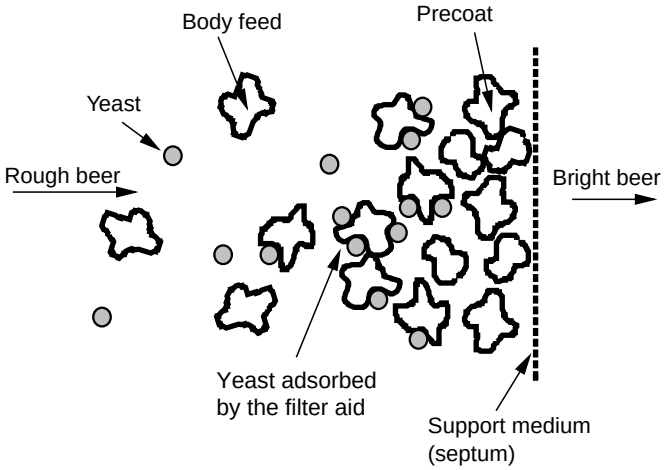


Kieselguhr (KG) and regenerative powder filtration.

Filtration using one or more filter "powders" uses the principles of absorption and depth, the technique as follows:-

A supporting medium (filter cloth or mesh) is **pre-coated** with filter aid. The precoat forms a depth filter, but is mainly required to bridge the gaps in the support medium (wire mesh, wedge wire, or cellulose fibre sheet) and prevent the support medium being blinded or allowing filter aid, yeast or proteins to pass through into the final filtered product.

After pre-coating is complete, beer is introduced into the filter. To prevent the filter bed blinding with yeast and protein, additional powder, known as **body feed** is dosed into the beer as it runs into the filter. The yeast and protein particles are adsorbed by the body feed filter powder, gradually building up a layer of powder, yeast and protein until the filter is filled. The filter does not 'blind' because the body feed continually creates a new filter bed.



Filter aids

The common types of filter aid are:-

Diatomaceous earth (DE) or **kieselguhr** is made from the skeletons of minute sea plants which have been kilned and milled to various grades of fineness. This is the most porous, rigid and effective filter aid. Kieselguhr can used for both precoat and body feed, depending on the grade (i.e. KG particle size). Kieselguhr is sometimes referred to by trademarked brand names such as Celite.

Perlite is made from volcanic minerals which are heated in a furnace to form minute glass bubbles. It has a less complex structure than kieselguhr and is less effective. Perlite is often used for pre coating. Some small breweries also use it for the bodyfeed.

Cellulose fibres, usually mixed with other materials such as kieselguhr, perlite starch or silica gel to give a product that is less harmful but still provides good filtration properties. Brands include Becofloc, Arbocel and Celtrox.

Silica hydrogel or lucilite is less rigid but it also acts as a stabiliser (by adsorbing proteins and polypeptides) as well as a filter aid.

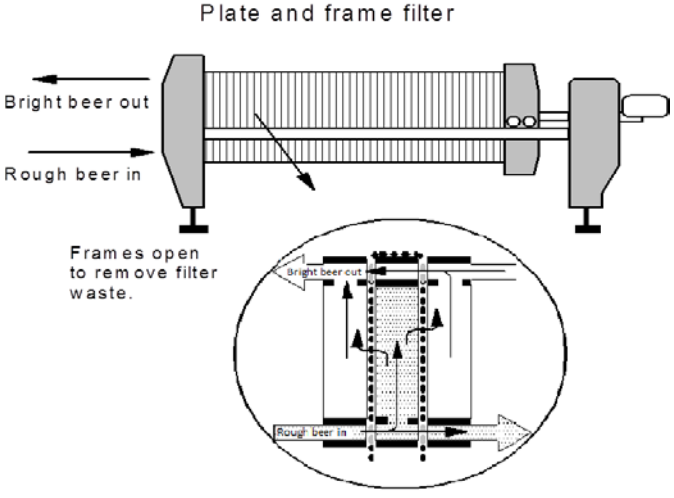
The handling of the unused KG requires considerable care, particularly the avoidance of, or provision of protection against inhalation. The disposal of KG waste filter aid is also becoming more of a problem for environmental and personal safety reasons. Handling systems include the supply of filter aids in big bags (e.g. 1,000 kg) instead of 20 – 25 kg bags, and ventilation systems to suck dust away from the operator. The air drawn through the plant carrying away the dust is filtered to remove the dust before discharging clean air to atmosphere.

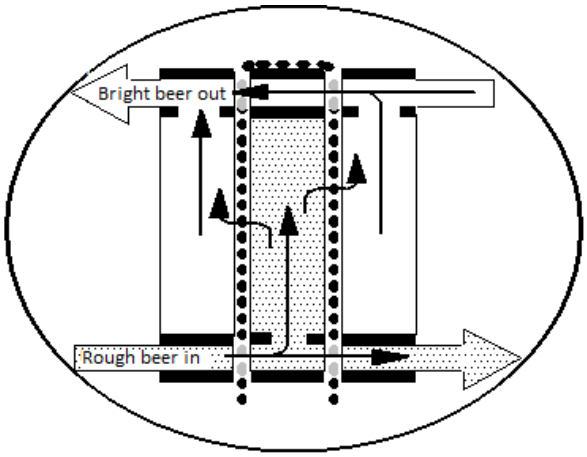
Types of rough beer filter

Filters are designed so that the rough beer is delivered onto the filter bed in as even a flow as possible. Both the particles being removed and the filter aid will eventually block up the filter by their sheer volume so filters are designed for easy emptying and cleaning.

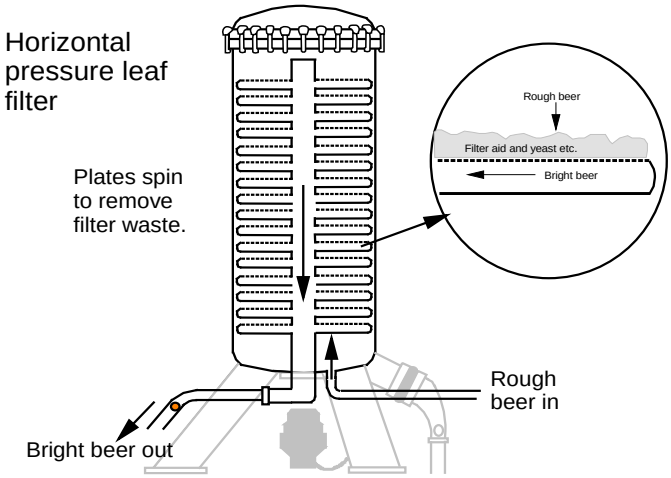
Four types of filter are illustrated in the diagrams below:-

1. Plate and frame filter





2. Horizontal leaf filter

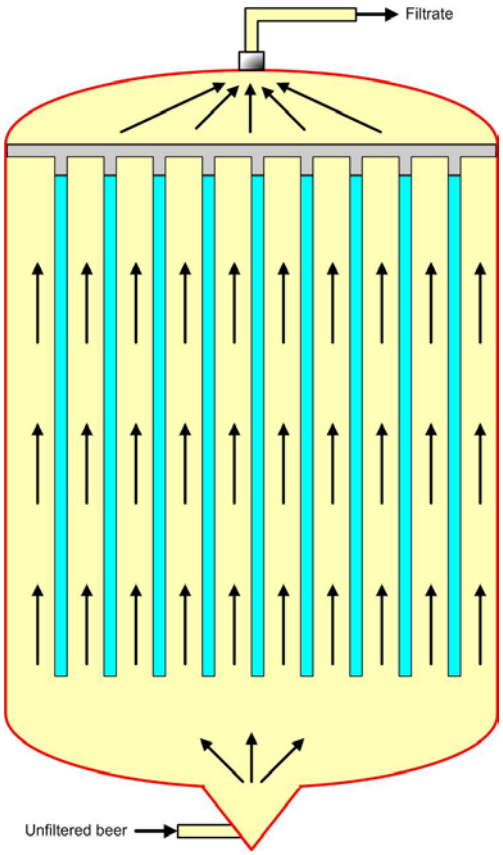


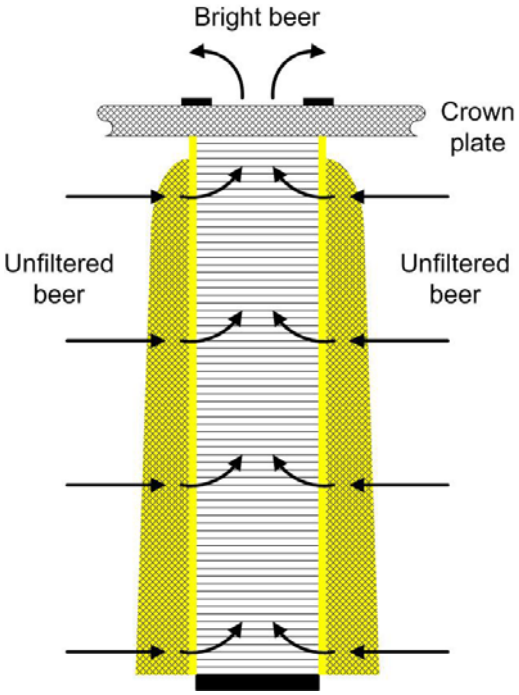
3. Candle filter

The candles in modern candle filters are formed from spirally wound wedge wire, with much smaller gaps between the wires than used in mash tuns and lauter tuns – sufficiently small to hold back the precoat particles.

During filtration, the filter cake builds up around the individual candles.

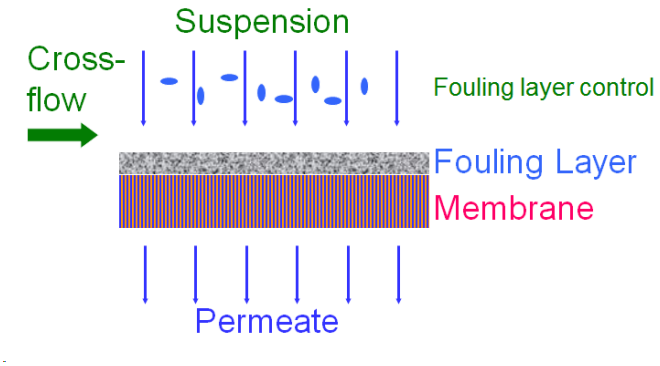
At the end of filtration, the filter is back washed with water. The filter cake drops off into the cone and removed via another larger outlet (not shown).





4. Cross flow filtration

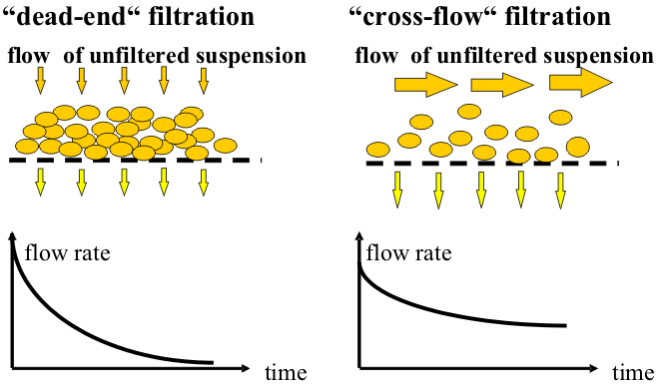
Cross flow filtration does not use kieselguhr or similar filter aids, but instead uses semi permeable membranes with pores of approximately 0.5 micron diameter, with high beer flow rates to help keep the membranes from blinding.



Unfiltered beer contains solids, with particles which are different in size, quantity and structure. These have to be filtered from the beer to get a bright beer which meets the expectation of the customer.

In cross flow filtration, these particles build up a fouling layer on the membrane. Excessive layer build up is delayed by use of high flow rates across the membrane, which helps to keep the layer thickness down and slows down the blinding of the individual pores in the membrane. To achieve the required high flow rates, the system needs powerful pumps, resulting in high energy consumption. This energy warms the beer up, resulting in the need for an inline cooling system.

Comparison of filtrate flow rates from cross flow and dead end filtration (no filter aid used). The high flow rates across the membrane help to keep the pores clear, thus maintaining the filtrate flow rate.



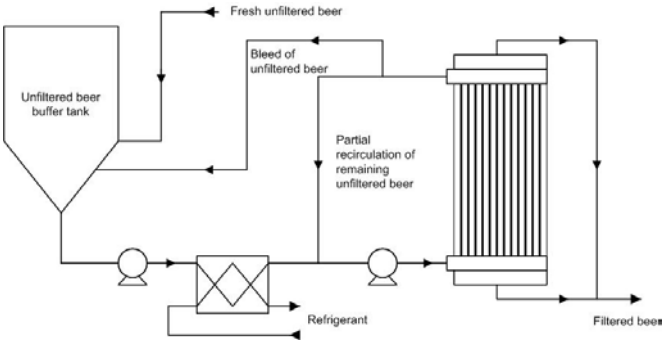
In most systems, the beer is pumped through a buffer tank or so called feed and bleed tank where, after period of production, a quantity of beer remains with a high solid loading, which is discharged for further treatment or disposal.

A filter run is considered complete when the differential pressure builds up due to blinding of the membrane pores and the filtrate flow rate reduces to an unacceptable rate. The membrane is cleaned using caustic, normally hot, often with additives and an acid neutralization flush afterwards.

In spite of the high energy and detergent costs, the savings in filter powder purchases, effluent disposal, and the high degree of automation are making this an increasingly attractive proposition, particularly for larger brewers. Increasing numbers are being installed around the world instead of filter aid filters.

The membranes for bright beer production are typically manufactured from PolyEtherSulphone (PES), the filter modules consisting of bundles of hollow fibres in a housing.

Example layout of cross flow filter plant



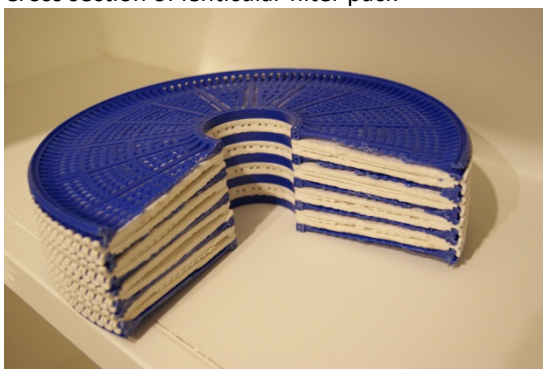
In the above process, the unfiltered beer is recirculated, with a partial bleed off back to the unfiltered beer buffer tank, and fresh supply of unfiltered beer is drawn in to replace the volume of filtrate and bleed off.

Lenticular filters

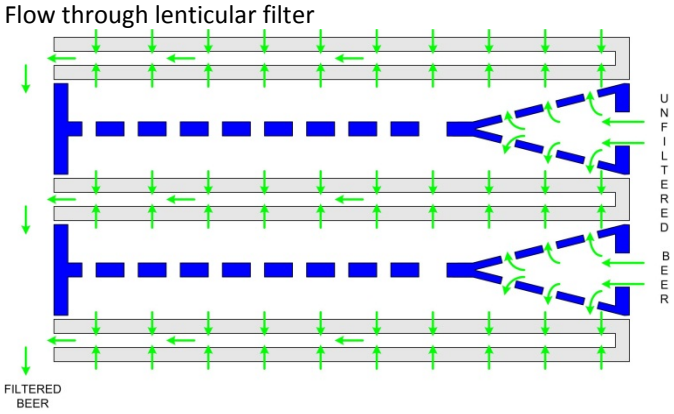
Lenticular filters are used by some larger breweries for polishing filtration or for removal of low particulate loads, such as yeast and proteins after beer recovery, and by numerous microbreweries as the main form of primary filtration. In all cases, these filters are used because of the convenience of lack of powder handling systems, simplicity of filtration operations, and ease of regeneration and the flexible sizes of the installations.

The filter sheets are of modular design, allowing for easy fitment into the housings and use of spacer units in larger housings when filtering small volumes / low flows. The filter sheets are supported and separated by polypropylene support discs

Cross section of lenticular filter pack



Flow through lenticular filter



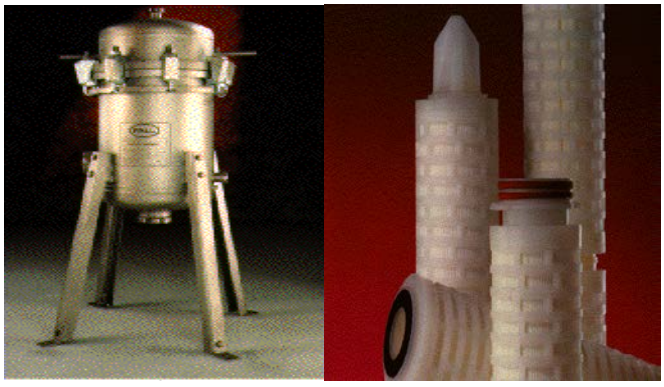
Lenticular filters are normally capable of being cleaned with detergent and capable of being hot forward flushed, and cold back-flushed to regenerate the filter medium.

Similar filters are obtainable in pre-packed filter form, the filtration medium consisting of a mixture of kieselguhr and cellulose fibre, instead of simply cellulose or polypropylene fibre. These are also capable of being regenerated a considerable number of times reducing the purchase or rental costs.

Polishing filtration

The polishing filter utilises the depth filter effect with a fine pore filter sheet or a fine filter powder to trap very small particles including micro-organisms. Where high flow rates are required, a plate filter may be used to house and support the filter sheets.

Trap filter (cartridge filter)



Trap filters are used to catch any small amounts of filter aid leaking through. A cartridge filter consists of a chamber which is fitted with filter elements housed in nylon supports to form replaceable cartridges. These are designed to be cleaned and sterilised a number of times before replacement is required due to excessive blinding of the filter material. The cartridges are often back-flushed at high flow rates as part of the cleaning process.

Depending on the material the elements are made from, they may use mainly depth filtration, or surface filtration. They are ideal for sterilising purposes, both for liquids (water, beer, cider) and for gases (e.g. oxygen, aeration air, CO_2). The typical pore size used in breweries for "sterile" filtration is 0.45 micron. Note that this would not be considered suitable for the level of sterility required for pharmaceuticals for example, but is considered adequate for the type of contamination experienced in breweries.

Stabilising filtration

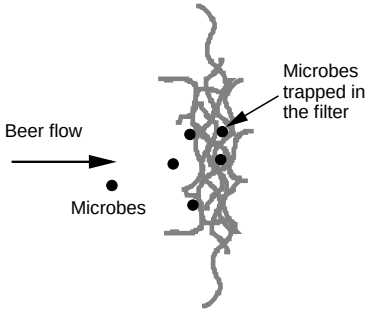
Stabilising agents such as silica gel and PVPP can be dosed into the beer on its way to the filter, either the KG filter, or standalone filter systems. Alternatively, filter sheets can be impregnated with a stabilising agent, for example, PVPP. Due to the expense of PVPP, standalone filter systems incorporating recovery and regeneration systems are used in some breweries.

Sterile Filtration

Microbes are by definition very small, but they do have a finite size and they can be trapped or held back by a very fine filter. This is the principle of sterile filtration.There are three types of filter that can be used to produce sterile beer:-

A **kieselguhr filter** with a very fine powder grade, although it is usual and recommended to follow this with a final polish or membrane filtration. The KG filter is never considered able to produce consistently sterile beer on its own.

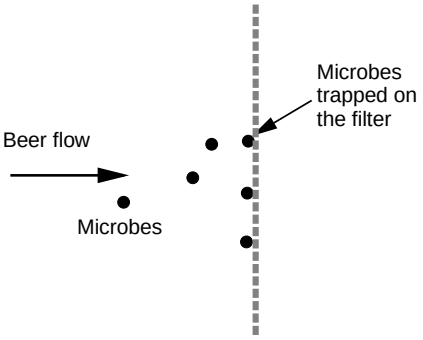
The **sheet filter** where the cellulose mesh of the sheet is very fine and tightly woven / packed. This type of filter traps the micro-organisms because the passages between the fibres of the sheet are so narrow. There is also an electrostatic effect whereby the microbes adhere to the fibres. The sheets may be held in plate filters or cartridge filters.



The **membrane filter** works on a slightly different principle,

namely that of a very fine sieve where the particles are held back on the surface of the membrane which has extremely small pores in it (usually 0.45 µm).

Membranes may be as sheets or as fine tubes. Cross flow filtration is capable of producing beer which is considered almost sterile, and some companies using cross flow are not using secondary sterile filtration prior to packaging.



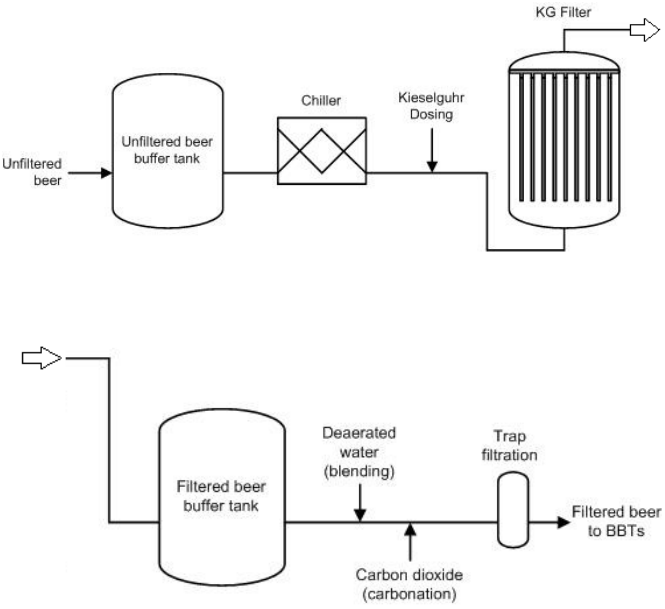
There are some benefits derived from the use of sterile filtration as opposed to pasteurisation.

There is a significantly reduced risk of developing those pasteurisation flavours ('papery', 'cardboard') that result from pasteurising beer, particularly if the beer contains high levels of dissolved oxygen or is treated with excessive numbers of pasteurisation units (PUs).

NB - Beers with high levels of dissolved oxygen at packaging will, over time, develop papery, cardboard and stale characteristics even if they are not pasteurised.

The very fine filter traps haze forming particles as well as microbes so that the beer is more stable.

Example kieselguhr filter plant process overview



- The trim chiller is used to maintain cold storage temperature and ensure that particles do not re-dissolve before they can be filtered out.

- Buffer tanks are used to protect the filter from pressure shocks.

- Filter aids are dosed into the beer via a dosing tank.

- The addition of blending water and carbonation to high gravity beer on transfer from the filtered beer (bright) buffer tank to the bright beer tanks is shown here as a typical installation.

- Trap filters are used to catch any small amounts of filter aid leaking through. These are typically located after the filtered beer buffer tank and also often after dilution and carbonation if high gravity brewing.

Filtration efficiency

The throughput of a filter system is influenced by both the amount of solids remaining in the beer that the filter is required to remove and the nature of the solids.

High levels of TSM (total suspended matter) will result in the need for higher kieselguhr addition rates, which can then fill the space between the filter elements very quickly. The presence of gummy material from the malt (β-glucan) increases the beer's viscosity and slows down its flow rate through the filter.

The loading onto the filter (the amount of yeast and other particles in suspension) can be reduced by:-

- Using long maturation times to allow good clarification by settling (traditional process).

- Centrifuging the beer before it is filtered.

- Increasing the settling rate by addition of isinglass finings on transfer from FV to MV.

Safety

Filter aids are considered dust hazards, some of them being more hazardous (dangerous) than others.

Kieselguhr is the most hazardous especially when calcined and ground to a fine powder. Hydrated silica gel is the least hazardous. Filter aids are often delivered in bags which have to be opened manually and the contents emptied into a hopper.

Examples of safety equipment used when handling filter aids:-

- Powder hoppers with negative pressure extraction systems, where any dust created when bags are opened is carried away from the operator, and

filtered out of the air before discharge into the atmosphere. These may continue to require manual slitting and emptying of the bags, or the bag slitting and emptying may be automated.

- 'Big bag' or other bulk systems, with automated transport and mixing with water of the powder from the base of the bag.

- Personal protection in the form of dust masks etc.

Notes.

Draw the workings of the filter in a brewery that you are familiar with.
Why was that design of filter chosen?
What filter aids are used and what are their usage rates?
Describe a filtration operation that you are familiar with.
Draw a flow diagram of the plant.
Describe the 'start up' and 'shut down' procedures.
What process control parameters are recorded?
Where are beer quality control samples taken?

9.3 High Gravity Dilution

High Gravity Brewing

High gravity brewing is a procedure where wort at a higher gravity than is required to produce the final beer is fermented. It therefore requires dilution with water at some point during processing after fermentation. By reducing the amount of water employed in the brewhouse, increased production volume can be met without increasing existing brewing, fermenting and maturation capacity.

Dilution with water to achieve the final sales gravity & alcohol can occur either entirely or in part at almost any stage in the process after fermentation but most commonly is after filtration, usually between the filter and bright beer tank. However, it can take place in MV, or pre filter if the capacity restriction is before these stages, or post bright beer tank.

High gravity brewing has been progressively introduced into breweries around the world for the past twenty-five years. However, internationally it cannot be said that its use is universal, because some companies have chosen, or are compelled by product and or legal/taxation reasons, not to adopt this process.

The legal and taxation issues are increasingly being addressed to permit the production of high gravity worts without undue financial penalties. Nevertheless, the impact on flavour of brewing and fermenting certain product types at high gravity remains a concern and challenge to some breweries.

There are a number of advantages and disadvantages to this process. The advantages can be summarised as follows:-

- Increased brewing capacity due to more efficient use of existing plant facilities.
- Reduced energy (heating, refrigeration, etc.), labour, cleaning and effluent costs.
- Improved beer physical and flavour stability.
- More alcohol per unit of fermentable extract because of reduced yeast growth and more of the wort sugars being converted to alcohol.
- High gravity worts may contain higher adjunct rates, and thus be cheaper to produce, or be less prone to hazes (if low nitrogen adjuncts are used).
- Beer produced from high gravity worts are often rated smoother in taste.
- High gravity brewing offers greater flexibility in product type. From one "mother" liquid a number of products can be brewed as a result of dilution and/or use of malt and hop extracts and syrups at the same time as dilution and carbonation.

The disadvantages can be summarised as follows:-

- Due to the more concentrated mash (increased rate of carbohydrate to water), there may be a decreased brewhouse material efficiency and reduced hop utilisation.

- Decreased foam stability (head retention). Hydrophobic polypeptides have been shown to be important in foam formation and, therefore, their presence in beer is essential. It has been shown that both high and low gravity wort loses hydrophobic polypeptides throughout the brewing process, with the high gravity process suffering a more rapid loss. It would appear that high gravity mashing does not extract high molecular weight polypeptides, which includes the hydrophobic polypeptides, as efficiently as low gravity mashing. Also during fermentation, there is a disproportionate loss of hydrophobic polypeptides of high gravity wort when compared to low gravity wort.

- There can be a difficulty when changing to high gravity brewing in achieving flavour match to the original lower gravity beers. The effects of high gravity wort on ester formation during fermentation are most important. However, flavour problems with high gravity worts have been exaggerated and adjustments to the process can be made (for example, yeast pitching rate, fermentation temperature profile, dissolved oxygen at pitching and the spectrum of wort sugars.

- High gravity worts can influence yeast performance with effects apparent upon fermentation and flocculation. The increased osmotic pressure, elevated

alcohol concentration and modified nutrient balance, all have a profound influence on yeast performance during fermentation. Stress tolerance during the fermentation of the worts by brewer's yeast is strain dependent.

Dilution of high gravity wort before or after fermentation requires that the water employed be given special treatment. The specifics of the treatment procedure will vary depending on the dilution point.

Most breweries add the water to the concentrated beer immediately after the final filter. The water for dilution at this point in the process requires treatment to ensure the quality and stability of the finished beer. Water must be free from colour and flavour taints, and suitable pH. Treatment includes demineralisation, filtration for particle removal, pH adjustment and sterilisation using filters, UV light or chlorine dioxide (ClO_2).

Most importantly, the dissolved oxygen content of the water must be reduced to less than the final beer dissolved oxygen spec, but typical levels aimed for are < 10 µg / l (or 10 ppb, parts per billion).

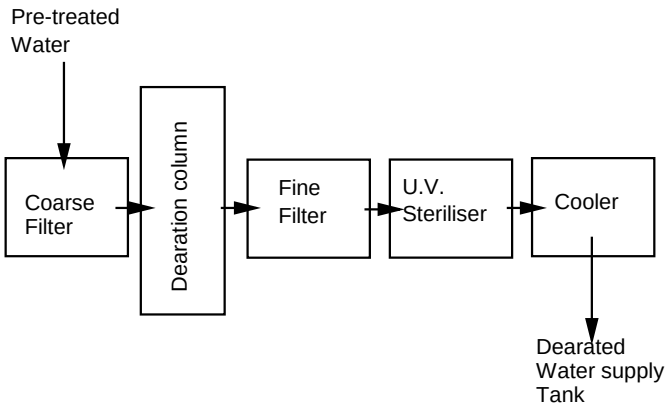
Methods of producing deaerated water are discussed in the following section.

In all cases, the water is cooled to typically 4°C or less prior to storage and use.

Dilution Water

It is most common when brewing beer at 'high gravity', to dilute the beer to its specified alcohol content at the latest stage, for example post filtration.

The de-aerated water plant is designed to supply water to the required standard of sterility and dissolved oxygen:-



The plant illustrated above has the following features:-

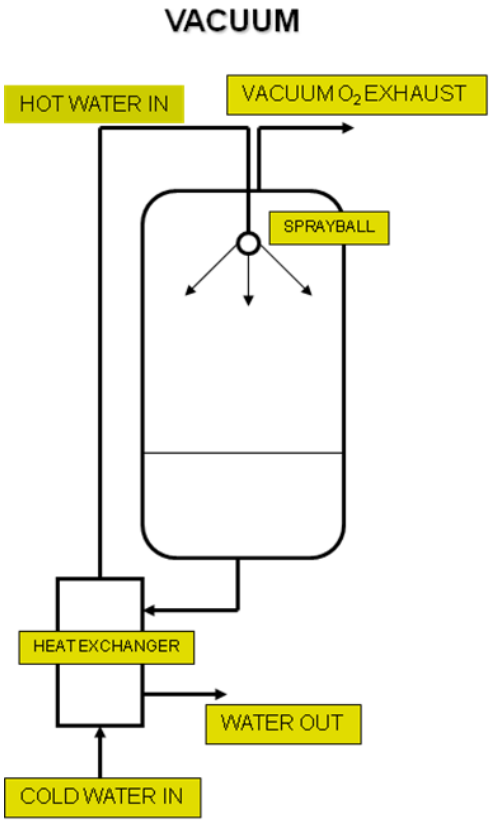
- A filtration system that ensures that the water passing through the Ultra Violet light steriliser is clear enough for the UV to pass through kill any remaining micro-organisms.
- A de-aeration system that works by spraying the water through an atmosphere of inert gas (carbon dioxide or nitrogen) where the oxygen in the water is stripped by the inert gas.
- Sterilisation by U.V. light. (Chlorine sterilisation would taint the water).
- Temperature adjustment. (The water will eventually be added to beer at low temperature).

De-aerated water production methods

- Vacuum de-aeration.
- Gas stripping.
- Packed bed gas stripping.

Vacuum deaeration

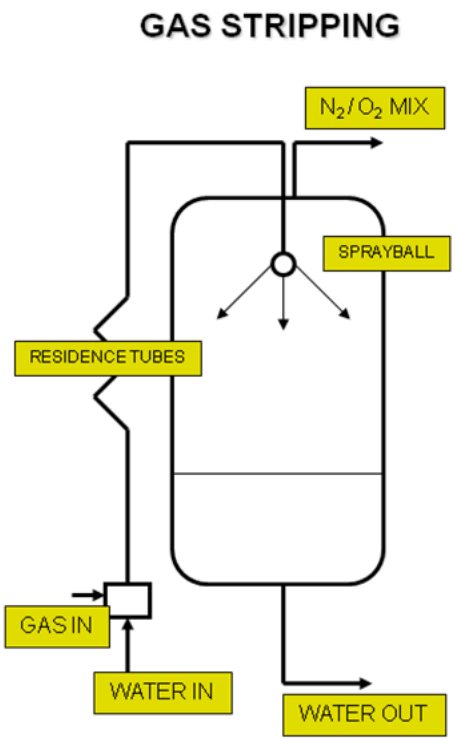
Water is sprayed into a chamber that has a partial vacuum - produced by a vacuum pump. Because of the low pressure in the vessel the oxygen in the droplets of water 'flashes off'. Vacuum deaeration can use either a hot or cold process. The hot system heats water to circa 77°C prior to flashing off. The dissolved oxygen flashes off faster than with a cold system, but the water must be cooled afterwards. Because the process acts to pasteurise the water no further sterilisation is likely to be needed. The cold system flashes water at a temperature of 3-4°C through the vacuum deaerator.



Gas stripping
Deaeration by purging water with an inert gas such as carbon dioxide or nitrogen may use a batch process, a tank at a time, or a continuous process using a gas stripping column.

Nitrogen or carbon dioxide is injected into water using a sinter. The water then passes through a series of holding tubes to ensure it is fully dissolved, before being sprayed into a stripping vessel. The level of inert gas in the water is so high that on entering the stripping vessel / column, the gas comes out of solution, causing the stripping of oxygen along with the injected gas. The mixture of gas and oxygen is vented through the top of the vessel by a pressure relief valve. The deaerated water is pumped away from the bottom of the vessel.

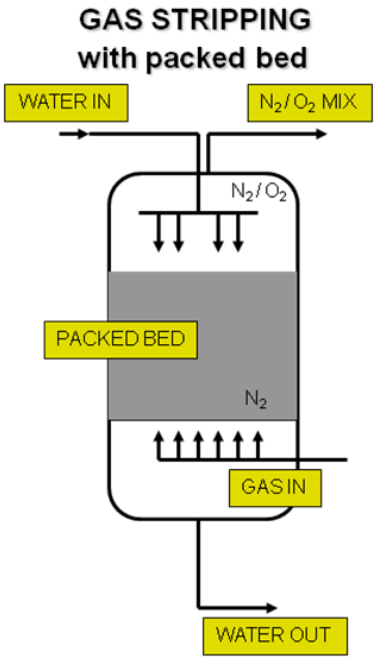
The gas used is chosen depending upon the gas targets of the final beer. Nitrogen is often used because it is cheaper to obtain from the air than to purchase the additional CO_2 required. If low CO_2 beers are required nitrogen will invariably be used as otherwise some of the CO_2 used for gas washing will dissolve in the water until the water is CO_2 saturated. This level of CO_2 may cause the CO_2 of the diluted beer to be out of specification (high). By using nitrogen, this problem is overcome. Increasingly, a small quantity of dissolved nitrogen is seen as a useful means of improving the head formed when a beer is dispensed.



Packed bed stripping
Water is again fed into a stripping vessel. The vessel contains packing material often in the form of metal rings. This packing gives an increased surface area for oxygen stripping to occur.

Gas (nitrogen or carbon dioxide) is injected at the bottom of the column and as it passes the water falling downwards gas exchange occurs. Oxygen in the water is stripped out by the gas used. To make the process more efficient additional gas can be injected into the water before it is sprayed into the stripping vessel.

As with sprayed water gas stripping (see previous point) the gas used is selected on the grounds of cost and or the gas targets of the final beer.



Dilution control

Batch dilution
The volume of water required is calculated and is added to the BBT either before or after a measured quantity of beer. This requires very effective mixing in the tank and often results in layering, i.e. the diluted beer may have different ABVs etc. at different levels in the tank – this can be avoided by a high enough flow rate of beer into the tank. However, this is the simplest method, requiring no automation other than an accurate liquid metering method (and lab analysis) and can be used successfully for small batches.

Flow ratio control
In this method the required dilution rate is calculated based on the OG and alcohol in the high gravity beer. This is then entered into a control system that measures beer flow rate and controls water flow rate to give the required dilution.

Where installed immediately after a filter which produces large interfaces, such as a plate and frame filter, the system can be designed to take the volume of the filter into account so that water in the filter can be pushed to BBT by the beer.

Diluted beer can be analysed off line and the dilution altered manually. Increasingly, the diluted beer is

monitored by in line instrumentation, and the result is used to feedback to the blending system, which adjusts the calculated dosing rate to improve the accuracy of measured value.

Standardisation/blending procedures and calculations

Dilution calculation

500 hl of high gravity brewed beer at 7.5% alcohol by volume (%ABV) can be diluted with:

250 hl of water to produce 750 hl of beer at 5.0% ABV,

Or

$$\frac{\text{Original volume} \times \text{Original \%ABV}}{\text{New Volume}} = \text{New \%ABV}$$

Blending beers calculation

Blending beer to meet quality requirements may be required. For example, a high colour beer may be blended with a low coloured beer to achieve a beer of a desired colour.

The calculation below illustrates the effect of blending 100 hectolitres of beer at a colour of 10 units with 50 hectolitres of beer at a colour of 8 units:-

$$\frac{(100 \times 10) + (50 \times 8)}{(100 + 50)}$$

Therefore the colour of the mixture = 9.3 units.

The same blending principles can be applied to bitterness, alcohol content, dissolved gas content and specific gravity.

The resultant pH of blended beers of similar types (e.g. two batches of the same brand, but with differing pHs) is generally in proportion to the volumes and tends not to vary much with the alcohol content of each beer.

Note that if blending two or more beers of different alcohol content, and then diluting with water to produce sales gravity beer, then the bitterness, specific gravity, dissolve gas (oxygen / CO2) of each beer need to be converted to a standard value, (normally taken as the post dilution value) to be able to calculate the final values of the blended and diluted product.

The following points need to be considered when attempting to blend beers in tanks:-

The beer transfer and tank inlet systems may have been designed such that good mixing in the tank simply relying on the infeed flow rate is unlikely, due to intentional low inlet flow rates, and therefore mixing the beers thoroughly without for example gas rousing (not good practice) or mixers (hygienic design problems) will be difficult.

Every time beer is moved from one tank to another, there is the risk of the beer picking up oxygen or other contamination such as micro-organisms.

Notes:-
Calculate the alcohol content of a beer that results from mixing 120 hectolitres of beer at 4% alcohol with 90 hectolitres of beer with 5% alcohol.

9.4 Considerations for Other Package Types

Filtration and chilling to produce 'bright' or 'filtered beer' is the most widely used production method to prepare beer for packaging, either into bottle, can, or keg. Storage in Bright Beer Tank (BBT) or Filtered Beer Tank (FBT) prior to packaging marks the end of the brewing process in this General Certificate in Brewing, and from here the packaging process takes over.

Beer can also be packaged un-filtered as either pasteurised or un-pasteurised (live) product, and this is very common in some beer markets around the world.

Cask Conditioned Beer
Traditional cask conditioned beer is still most commonly found in the United Kingdom, but with increasing interest in this style of beer dispense around the world. It is defined as beer that:-

- Is not filtered.
- Is not pasteurised.
- Contains live yeast.
- Contains residual fermentable sugar.

It is beer that is 'racked' into casks with the minimum of treatment or clarification. The beer conditions and matures in cask and is clarified by the addition of 'finings' to produce a bright product.

The beer is then sold without, or with minimal top pressure of CO2, using specialised pumps, or directly from a tap fitted to the cask.

Purposes of cask conditioning:-

The purpose of cask conditioning is to

- Allow the beer to clarify to produce visually "bright" product (though rarely if ever as "bright" as filtered beer), which is acceptable to the customer.
- If the beer has been dry hopped, extract oils from aroma hops to give a specific characteristic aroma to the beer.
- Increase the CO_2 content as a result of the slow fermentation of the residual sugars, increasing the "drinkability".
- Change flavour, such as diacetyl removal, mainly as a result of yeast metabolic activity.

Candidates should follow, and will be examined on, either section 9A or 9B.

SECTION 9B – CASK AND CRAFT BEER PREPARATION AND PACKAGING

9.1 Cask beer preparation for racking

Introduction

Traditional cask conditioned beer is still most commonly found in the United Kingdo, but with increasing interest in this style of beer dispense around the world. It is defined as beer that:-

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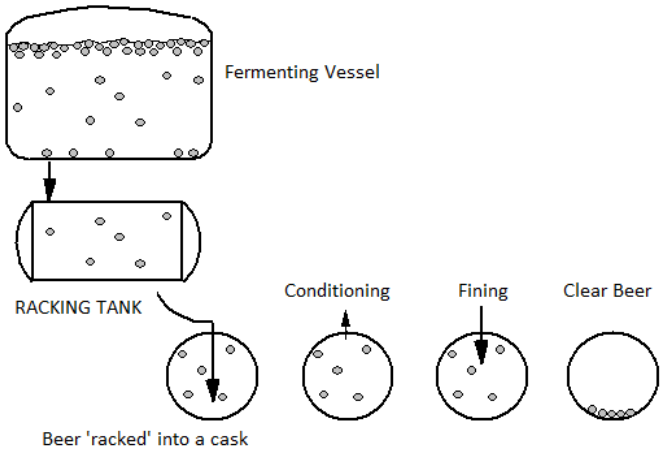
- change flavour, such as diacetyl removal, mainly as a result of yeast metabolic activity.

Yeast count control:



Beer from the fermenter is run either directly into cask (typically microbreweries) or, more usually in larger breweries, by way of a racking tank.

The brewer will tend to hold it in the fermenter until yeast removal by skimming and /or sedimentation has reduced values to a range suitable for cask racking. Additional storage time in the racking tank may help in this respect by allowing further sedimentation.

It is essential that the correct amount of yeast is carried forward into the cask. Too much and the beer will be difficult to clarify on addition of finings, and may lead to off flavours due to autolysis of the yeast. Beer losses due to excess sediment may also become an issue in extreme cases. Too little may also result in the beer remaining slightly cloudy, because the finings are not effective at removing proteins alone. Removal of suspended protein requires a certain amount of yeast to be fully effective. The lack of yeast may also result in insufficient condition (CO_2) being developed. A yeast count of not greater than 2 million cells per ml is usually adopted, although different brewers will use different target yeast counts, but usually not less than 0.5 million cells per ml. Should the yeast count be too low, additional yeast can (and should) be added to the beer before it reaches the cask.

Yeast concentration can be controlled by:-

- Yeast strain selection (top cropping yeasts, which work well with finings are usually used).
- Fermentation management, for example, allowing sufficient time for the yeast to settle out when cooling the beer after completion of fermentation.
- Centrifuging the yeast out of beer ex fermenter, and adding back a controlled amount of yeast. The yeast added back is rarely the yeast removed by action of the centrifuge as this yeast will contain a large number of atypical yeast and proteins. Freshly cropped, highly viable yeast is used instead.

Residual sugars for conditioning

It is important that there is some fermentable sugar left in the beer at the end of fermentation. Secondary fermentation is desirable to augment the low level of dissolved carbon dioxide in the beer flowing from the fermenters. As occurs in maturation tanks for beers destined for filtration, the evolution of CO_2 during conditioning also helps to wash out small amounts of off flavours.

Beer from tall enclosed cylindro-conical fermenters tends to have a residual CO2 content which is too high for cask beer. It is therefore usual to use fermenters which are comparatively shallow specifically for producing cask beer.

However, too much sugar and the beer will over-condition causing excess pressure in the cask and fobbing. Too little and conditioning will not be effective. 2 degrees of fermentable sugar (0.5 °Plato) is generally considered about right.

Secondary fermentation leads to the production of ethanol as well as carbon dioxide and heat energy.

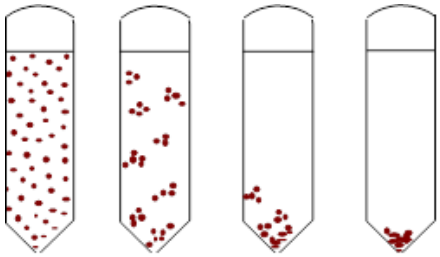
Fermentability is controlled by:-

- Fermentation management, for example, cooling before the fermentation is complete, though this can be difficult to control without accurate measurement of specific gravity to determine the required cooling start point, and good (rapid) cooling systems, or
- Adding a controlled quantity of fermentable sugar, known as primings just prior to filling the casks.

9.2 Cask beer clarification

Particles, for example yeast and insoluble protein particles, will sediment out as long as they are heavier than the beer. The rate of clarification depends on the size of the particles, how dense the particles are and how far they have to fall.

If clarifying agents, for example isinglass finings or auxiliary finings are added, they help the particles clump together to form larger diameter particles, and thus sediment quicker.



Brewers may have to use two different kinds of finings – auxiliary and isinglass. They may be added, either in racking tank or directly into cask at racking or a few days later, but allowing time to settle prior to dispense.

Factors affecting Beer Fining

The fining of a beer and the propensity of a beer to form hazes is dependent upon many factors.

1. Water composition
   - Sufficient calcium to precipitate phosphates, proteins and oxalates.
   - Control of mash pH to consistently achieve best practice levels.
   - Absence of heavy metals, colloidal silica, etc.
2. Malt quality
   - Low ß-glucan levels are required. High levels of ß-glucan lead to high wort and beer viscosities, slowing fining action (apart from the risk of hazes).
3. Mash pH
   - Controlled in part by liquor composition.
   - Lower pH values optimise proteolysis.
4. Gravity of last runnings
   - Excess sparging will leach undesirables from the mash, leading to increase in haze forming potential and fining difficulties. This is exacerbated by high pH values, when extraction of tannins and silicates is increased.
5. Length and vigour of the boil
   - Adequate boiling promotes protein precipitation.
   - The effectiveness of any copper finings regime is fundamental to final beer clarity and fining ability, and is dependent upon the wort pH.
6. Break removal
   - Excess break (nitrogenous compounds) allowed through to the FV can coat the yeast, leading to poor fermentations, reduction in the final beer stability and finings difficulties.
7. The yeast strain/s used
   Yeasts may be very flocculent or powdery, or anywhere between the two extremes. Some breweries use yeast which is a mixture of strains, a flocculent yeast which rapidly settles out to improve fining performance, and a powdery yeast which remains in suspension to provide those last few degrees of attenuation and conditioning. Other factors include:-
   - The yeast count at rack.
   - Whether top or bottom fermenting yeasts.
   - The continued presence of adequate calcium to promote flocculation.
8. Conditioning
   - The type of and design of vessel used for the settlement after fining - FV, cold conditioning tank, cask.
   - Time and temperature - the colder the conditioning temperature the more likely the removal of potential chill haze forming proteins.
   - The attenuation limit of the beer - how much fermentable sugar remains when the yeast is cropped and the cooling started. 2°SG (0.5 °P) is about right for a cask conditioned ale. Above this the secondary fermentation process will be too vigorous, producing excess carbon dioxide and causing turbulence that reduces fining performance.
   - Beer pH and viscosity.
9. Quality of the finings used
   There are a number of different types of auxiliary finings available, and not all isinglass finings are the same. One particular type may work better on a beer than another.

Auxiliary finings

There are a number of different types of auxiliary finings. The most common is based on acidified silicates. Polysaccharides (gums such as acacia, gum arabic) and seaweed extracts - finings based on carrageenan or alginates (carbohydrates from seaweed) and blends of part silicate/part polysaccharide finings are also available.

All of these systems are colloidal solutions. They carry a high negative charge and react with positively charged proteins, including collagen and other positively charged materials to clump together to form flocs which can then sediment. Auxiliary finings normally enhance the activity of the isinglass finings. The treated beer is less liable to form a

haze, thus improving saleability and shelf life. They are usually used in combination with isinglass finings, but must be added and mixed with the beer before the isinglass finings, never at the same time.

The best type of auxiliary finings used will vary dependent upon the individual beer. The spectrum of proteins present will usually react positively to a number of different finings agents, but just occasionally one finds a beer that will respond to only one particular type.

The advantages gained by using an auxiliary fining agent include:-

- Reduced use of isinglass finings.
- Brighter finished beer.
- Increased speed of fining.
- Increased speed of re-settling.

Silicated finings also give:-

- stabilisation against non-biological haze formation
- a degree of protection against chill hazes

Isinglass finings

Isinglass finings are made from the swim bladder of specific types of tropical and subtropical estuarine fish. This contains high levels of a protein called collagen which makes the yeast cells clump together by an electrostatic effect.

As the active component of isinglass, the collagen must be in solution and must be microbiologically stable. It is prepared by cleaning and drying the swim bladders, then shredding and soaking them in dilute acid (either sulphurous or tartaric to which metabisulphite (SO_2) is added). This yields a viscous, translucent material, which is diluted to 0.5 to 1.0 % (w/v) for use. Additions to beer at approximately 1.0 g/hl are usually required.

The collagen fibres in the isinglass are teased apart by the dilute acids used to make finings. There are three strands of collagen in each coil, which gently unwind in dilute acid, and produce a lattice like structure. The turbid cloudy solution consists of soluble collagen (active component) and gelatine (denatured product).

The temperature of solution is critical, and solubilisation should take place below 10°C. Collagen is a protein and will denature above 25°C, so preparation and storage is also best below 10°C.

Finings solutions also usually contain sodium metabisulphite which restricts the growth of bacterial contaminants, notably lactic acid bacteria.

Generally speaking top fermenting brewing yeasts (includes most ale yeasts) have a negative electrical charge. As with magnetism, opposites attract, and the negatively charged yeast cells are attracted to the positively charged collagen molecules in the finings. A number of yeast cells are attracted to each collagen molecule because of the enormous difference in size and charge, become physically enmeshed within the long molecules which form a net, and the positive charge of the collagen ensures the cells are entrapped. Collagen also produces flocs with certain negatively charged proteins, though most of the proteins are trapped by the mesh of yeast and collagen. The flocs are large, and fairly compact, and settle comparatively rapidly, so clarifying the beer. The greater the density of the floc (known as “more compact”), the more rapid the settlement.

Beers vary greatly in their reaction with collagen. The flocculence of the yeast strain, the protein / polyphenol concentration, pH, calcium and magnesium content can all have an influence.

Another feature of isinglass finings molecules is that they are sufficiently long for some negative groupings also to be present, so that reactions may occur with limited amounts of positively charged material, including fatty compounds (so improving head formation).

Finings storage

To reduce transport and storage costs, finings are often delivered in “triple strength” or paste form. They should be stored in a cooled room (ideally < 10^{o}C), but not at freezing, until ready to be used, when they are normally diluted with potable water, to “ready for use” (RFU) strength. This is for ease of measurement and where bulk finings are used, to reduce the viscosity and make pumping easier.
Sufficient RFU isinglass for about one week’s use can be made up at a time. This can be prepared a day before the first intended use in order to allow time for any air introduced to the finings to dissipate / be absorbed by the metabisulphite.

In spite of the use of metabisulphite, it is essential that all equipment associated with finings transfers and storage is maintained to the same microbiological standards as say fermenting vessels and associated mains.

Finings have a limited shelf life and stocks must be controlled to ensure they do not go out of date.

Finings addition rates

There are three principle objectives of beer fining:-

- Bright beer.
- Rapid speed of fining.
- Tight and minimal cask bottoms.

Dosing rates for both auxillary and isinglass finings should be regularly checked, and optimised for every brand of beer. When attempting to optimise the addition rate of auxiliary finings it is important to include a range of isinglass rates as well to give a matrix of results. The brewer can then decide on the optimum clarity compared to speed of fining, and volume of sediment, according to requirements.
For example, comparative clarities would be obtained using the following addition rates, in pints per UK barrel, though the ranges of both products may be extended if none of these results give satisfactory results.

Auxillary finings addition rates			
Pints / barrel	mls / 9 gallon cask	mls / pint sample	mls / 500 ml sample
0.5	71	1	0.90
1.0	142	2	1.75
1.5	213	3	2.65
2.0	285	4	3.50

Isinglass finings addition rates			
Pints / barrel	mls / 9 gallon cask	mls / pint sample	mls / 500 ml sample
2.0	285	4	3.50
2.5	355	5	4.40
3.0	426	6	5.30
3.5	497	7	6.20
4.0	568	8	7.00

Note: rates quoted are for a UK barrel equivalent to 36 gallons (gallon = 8 pints, pint = 568 ml) or 164 litres.

The optimum rate of use of isinglass is determined by a relatively simple method. This involves the addition of various quantities of standardized isinglass liquid to beer in the appropriate state and assessing haze and sediments after twenty four hours. The optimum rate is that which gives clear beer together with low levels of **compact sediment**.

Typical evidence that the addition rates are not optimised include the following:-

Under dosed auxiliary	Over dosed auxiliary
slow beer fining	bulky, loose cask sediments
slow re-settlement	unstable sediments - cloudy beer
poor beer clarity	

Under dosed isinglass	Over dosed isinglass
slow beer fining	bulky sediments
slow re-settlement	
poor beer clarity	

Typical addition rates in commercial use are

- Auxiliary finings 1 pint / barrel
- Isinglass finings 2 pint / barrel

Note that finings will **not** remove effectively:-

- Colloidal hazes caused by metallic contamination.
- Bacterial contaminations.
- Dead yeast cells.
- Wild yeasts.
- Beers with particle loadings much higher or much lower than the optimum range.

Finings additions systems

The simplest method, commonly used in micro-breweries is for auxiliary finings to be added to the FV and mixed in after the yeast has been removed (skimming / settlement & removal) and the beer cooled to racking temperature, and for the isinglass finings to be measured out and added to each cask immediately prior to filling.

Larger scale breweries may add auxiliary finings on transfer to the racking tank, or to the beer stream or on transfer from racking tank to the cask racker. If added to the beer after the racking tank, sufficient time must be allowed for the auxillary finings to mix in and react before adding the isinglass finings.

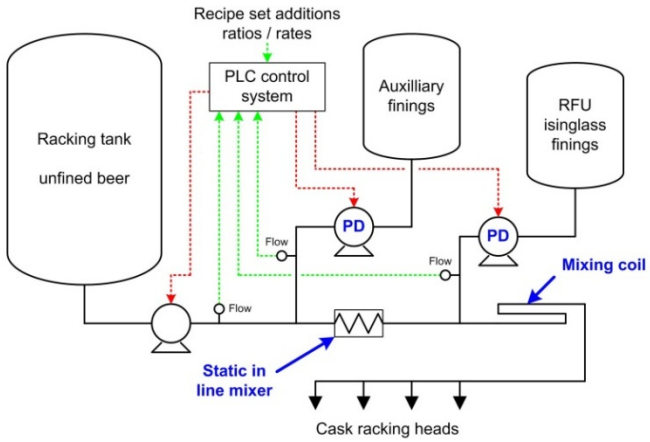
Both auxilliary and isinglass finings should be dosed in proportionally during beer transfer. Dosing all the finings into a small portion, and adding the rest of the beer on top will result in portions of over-fined and under-fined beer. The high viscosity of the finings affects the design and selection of equipment for automated finings dosing. Positive displacement pumps are generally used for finings dosing.

To ensure good mixing without excessive turbulence which would result in small floc formation and thus poor fining action, addition should be made at a point of fairly high turbulence such as a sharp 90 degree bend, before a static mixer, or before a chiller (which acts as a highly effective mixer).

The finings may be dosed into the common beer supply from the racking tank to the racker, or into the flow to individual heads.

Dosing is controlled by measuring the beer flow using in line meters and dosing proportional to the beer flow. It is therefore simpler, requiring less equipment, to dose into the main beer flow to the racker than into the flows to the individual racking heads.

The following diagram shows the setup of a larger cask racking operation, where both auxiliary and isinglass finings are dosed into the beer on transfer from the racking tank to the cask racker filling heads.



The racking tank contains settled, but un-fined beer. The beer delivery pump is a centrifugal pump controlled to develop a constant pressure (pressure feedback system not

shown). The beer passes through a flowmeter, which feeds back to the PLC system, which then controls the flow of auxiliary finings dosed in using a variable speed positive displacement pump. This is mixed in using a static mixer, or perhaps simply sufficient main to give approx. 30 seconds contact time. RFU finings are then dosed in based on the beer flow rate using a variable speed positive displacement pump. One or more sharp bends are then installed between the injection point and the racker filling heads to ensure thorough dispersion, without excessive turbulence.

PRIMINGS AND HOP ADDITIONS TO CASK

Primings sugar

Primings - sugar added to either promote secondary fermentation (conditioning) or to make the beer sweeter, invariably added as syrup.

Instead of stopping primary fermentation in the FV (by crash cooling) in order to ensure sufficient fermentable extract, the brewer may add thin syrup (e.g. SG 1180) to the beer either in fermenter, racking tank, or directly to the cask. The syrup may be sucrose, inverted sucrose, or a mixture of cereal starch hydrolysate plus inverted sucrose. The degree of fermentability of the sugar is determined by the amount of secondary fermentation (conditioning) required. Some colouring matter in the form of caramel, naturally coloured sugar (e.g. molasses) or extracts of coloured malts may be present in this "priming sugar".

Additions vary in the range 0.35 - 1.75 litre/hl (0.35 – 1.75% v/v, assuming an SG of 1.080), with sweet milds and stouts receiving the greatest sugar additions.

Colour may be added, in the form of caramel or coloured malt extracts, to adjust the beer's colour.

Hop additions

Dry hops, aromatic hop pellets or hop oil are added to give the beer a hoppy character and aroma. These add extra bouquet to the beer derived from the hydrocarbon and oxygenated fractions of the essential oil. No discernible increase in bitterness occurs.

In some breweries pre-isomerized hop extracts may be added to a beer on transfer to the cask racking tank, or even, very occasionally, en route to the racker itself. This is either to correct a low bitterness, or more commonly, to create a distinctively bitter variation of another brand.

Types of hops & hop products used

Dry Hops

The characteristic "hoppy" aroma in cask-conditioned beer is achieved traditionally by adding compressed leaf hops directly into the casks immediately before filling.

These compressed hops are referred to as "hop plugs", "whole hop" pellets or "Type 100" pellets. They are produced by breaking up baled hops and compressing weighed amounts into a single very large pellet or plug.

The hop plugs are either ½ ounce (oz.) or 1 oz (14.2 and 28.3 grams, respectively) and are vacuum-packed in laminated bags and inert gas flushed, in order to reduce the loss of essential oils.

It is usual then to add one or more pellets or plugs to each container at filling, depending on the desired hop character.

Oil-rich Extracts

Produced by liquid CO_2 extraction of whole hops or pellets, the enriched oil extracts can be added to unfiltered beer to enhance hop character and substitute for dry-hopping (leaving no hop residue in the casks, which has to be removed at the start of cask washing prior to refilling).
In order to achieve rapid dispersion of hop oil in beer, the extract is usually dissolved in alcohol prior to addition to the beer. It can be added either on transfer to maturation tank, to racking tank or in-line on transfer to the cask racker.

Hop oils can be further fractionated into separate, highly flavour-active elements, which are described as "spicy", "estery", "herbal", "floral" or "citrussy". These products are normally available as 1% solutions in ethanol and be used separately or in various combinations to produce a wide and varied range of hop-related aromas.

9.3 Cask washing and racking

Cask preparation & inspection

Before the cask can be washed and sterilized, it is necessary to remove the old shive and bung. The external washer does not guarantee that all labels will be removed, and it is common for personnel to remove labels prior to the washer, when removing the old shives and bungs, though sometimes this may take place when carrying out the internal inspection after cleaning.

The cask is generally inspected manually for:-

- Damage, which might for instance cause the cask to leak when refilled.
- Excessive weight of beer or other fluids in the cask. The overfilled casks should be taken to one side and emptied and carefully inspected before being returned if OK, to the packaging line.
- Own brewery markings, or recognised breweries where for instance a marketing agreement has been made.

Cask Washer:

Purpose: To clean both the inside and outside of the cask and to present a 'commercially' sterile empty package to the filler.

Features: The casks are transferred to the cask washer where they are cleaned externally, normally by rotating over brushes, but occasionally by using high pressure water jets. They are then transferred to the internal washer on a moving beam or chain and positioned onto stations where they are cleaned with internal jets, normally hot and containing detergents.

The final station is for steam sterilisation.

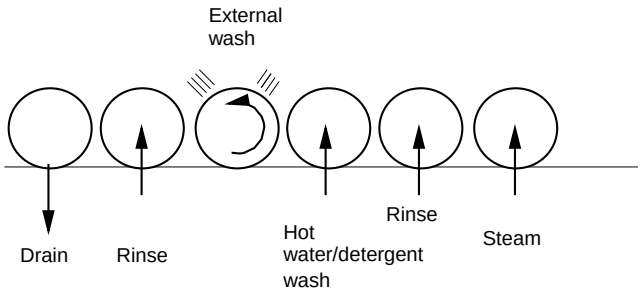
Notes: The incoming casks will contain debris and possibly dry hops. The drainings and in particular the hop debris may be collected to prevent high effluent costs.

Detergents must never be used on wooden casks as the detergent will soak into the wood and taint the beer. Hot water and steam only must be used.

Wooden casks are very difficult to sterilise, even with a long steaming time.

After cleaning, the casks should be internally inspected to ensure there is no residual debris such as bungs, shives, hops or insects stuck to the internal walls, which are commonly found, particularly towards the end of summer, or that the casks are heavily scaled up and liable to be harbouring microbiological contaminants.

Cask Washing Machine

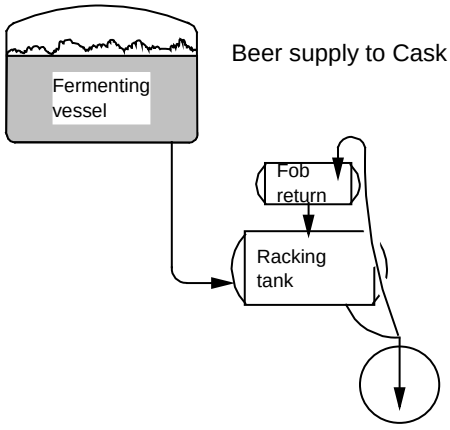


Cask racking installations & practices

Beer for cask racking can be supplied directly from the fermenting vessel or from a separate racking tank. In the illustration below, beer is run from the FV into a racking tank and fob from the filling operation is returned to a fob tank. The settled fob is then run back into the racking tank.

The temperature of the beer when racked will vary from brewery to brewery, some filling as cold as 2°C, though more typical temperatures in small breweries are around 7 – 9° C. However, the temperature should always be low enough to have encouraged sufficient yeast and protein to have settled in the FV and racking tank, and so not overload the finings, and to be below dispense cellar temperature. Fining action and final beer clarity is better if the temperature rises slightly after finings addition.

Beer supply to Cask Racking



Cask racking (filling) machine

Purpose: To transfer beer into the cask to achieve the following parameters:-

- Filling with the specified volume of beer.
- Protecting the quality of the beer by minimising air pickup and avoiding fobbing.

Features: Racking machines consist of filling heads with down tubes to fit the size of cask.

The cask is counter pressured or simply purged with CO2 before the beer valve opens.
The beer may be metered into casks. Normally filling is stopped only when the cask is full to reduce air pickup, though it has to be accepted this is likely to result in filling with more than the nominal volume.

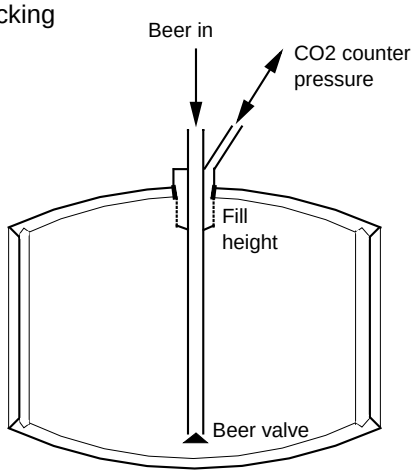
Excess beer is returned to a fob return tank

Notes: A diagram of the cask racking system is shown below.

Minor air pickup during filling is not so detrimental to quality because yeast present in the beer scavenges oxygen during cask conditioning.

However, it is good practice to minimise oxygen pickup wherever possible to reduce off flavours and hazes resulting from high oxygen levels.

Cask Racking



Full cask inspection

Purpose: To check that the casks from the filler are filled with the correct volume of beer.

To ensure the cask is not leaking.

The cask is usually labelled at this point, with beer quality and other information required to allow tracking of the cask and the beer inside.

Features: Inspection is by eye as the shive is inserted immediately after filling.

In larger installations, the filled casks will be individually weighed as a check against gross short fill. Because of the small size of even larger cask operations, the individual casks are rarely tared prior to filling, but an assumed average empty cask weight is used.

Notes: The need for the cask racker to demonstrate due diligence in meeting the requirements of both the national taxation* and the regulatory authorities* means that inspection is essential. (* Will depend on country or region).

Inspection is backed up with accurate volume measurement for individual packages. In the case of casks this means filling into specially tared (pre-weighed or standardised) containers

Records of inspection are kept for the relevant authorities. Correct filling procedures should conform to the appropriate codes of practice.

Safety

There are numerous hazards associated with cask racking. Some are listed below along with the normal procedures used to reduce or eliminate them:-

Hazard	Safety procedure
Manual handling accidents	Plant designed for minimum manual handling. Staff trained in safe working procedures.
Noise	Plant designed to reduce metal casks colliding etc. Building designed to absorb noise. Use of ear protectors mandatory.
Slips trips and falls	Use of non slip materials for floors and steps etc. Regular cleaning of floors.
Machinery accidents	Permit to work procedures for maintenance. Guarding of machinery.
Heat and chemicals	Guarding of machinery. Staff training in safe working procedures. Personal protective clothing & appropriate handling equipment

Conditioning in cask

Storage temperature of cask beer

Conditioning in cask is affected by both the temperature of beer storage (ideal is 12 - 14°C) and the time that it is stored. Cask beer contains yeast and, therefore its flavour is liable to change during its shelf life far more than filtered beer.

Because cask beer is not filtered and /or pasteurised, the shelf life is significantly less than keg or small pack beer, being usually not more than 6 weeks. Once opened, cask beer should ideally be consumed within 3 days, if dispensed by a traditional beer engine and venting, when air is drawn into the cask as the beer is drawn out. However, as with all foodstuffs, stock control should ensure the minimum storage time at point of sale, with ideally no more than one week between receiving the cask and it being dispensed.

Before the addition of clarifying agents (finings) the beer's condition (CO_2 content) will continue to develop. The presence of yeast helps to protect the beer quality by scavenging oxygen.

After the addition of finings and when the beer has clarified, it is more vulnerable. It must be kept still so that the settled yeast is not disturbed and it must be sealed (closed) to prevent the access of air.

Disturbance of the flocs in the final cask will lead to the beer being turbid, but resettlement / re-clarification is usually possible up to five times (only once or twice in the cellar, because it is likely to have resettled a number of times during distribution) without fresh finings being added.

Use of soft and hard pegs

Conditioning in cask is affected by both the temperature of beer storage and the time that it is stored.

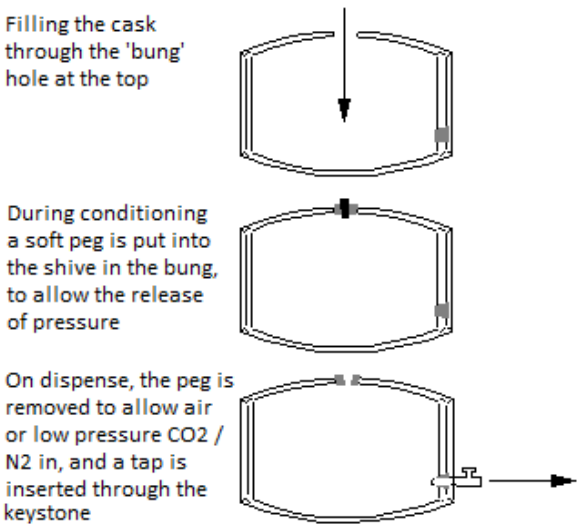
Immediately after delivery, when the cask has been set in the final position for dispense, the cask should be vented for 3 – 6 hours to vent off excess pressure, usually by replacing the hard insert in the "shive" (inserted at the end of fill), with a soft peg. This is the conditioning / settling period. The soft peg is cut from wood "with the grain" so that gas can vent through the vertical "pores".

Once the cask has "settled", i.e. is not generating more CO_2, the cask should be hard spiled to reseal the cask. This maintains the condition of the beer by preventing any gas loss (or ingress). In this case, the wooden peg is cut "across the grain" so that there are no pores or openings.

The soft spile should be replaced during periods of dispense, or if regular dispense occurs, the soft spile should be loosened to prevent a slight vacuum developing, and lifting of the sediment due to CO_2 bubble evolution.

At the end of each period of dispense, the cask should be resealed with a hard spile to maintain beer condition as much as possible.

Shives (bungs) are traditionally made from beech wood, but have been largely replaced by various synthetic plastics, principally for improved hygiene.



Shelf life

Dispense
The beer is dispensed through a beer pump, some of which can draw air into the drinking glass. The effect of this is to create a foaming head on the beer because of the presence of nitrogen although there is insufficient time for the beer to be oxidised.

During dispense, unless a CO2 or nitrogen top pressure blanket is applied, air is drawn into the cask to replace the beer. The effect of this is to oxidise the beer and make it go stale, but also to risk the introduction of potential spoilage organisms, such as lactic and acetic bacteria.

Consequently once cask beer has been put on sale, it has a very short shelf life, perhaps one or two days. As noted above, this problem can be reduced by keeping a low pressure of an inert gas (CO_2 or N_2) say 1 – 2 psi on the cask.

The cellar
Beer must be stored in a clean environment: it is a food and is perishable. The cellar is a food room and is subject to Food Hygiene Regulations and may be visited by the Environmental Health Officer (or equivalent).

In perhaps the majority of cases poor product is caused by 'in-house' problems. These can also be resolved 'in-house'. Common causes of poor quality beer include incorrect storage temperature, dirty dispense lines, poor quality glass washing and disturbing cask beer, for example when tilting as the cask empties.

Notes
Describe a cask beer operation in a brewery that you are familiar with.

How many times are the casks moved after fining before the beer is dispensed?

What effect does this have on the beer's quality?

9.4 Craft beer preparation for packaging

BEER CHILLING

The final stage of beer maturation, prior to packaging, is usually cold storage at less than 0°C and again, usually for several days. The most efficient way to chill beer to low temperatures is to use a heat exchanger, either on transfer from FV to MV, or if uni-tanking, by recirculating through a heat exchanger. Most breweries use plate type heat exchangers (PHE) using glycol or brine as the refrigerant, but some use shell and tube types, using ammonia, glycol or brine.

The beer is cooled to close to its freezing point (typically –1.0 to –2.0°C, depending on the alcohol content) in a heat exchanger, the temperature change coming from the use of secondary refrigerant, such as propylene glycol solution, as the coolant, at approximately -4°C.

In this way, passing beer through the heat exchanger will safely chill the beer to just above the freezing point of the beer.

Plate heat exchanger

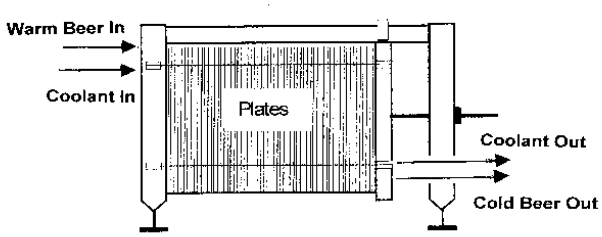


Plate Heat Exchanger (PHE) Design

The plate heat exchanger is by far the most widespread type of heat exchanger in the beverage industries. For brewery applications, a stainless steel frame is often preferred to the coated steel frames for reasons of hygiene, maintenance and appearance.

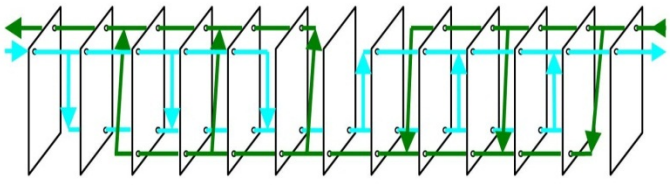
The PHE comprises a collection of plates assembled within a frame. The two process fluids flow in the spaces between the plates and are distributed along the length of the heat exchanger by means of circular passages cut into the corners of the plates. The flow channels between the plates and the distribution passages are sealed by a gasket fixed to the face of each plate. A seal is made between the gasket and the reverse face of the adjacent plate.

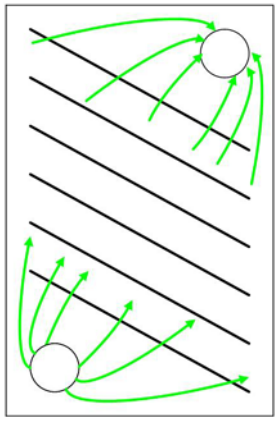
There is a high degree of turbulence in the fluids flowing in the narrow passages, created by the high velocities and the pattern embossed into the plates. Very good heat transfer and a degree of 'self-cleaning' are achieved under these conditions.

The flow patterns through a heat exchanger can be either counter-current or co-current. The normal PHE flow arrangement for a beer cooler is counter-current where the two fluids flow in the opposite directions.

A co-current heat exchanger is also suitable for chilling beer by only a few degrees, where there is a risk of freezing if the control is poor, but with the improvements in control systems, co-current chillers are rarely used nowadays. Only a counter current heat exchanger is therefore described.

Example of flows through a counter current PHE.



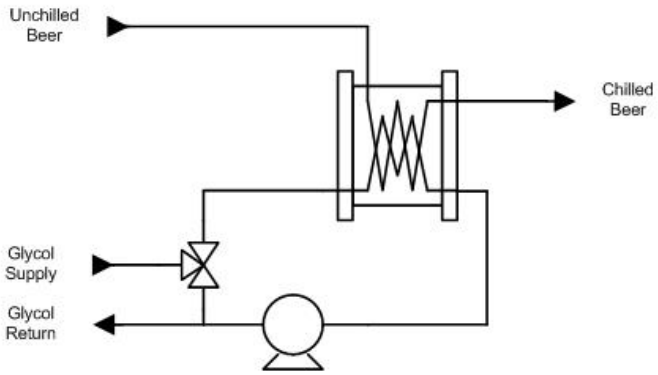


Good flow rate across plate surface

Cross section of plates and counter-current flow:-

Modern beer plate heat exchangers may use a recirculating loop of glycol (or other cooling medium) with small quantities of fresh glycol being fed into the system, displacing the equivalent volume of warmer glycol. The benefit of such a system is the reduction in temperature difference between the glycol and the beer, so reducing risk of freeze ups.

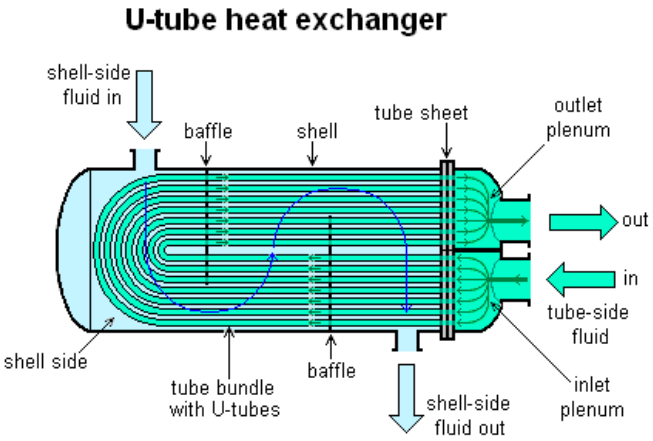
Co-current PHE with partially recirculated coolant for improved temperature control.



Shell and tube heat exchangers

Two fluids, with different supply temperatures (in this case beer and the coolant, typically glycol, brine or ammonia) flow through the heat exchanger. The beer flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from the beer to the coolant through the tube walls. In order to transfer heat efficiently, a large heat transfer area is used, leading to the use of many tubes.

There are a number of different configurations of shell & tube heat exchangers. The following is shown to give the basic principle of such a heat exchanger.



BEER FILTRATION

Consumers have come to expect visually clear beer, free of haze.

Beer that is intended to be clear (bright) is often assumed to be of better quality and there is much historical evidence to prove that this is often true. However, unfiltered, intentionally cloudy beer, including wheat beer, is still produced and enjoyed in many countries.

Matured beer will still have particles in suspension, mainly yeast but also smaller particles, mainly protein, unless it has been fined. There are three types of filtration:-

The purpose of **'rough' filtration** is to remove all the particles that would make the beer cloudy.

The purpose of **'polishing' filtration** is to remove all yeast and bacteria so that the beer is sterile.

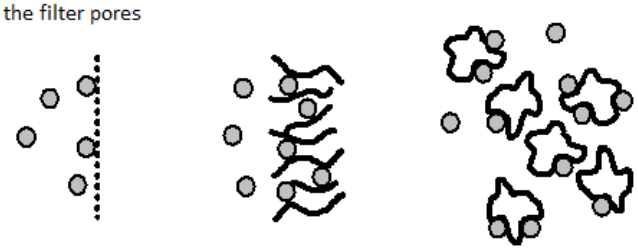
Traditionally, beer has been filtered using filter aids, predominantly kieselguhr (KG). More recently however, new filter aids that are capable of being regenerated have been developed. These reduce powder purchase costs, waste disposal and improve safety aspects, albeit at the additional cost of a regeneration process. However, the underlying physical principles by which beer is filtered remains the same as with KG.

Filtration uses one or more of the following three principles:-

Sieving where particles are held back because they are larger than the filter pores

Depth filtration, where the particles are trapped in complex pathways

Adsorption, where particles adhere to the pores of filter powder granules

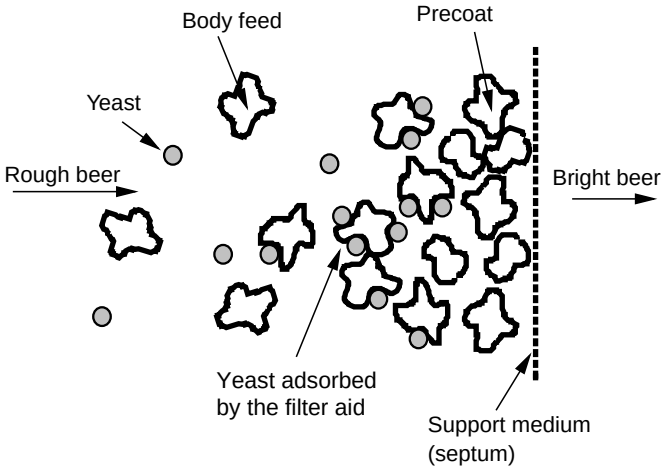


Kieselguhr (KG) and regenerative powder filtration.

Filtration using one or more filter "powders" uses the principles of absorption and depth, the technique as follows:-

A supporting medium (filter cloth or mesh) is **pre-coated** with filter aid. The precoat forms a depth filter, but is mainly required to bridge the gaps in the support medium (wire mesh, wedge wire, or cellulose fibre sheet) and prevent the support medium being blinded or allowing filter aid, yeast or proteins to pass through into the final filtered product.

After pre-coating is complete, beer is introduced into the filter. To prevent the filter bed blinding with yeast and protein, additional powder, known as **body feed** is dosed into the beer as it runs into the filter. The yeast and protein particles are adsorbed by the body feed filter powder, gradually building up a layer of powder, yeast and protein until the filter is filled. The filter does not 'blind' because the body feed continually creates a new filter bed.



Filter aids

Diatomaceous earth or **kieselguhr** is made from the skeletons of minute sea plants which have been kilned and milled to various grades of fineness. This is the most porous, rigid and effective filter aid. Kieselguhr can used for both precoat and body feed, depending on the grade (i.e. KG particle size). Kieselguhr is sometimes referred to by trademarked brand names such as Celite.

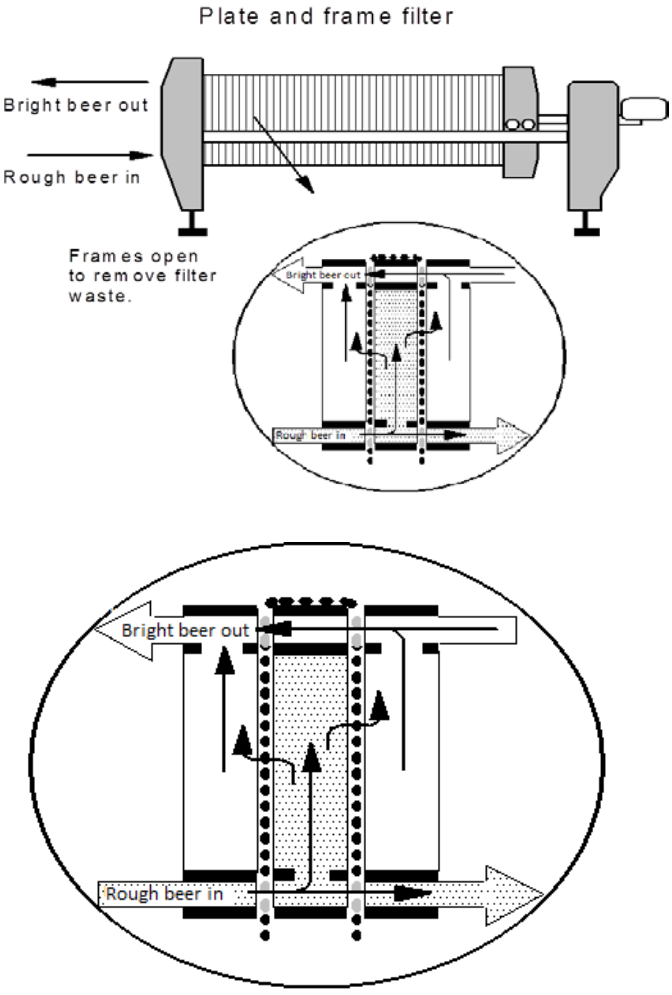
Perlite is made from volcanic minerals which are heated in a furnace to form minute glass bubbles. It has a less complex structure than kieselguhr and is less effective. Perlite is often used for pre coating. Some smaller breweries also use it for the bodyfeed.

Cellulose fibres, usually mixed with other materials such as kieselguhr, perlite starch or silica gel to give a product that is less harmful but still provides good filtration properties. Brands include Becofloc, Arbocel and Celtrox.

The handling of the unused KG requires considerable care, particularly the avoidance of, or provision of protection against inhalation. The disposal of KG waste filter aid is also becoming more of a problem for environmental and personal safety reasons. Handling systems include the supply of filter aids in big bags (e.g. 1,000 kg) instead of 20 – 25 kg bags, and ventilation systems to suck dust away from the operator. The air drawn through the plant carrying away the dust is filtered to remove the dust before discharging clean air to atmosphere.

Plate and frame filter

Filters are designed so that the rough beer is delivered onto the filter bed in as even a flow as possible. Both the particles being removed and the filter aid will eventually block up the filter by their sheer volume so filters are designed for easy emptying and cleaning.



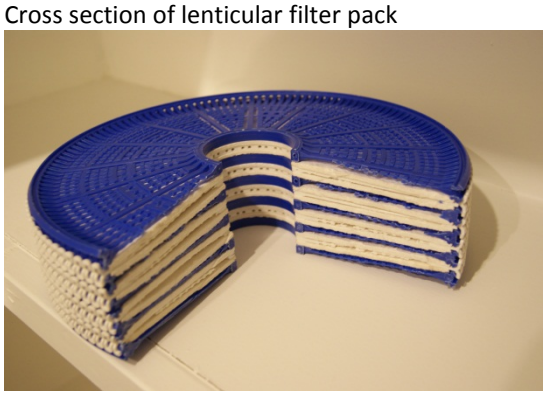
Lenticular filters

Lenticular filters are used by some larger breweries for polishing filtration or for removal of low particulate loads, such as yeast and proteins after beer recovery, and by numerous microbreweries as the main form of primary filtration. In all cases, these filters are used because of the convenience of lack of powder handling systems, simplicity of filtration operations, and ease of regeneration and the flexible sizes of the installations.

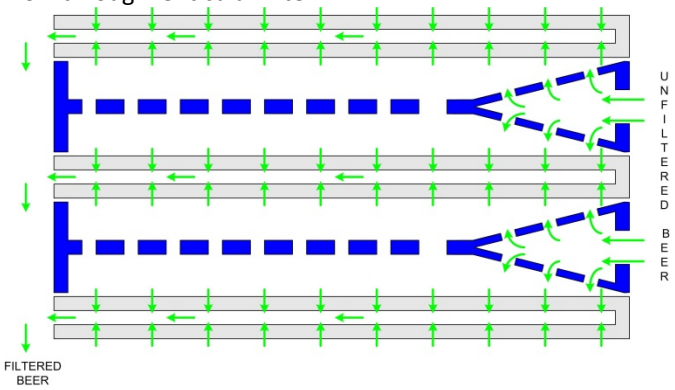
The filter sheets are of modular design, allowing for easy

fitting into the housings and use of spacer units in larger housings when filtering small volumes / low flows. The filter sheets are supported and separated by polypropylene support discs

Cross section of lenticular filter pack



Flow through lenticular filter



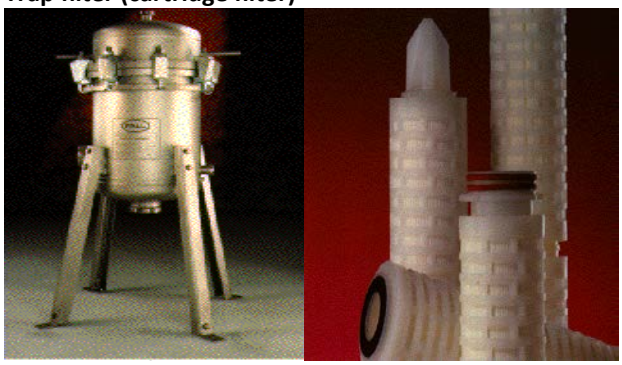
Lenticular filters are normally capable of being cleaned with detergent and capable of being hot forward flushed, and cold back-flushed to regenerate the filter medium.

Similar filters are obtainable in pre-packed filter form, the filtration medium consisting of a mixture of kieselguhr and cellulose fibre, instead of simply cellulose or polypropylene fibre. These are also capable of being regenerated a considerable number of times reducing the purchase or rental costs.

Polishing filtration

The polishing filter utilises the depth filter effect with a fine pore filter sheet or a fine filter powder to trap very small particles including micro-organisms. Where high flow rates are required, a plate filter may be used to house and support the filter sheets.

Trap filter (cartridge filter)



A cartridge filter consists of a chamber which is fitted with filter elements housed in nylon supports to form replaceable cartridges. These are designed to be cleaned and sterilised a number of times before replacement is required due to excessive blinding of the filter material. The cartridges are often back-flushed at high flow rates as part of the cleaning process.

Depending on the material the elements are made from, they may use mainly depth filtration, or surface filtration. They are ideal for sterilising purposes, both for liquids (water, beer, cider) and for gases (e.g. oxygen, aeration air, CO_2). The typical pore size used in breweries for "sterile" filtration is 0.45 micron. Note that this would not be considered suitable for the level of sterility required for pharmaceuticals for example, but is considered adequate for the type of contamination experienced in breweries.

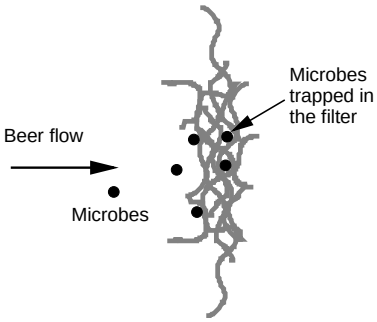
Sterile Filtration

Microbes are by definition very small, but they do have a finite size and they can be trapped or held back by a very fine filter. This is the principle of sterile filtration.

There are three types of filter that can be used to produce sterile beer:-

A **kieselguhr filter** with a very fine powder grade, although it is usual and recommended to follow this with a final polish or membrane filtration. The KG filter is never considered able to produce consistently sterile beer on its own.

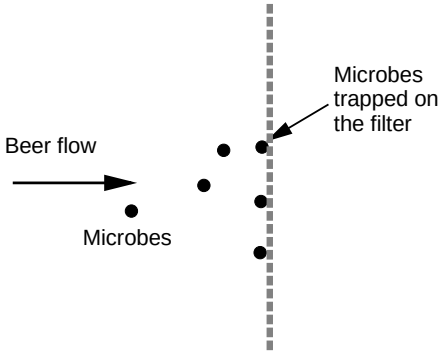
The **sheet filter** where the cellulose mesh of the sheet is very fine and tightly woven / packed. This type of filter traps the micro-organisms because the passages between the fibres of the sheet are so narrow. There is also an electrostatic effect whereby the microbes adhere to the fibres.



The sheets may be held in plate filters or cartridge filters.

The **membrane filter** works on a slightly different principle, namely that of a very fine sieve where the particles are held back on the surface of the membrane which has extremely small pores in it (usually 0.45 µm). Membranes may be as sheets or as fine tubes.

There are some benefits derived from the use of sterile filtration as opposed to pasteurisation.



There is a significantly reduced risk of developing those pasteurisation flavours ('papery', 'cardboard') that result from pasteurising beer, particularly if the beer contains high levels of dissolved oxygen or is treated with excessive numbers of pasteurisation units (PUs).

NB - Beers with high levels of dissolved oxygen at packaging will, over time, develop papery, cardboard and stale characteristics even if they are not pasteurised.

The very fine filter traps haze forming particles as well as microbes so that the beer is more stable.

9.5 Considerations for Other Package Types

Bottle Conditioned Beer

Bottle-conditioned beers may be either bottled unfiltered direct from the fermentation or conditioning tank, from cask, or even filtered and then re-seeded with yeast. The important differences to other bottled beers are that they are **unpasteurised** and contain **live yeast** cells so that the conditioning process can continue in bottle.

It is important when producing bottled conditioned beer that a consistent and reliable preparation procedure is followed prior to bottling, as variable product quality can be seen in the form of:-

- Variable %ABV due to over or under attenuatuation, or complete or incomplete conditioning in the bottle.
- Variable beer foam characteristics and carbonation levels.
- Variable amounts of yeast sediment at the base of the bottle, and clarity of the beer.
- Variable beer flavour, due to a combination of the above three effects.

This variation can result in a very different drinking experience for the consumer.

For this reason it is recommended that beer is fully attenuated and fined (or filtered) prior to packaging. This 'bright' beer, in a racking tank or cask, is then re-seeded with a known quantity of yeast and 'primed' with an additional amount of fermentable sugar to a packaging tank before being filled into bottle.

As well as improving consistency as described above, an additional advantage of this method is that a yeast strain more suitable for bottle conditioned beer may be chosen for re-seeding. The yeast for bottle conditioning is often chosen over the primary fermentation yeast strain due to it having the following properties:-

- More flocculent, resulting in a compact and stable sediment in the base of the bottle. If the yeast used for primary fermentation is too flocculent then yeast may not fully ferment and attenuate.
- Better equipped to ferment low levels of sugar.
- May give the 'base' beer a different flavour during the bottle conditioning.

The same 'base' beer can be re-seeded with different yeast strain, or different amounts / types of priming sugars, to give different bottle conditioned beer products. For example, using a Munich type yeast strain may give some wheat beer / cloves / good foam characteristics to a beer, whereas a Belle Saison yeast may give smokey / vanilla / fruity and sweet characteristics with poor foam characteristics.

Qualifications

The General Certificate in Brewing (GCB)

Learning Material © Institute of Brewing and Distilling 2016

Section 10 Beer Quality and Process Control

10.1 Process Specifications

The people who consume our beer expect and deserve a consistently high quality product.

The key factors in maintaining consistent quality are the establishment of, and the measurement for comparison to, a set of process and product **specifications**.

There are a number of measurements that are taken during the process and at the completion of the process which indicate whether the process is in control and whether the beer is of the right quality.

Examples of the most important of these measurements are given below.

The principle of controlling quality is based on setting specifications for each of these measurements, measuring the process and taking corrective action if the product or process is 'out of specification'.

Having said that, there are some factors to be taken into consideration:

- All measuring instruments have a degree of tolerance.
- The raw materials used in the brewing process are naturally grown and therefore cannot be expected to always behave in exactly the same way.
- Errors can be made in sampling, especially when a small sample is taken from a large batch.

Therefore it is usual to give specifications a 'range' to reflect the normal expected variation in values.

Methods for Recording, Reporting and the Interpretation of Data.

Sampling Schedules.

A sampling schedule is a plan specifying where, how and how frequently samples of the product in process and at the end of process are taken.

A routine sampling schedule is required so that:-

- Key measurements are taken without exception and the whole of the process is covered. It is too late if the first warning of a quality problem comes from the consumer.
- The quality picture can be seen from statistically presented data. A very useful quality control method is to look at historical trends. Using this method, current results are compared to those obtained in previous months/years. A sampling schedule makes sure that there is enough data to make these comparisons.
- The work of the people who are sampling and measuring can be organised effectively.

An example of a sampling schedule is detailed in the table below:-

Stage.	Frequency.	Notes.
Raw materials	Each delivery.	Frequency depends on supplier reliability and performance.
Brewhouse operations	Each batch/brew.	Corrective action can be taken swiftly.
Unfermented wort	Each batch/brew.	Corrective action can be taken swiftly.
Yeast	Each batch for use in pitching.	Only healthy contaminant free yeast is selected for pitching.
Fermenting beer	Each vessel/tank. Every 12 hours.	Process control to monitor the fermentation.
Fermented beer and beer ready for filtration	Each vessel/tank.	To monitor quality and to prepare for action in the event of problems.
Beer ready for packaging	Each vessel/tank.	To confirm conformance and therefore suitability for packaging and consumption.
Packaging materials	Each delivery.	Frequency depends on supplier reliability or 'just in time' agreement.
Beer in package	Each code.	To monitor packaging performance.
Plant	A specified number of tanks per week.	To monitor plant cleaning performance.
Cleaning materials	A specified number of samples per week.	To ensure that the plant is cleaned effectively.

Collation and presentation of data.

It is likely that there will be a large number of results from a sampling schedule like the one illustrated, especially in a large plant. The results must then be presented in a way that highlights the information as effectively as possible.

There are two main ways of presenting data so that problems are highlighted and action can be taken:-

- Defect highlighting.
- Control charts.

An illustration of how defects can be highlighted is given below:-

Sample number	Result for beer colour (Specification = 10 to 15)
1	13
2	13
3	12
4	13
5	15
6	13
7	14
8	16
9	14
10	14

It can be seen very quickly that sample number 8 is out of specification.

This type of presentation is useful, if for example, a simple decision is required as to whether the beer is passed as suitable for packaging.

It does not however, assist in analysing results so that some clue as to the cause of the problem can be discovered.

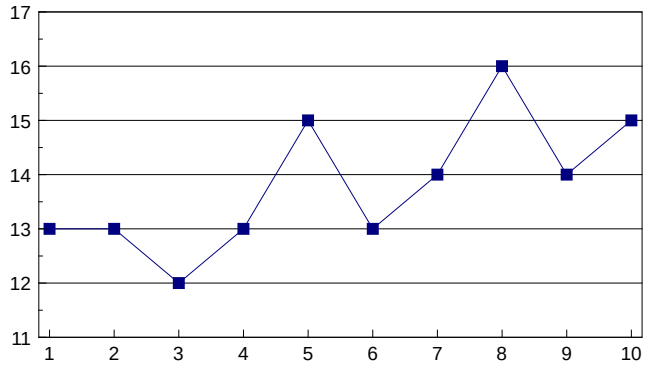
- It would be useful to know the average colour of these beers. If that was high, then an adjustment to the process upstream could be made.
- It would be useful to know the range or spread of colours of these beers. If the range is very wide, then the process may be out of control and action may be required to resolve the situation.

In order to resolve these problems, statistical analysis in the form of **control charts** is required. Pictures in the form of graphs have much more impact than simple tables.

Charts can be in different formats and can show:-

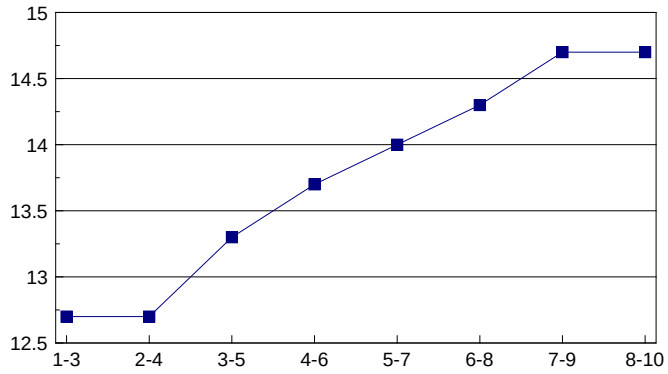
- Individual results plotted on a graph; the specifications can be drawn in.
- Average results or 'rolling' average results plotted on a graph.
- The range of results obtained.
- The cumulative effect of deviation from the target and the effect of any action taken.

This is a graph plotting the beer colours that were shown above as individual results:-



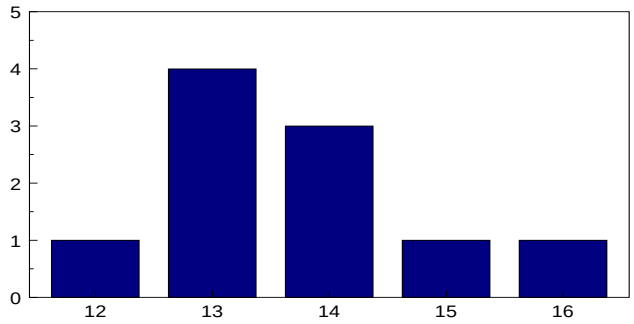
The defect sample 8 stands out from the others. Also it can be seen that there seems to be a trend of increasing colours.

The next graph was prepared by plotting a three point moving average of the same beer colour results. The first point is an average of colours 1, 2 & 3 the second point is an average of colours 2, 3 & 4 and so on.



This method of presenting data evens out the highs and lows and illustrates the rising trend very well. From this graph, it can be seen that the beer colours have been increasing steadily and that, unless something is done about it, they will continue to increase.

The next figure is a bar graph histogram that shows the numbers of samples that have the same beer colour results, that is how many beers have a colour of 12, how many have a colour of 13 etc.

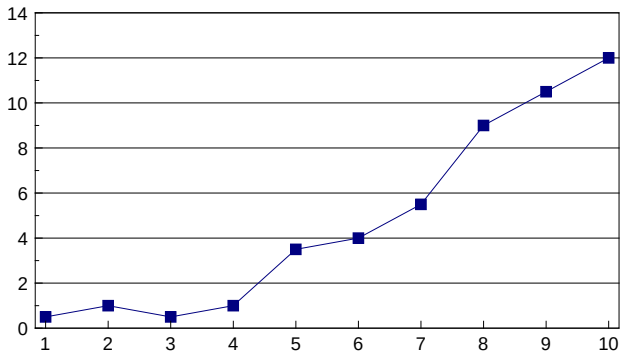


In this distribution curve, a wide distribution indicates a very wide range and a control problem, a narrow distribution indicates a narrow range with the process well under control.

The next graph below is called a 'cumulative sum' or 'cusum'. It is designed to exaggerate very graphically, how a trend is going and the effect of any action taken to correct a problem. It is plotted by taking as a starting point, the target value which would normally be the middle of the specification. (For our beer colours, the middle of the specification would be 12.5.)

The next step is to calculate the difference between the target value and the actual colour. Then the differences are added up cumulatively as follows.

Sample number	Result	difference from target of 12.5	Cumulative sum
1	13	+0.5	+0.5
2	13	+0.5	+1.0
3	12	-0.5	+0.5
4	13	+0.5	+1.0
5	15	+2.5	+3.5
6	13	+0.5	+4.0
7	14	+1.5	+5.5
8	16	+3.5	+9.0
9	14	+1.5	+10.5
10	14	+1.5	+12.0



The ideal situation for a cusum graph is for it to run along the zero line because that indicates that there is zero deviation from the target.

The graph above shows that beer colours were in control until sample number 5 and from then on they were too high.

Many breweries enter the results of analyses into computer databases. This gives a number of benefits:-

- Recording data is quick and easy.
- It means that cumbersome paper records are not required.
- Defects can be highlighted automatically.
- Records can be easily accessed from a number of points on a network.
- The sort of graphs discussed above can be generated automatically.

10.2 Process Control

Product and process specifications are based on a number of Quality Parameters and must take into account the factors affecting the brewing process and the analytical results during the production of wort and beer.

Wort and beer production involves a number of complex and interacting physical, biochemical and microbiological processes.

The table below lists the main quality measures taken during beer production and packaging along with an explanation why that measure is important.

Parameter	Relevance to beer quality.
Alcohol content (ABV)	Indicates the strength of the beer and value to the consumer. Indicates the degree to which a consumer can become intoxicated.
Original Gravity (OG) Present Gravity (PG)	Indicates the strength of the beer and value to the consumer. Indicates the strength of flavour of the beer.
pH	Mash & wort pH affect enzyme performance in the brewhouse. Wort & beer pH affect hop utilisation and beer bitterness. Wort & beer pH affects microbiological growth. Beer pH affects its flavour. Variable pH can indicate contamination.
Beer colour	Beer colour is immediately perceived by the consumer.
Beer bitterness (IBU)	Beer bitterness has a strong flavour effect.
Trace flavour compounds (Diacetyl, DMS, acetaldehyde, esters)	Trace by-products of fermentation give the beer its characteristic and distinctive flavour. Their balance ensures that the beer will be 'true to type'. Excess of any substance will cause flavour problems.

Dissolved oxygen (DO_2)	Dissolved oxygen is required in wort to encourage yeast growth and a healthy fermentation. Dissolved oxygen in beer causes oxidation which makes it taste unpleasantly stale and after pasteurisation the beer may also taste of wet cardboard. Dissolved oxygen in beer will make it unstable and hazes can form during ageing.
Dissolved carbon dioxide (CO_2)	Carbon dioxide gives beer its lively sparkling character. High levels of CO_2 will make the beer fob or over foam.
Dissolved nitrogen. (N_2)	Nitrogen gives beer a stable, tight foam which clings to the side of a glass as it is consumed.
Beer flavour. (Trueness to type).	Beer flavour is its most important characteristic and it is why people consume the product. Customers expect a specific beer to have a consistent flavour, that is, it should be true to type.
Beer clarity. (Haze, potential haze)	Customers expect the beer that they drink to be 'bright', it looks more attractive. Cloudy beer indicates poor quality and perhaps contamination or contamination.
Beer head stability, (Foam/cling).	Most customers expect the beer to have an attractive foamy head and for that head to cling to the sides of the glass.
Sterility	Microbiological contamination is the most destructive form of quality defect. Wild yeasts, moulds and bacteria will grow readily in wort of fermented beer and effect its flavour, aroma and clarity to the degree that makes it undrinkable
Sterility (continued)	Sterility is a key factor because of the microbes' ability to grow at phenomenal rates, so a small contamination quickly becomes a major problem.

O.G. or 'Original Gravity' is the specific gravity of the wort before it has been fermented.

P.G. or 'Present Gravity' is the specific gravity of the sample when sampled.

pH is a measure of the acidity or alkalinity of a substance. Water is neutral with a pH of 7; acids are lower than 7, alkalis are higher than 7.

Quality parameters are measured at each stage of the process so that the performance of each stage can be checked and the final outcome of beer quality can be predicted.

The tables below detail the stages where quality is measured and the factors that determine each parameter:-

Wort production and brewhouse operations

Parameter	Determining factors
Wort specific gravity (PG and OG)	• Amount of raw material (malt) used per unit of water. • Efficiency of the extraction process.
Wort colour	• Amount of coloured material used. • Degree of wort boiling. • Wort pH.
Mash pH Wort pH	• Quality of brewing water. • Liquor treatment. • Malt quality. • Adjunct type and usage rates.
Wort fermentability Wort attenuation limit (WAL)	• Enzyme activity affected by mash conditions (pH, time and temperature). • Fermentability of different types of raw materials and/or adjuncts used.
Wort sterility	• Wort chiller/mains sterility. • Fermenting vessel sterility.

Pitching Yeast Analysis.

Parameter	Determining factors
Microbiological contamination	• Contamination from the plant. • Contamination from previous yeast generation. • Integrity of yeast strain separation.
Yeast viability (% dead cells)	• Age of the yeast. • Condition of yeast
Yeast vitality	• Health of previous fermentation.

'Green' Beer production and Fermentation operations.

Parameter	Determining factors
Alcohol content (ABV)	• Fermentation degree/efficiency. • Original gravity.
Final specific gravity (OG & PG)	• Fermentation degree/efficiency. • Original gravity.
Beer pH	• Wort pH. • Fermentation degree/efficiency.
Beer colour	• Wort colour.
Beer bitterness. (IBU)	• Hop additions in the brewhouse. • Hop utilisation.
Yeast count (Yeast cells in suspension)	• Yeast strain/flocculation characteristics. • Yeast cropping/purging operation.
Beer flavour	• Brewhouse and fermentation operations. • Raw materials, quality & usage rates. • Contamination.
Beer sterility	• Wort sterility. • Yeast purity.

Mature beer production and Maturation/Conditioning operations.

Parameter	Determining factors
Alcohol content (ABV)	• Conditioning degree/efficiency. • Original gravity.
Final specific gravity (OG & PG)	• Conditioning degree/efficiency. • Original gravity.
Beer pH.	• Fermented beer pH.
Beer colour	• Fermented beer colour.
Beer bitterness (IBU)	• Fermented beer bitterness.
Yeast count. (Yeast cells in suspension)	• Yeast count from Fermenting vessel. • Time of maturation. • Yeast cropping and purging operations.
Diacetyl	• Length (duration) of maturation. • Temperature of maturation.
Dissolved oxygen (DO_2)	• Transfer-in procedure. • Air levels in maturation tank before transfer in.
Dissolved carbon dioxide (CO_2)	• Fermentation degree. • Back pressure on transfer in.
Beer flavour	• Brewhouse and fermentation operations. • Raw materials, quality & usage rates. • Contamination.
Beer sterility	• Fermented beer sterility. • Transfer main sterility. • Maturation tank sterility.

Bright beer production and Filtration operations.

Parameter	Determining factors
Alcohol content (ABV)	• High gravity beer dilution performance. • Filtration/liquor flush operations. • Original gravity.
Final specific gravity (OG & PG)	• High gravity beer dilution performance. • Filtration/liquor flush operations. • Original gravity.
Beer pH	• Mature beer pH.
Beer colour	• Mature beer colour.
Beer bitterness (IBU)	• Mature beer bitterness. • Bitterness loss on filtration.
Diacetyl	• Length of maturation. • Temperature of maturation.
Dissolved oxygen (DO_2)	• Transfer-in procedure. • Air levels in the bright beer tank before transfer in. • Filtration performance.
Dissolved carbon dioxide (CO_2)	• Mature beer CO_2. • Back pressure on transfer into bright beer tank. • CO_2 trimming during filtration.
Beer flavour (Trueness to type)	• Mature beer flavour. • Contamination.
Beer clarity (Haze, potential haze)	• Time of maturation. • Temperature of maturation. • Filtration performance. • Stabilisation.
Beer head stability, (Foam/cling)	• Brewhouse and fermentation operations. • Raw materials, quality & usage rates. • Beer handling. • Contamination. • Beer additions.
Beer sterility	• Mature beer sterility. • Filter & filter main sterility • Bright beer tank sterility.

Product Specification - Key Packaged Beer Parameters.

The table below lists the additional quality measures taken during and at the completion of beer packaging along with an explanation why that measure is important.

Fill level	• The fill level determines the amount of beer in the package. This is what is sold to the customer who expects to get what is paid for. It also is the volume of beer that is specified in the 'contents' statement.
Label quality	• Customers expect to see an attractive bottle. • Legibility. • Conformance to local regulations. • Labels correctly aligned with no creases or tears.
Bottle crown quality	• The bottle must be sealed so that beer cannot leak out or air leak in.
Can printing quality	• Customers expect to see an attractive can.
Sterility	• Microbiological contamination is the most destructive form of quality defect. Wild yeasts, moulds and bacteria will grow readily in beer and effect its flavour, aroma and clarity to the degree that makes it undrinkable. • Sterility is a key factor because of the microbes' ability to grow at phenomenal rates, so a small contamination quickly becomes a major problem.

Packaged beer production and Packaging operations.

Parameter	Determining factors
Alcohol content (ABV)	• Packaging/liquor flush operations. • Original gravity.
Final specific gravity (OG & PG)	• Packaging/liquor flush operations. • Original gravity.
Beer pH	• Filtered beer pH.
Beer colour	• Filtered beer colour.
Beer bitterness (IBU)	• Filtered beer bitterness.
Diacetyl	• Filtered beer diacetyl. • Microbiological contamination from plant/package.
Trace flavour compounds. (DMS, acetaldehyde, esters)	• Trace flavour compounds in filtered beer. • Contamination.
Air in headspace	• Packaging performance.
Dissolved oxygen (DO_2)	• Transfer-in procedure. • Air levels in the bright beer tank before transfer in. • Packaging performance.
Dissolved carbon dioxide (CO_2)	• Bright beer CO_2. • Packaging performance, counter pressure.
Dissolved nitrogen. (N_2)	• Nitrogen additions/dosing. • Packaging performance, counter pressure.
Beer flavour (Trueness to type)	• Bright beer flavour. • Contamination. • Beer DO_2. • Pasteurisation performance.
Beer clarity (Haze, potential haze)	• Bright beer clarity/stability. • Beer DO_2. • Packaging performance. • Pasteurisation performance.
Beer head stability, (Foam/cling)	• Bright beer head stability. • Beer handling. • Contamination from plant/package. • Packaging performance.
Fill level	• Packaging performance.
Label quality	• Packaging performance, labeller. • Label stock quality.
Bottle crown quality	• Packaging performance, crowner. • Crown stock quality.
Can print quality	• Can stock quality.
Can seam quality	• Packaging performance, seamer.
Beer sterility	• Bright beer sterility. • Packaging plant sterility.
Fill level	• Packaging performance.
Label quality	• Packaging performance, labeller. • Label stock quality.

Action to be taken when parameters are out of specification:

There are two points to consider when confronted with an out of specification result:

Firstly, what to do with the current problem.

Secondly, what to do to prevent things going wrong in the future.

When handling any problem, it is best to start with some form of investigation and not to jump to conclusions. The sort of questions to ask are:

- Is it real? Are the results correct?
- What is the extent of the problem? Are other beers affected?
- When did it happen? Where did it happen? What else was going on at the time?
- What are the possible causes? What are the likely causes?
- What can be done about it?

This is an example of the action that could be taken to resolve the out of specification high colour beer discussed earlier in this section.

Investigation and action:-

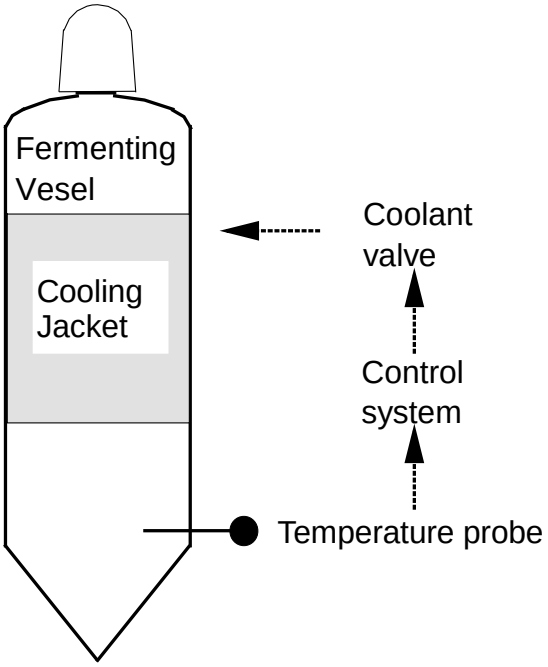
Are the results correct?	Recheck the analysis. -The result is correct
What is the extent of the problem?	Check other beer colours. -There are no other defects.
When did it happen?	Check the cusum graph. - Colours started to increase at sample 5.
What else was happening at the time?	Check process activities that could affect beer colour at the time that sample 5 was brewed. - A delivery of a new coloured malt.
What are the possible or likely causes?	It is likely that the new malt is causing high colours.
What can be done about it?	For the current problem:- "Isolate any affected stock, then either blend away, with specially brewed product if necessary, or otherwise destroy the affected stock. For the future:- - Reduce the amount of coloured malt added. - Investigate the cause of the high coloured malt.

Notes.
Describe the action that was taken to resolve an out of specification parameter in a brewery of your experience.

Instrumentation for in-line process control.

The brewing industry uses instruments to measure the quality of the beer in process or the conditions of a process so that the process can be controlled.

A typical control loop is illustrated below:-



In this model, the temperature of the beer in the fermenting vessel is being controlled. The temperature probe measures the temperature of the beer and sends the information to the control system which compares it to the required value. If it is different, say for example that the actual temperature is too high, then the controller sends a signal to the valve to open sending coolant to the jacket and lowering the temperature of the beer.

Notes.
Draw a control loop for a process that you are familiar with.

The table below details the principles of instruments in common use in brewing and packaging:-

Value measured	Instrument description	Special points
Temperature e.g. for mash temp, fermentation temp.	• Glass thermometer. • Transmitting resistance thermometer (electrical resistance ≅ temp).	The signal from a transmitting thermometer may need checking.
Pressure e.g. for filter pressure differential.	• Pressure gauge. • Pressure sensor using a transducer.	Pressure sensors are easily damaged and need regular maintenance.
Flow rate e.g. for lauter tun run off flow rate.	• Rotary vane meter. • Magnetic flow meter (change in magnetic field ≅ flow). • Pressure differential across an orifice.	Can be used to measure total volume.
Alcohol (ABV) e.g. for dilution of high gravity beer.	• Infra-red adsorption. • Refractive index.	Results usually backed up by laboratory analyses.
PG e.g. for automatic wort breakdown.	• Weight of the liquid in a known volume. e.g. a 'U' tube in line. • Vibrating 'U' tube in line. (resonance ≅ density).	
Haze e.g. for filtration monitoring.	• Light beam scattered by the particles in suspension is measured.	Regular calibration using a clear liquid (water).
Volume e.g. for measuring the contents of a tank.	• Pressure sensors at strategic levels in the tank. • Flow meter on the tank inlet line. • Ultra sonic beam measures depth of liquid in the tank.	It is useful to have an alternative method of checking for example dipping the tank.
Mass/weight e.g. for weighing the amount of malt transferred out of a silo.	• Counter balanced hopper with inlet/outlet gates. • Load cell on the supporting leg of a tank..	
Dissolved oxygen e.g. for checking DO2 pickup during beer transfer.	• Gas transfer through a membrane where the increase in pressure across the membrane is measured.	The membrane is sensitive and is easily poisoned (corrupted) by fouling or damage.
Dissolved nitrogen e.g. for monitoring N2 injection.	• Gas transfer through a membrane where the increase in pressure across the membrane is measured.	The membrane is sensitive and is easily poisoned (corrupted) by fouling or damage.
Carbon dioxide e.g. for monitoring CO2 injection systems.	• Gas transfer through a membrane where the increase in pressure across the membrane is measured. • Infra red adsorption.	The membrane is sensitive and is easily poisoned (corrupted) by fouling or damage.
Conductivity e.g. for measuring detergent strength in a C.I.P. system.	• Measuring the electrical differential across two sensors located in the liquid.	Regular maintenance required especially if the values control a system.
pH e.g. for monitoring water supplies.	• Measuring the electrical differential across a membrane between the liquid and a salt solution.	The membrane is sensitive and is easily poisoned (corrupted) by fouling or damage.

Notes.
List the instrumentation in an automatically controlled process in brewing that you are aware of.
What is the basis of their operation and how do they control the process?

Qualifications

The General Certificate in Brewing (GCB)

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Section 11 Beer Quality - Flavour

11.1 Flavour Evaluation - Terminology.

Candidates need to be able to define concisely particular beer styles in terms of their aroma, alcohol, colour, bitterness and palate feel.

The main differences between lagers, ales and stouts:-

Beer type: Lager.

Raw materials:
Undermodified and very pale malt.
Possibly some cereal adjunct (e.g. maize or rice).
Delicately flavoured hops.

Brewing process:
Temperature staged mash.
Bottom fermentation.
Long, cold maturation followed by filtration.

Characteristics:
Light colour, delicate flavour.
Often dry and astringent with an 'onion' character.
Premium beers at 5% alcohol.
Lower strength beers at 3-4% alcohol.

Beer type: Ale - Bitter beer.

Raw materials:
Well modified malt with rich flavour.
Possibly some sugar adjunct.
Strongly flavoured hops.

Brewing process:
Single temperature mash.
Top fermentation.
Short maturation, possibly in cask

Characteristics:
Pale colour, strong bitter flavour and hoppy aroma.
Normal strength 4-5% alcohol.

Beer type: Ale - Mild beer.

Raw materials:
Well modified malt with rich flavour.
Possibly some sugar adjunct.
Flavoured hops.
Possibly some priming sugar.

Brewing process:
Single temperature mash.
Top fermentation.
Short maturation, possibly in cask.

Characteristics:
Pale or dark colour, slight bitter flavour and usually sweet.
Normal strength 3-4% alcohol.

Beer type: Bitter Stout.

Raw materials:
Well modified malt with additions of coloured malt and roasted barley.
High levels of hop additions

Brewing process:
Same as an ale.

Characteristics:
Very dark colour with strong flavours of roasted barley. Very bitter.

Beer type: Sweet Stout

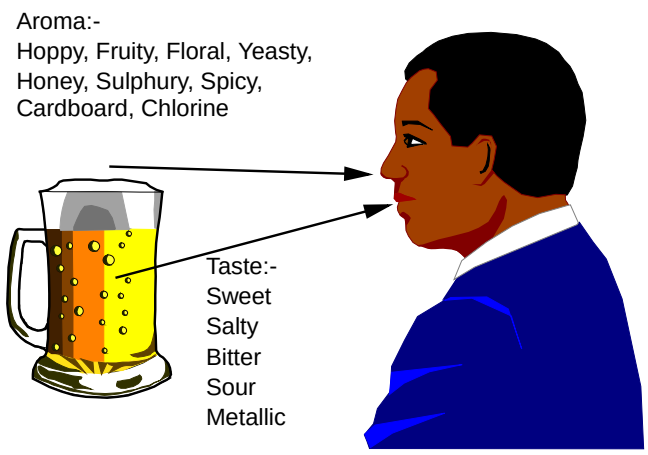
Raw materials:
Well modified malt with additions of coloured malt.
Possibly some caramel and sweet primings.

Brewing process:
Same as an ale.

Characteristics:
Very dark colour with flavours of roasted barley. Very sweet.

Terminology.

People sense the flavour of a beer in two ways, aroma and taste:-



Another factor which influences taste is 'mouth feel' that is how the liquid stays on the tongue and helps the flavour to linger.

The various characteristics of the flavour can be given standard terms so that people tasting the beer can recognise and describe that flavour in a common language.

That way, a beer can be tested and analysed for flavour just as it can be analysed for other quality parameters like colour or pH.

People need to be trained to taste and this is done by exposing them to the tastes and aromas normally associated with beer so that they learn to recognise them and to judge their intensity. A common language has been devised to describe beer flavours and brewers throughout the world have agreed on a terminology that is used for beer.

In this terminology, each of the recognisable flavours has been given a name and the **flavour wheel** is a pictorial summary of the main flavour characters:-

Beer Flavour Components

Introduction

Appearance and taste are the two sensory attributes on which beer consumers judge the acceptability of the product and they use them to critically evaluate every glass of beer they drink. The appearance, colour, hue, brightness, foam quality and glass fullness are all qualities which can be physically measured and, thereby controlled. The taste or flavour of the product, on the other hand, cannot be adequately described in physical or chemical terms and we have to rely on human taste senses to control and monitor the product.

However, it is a fact that we can analyse for several hundred components of beer which are known or are expected to contribute to beer flavour in a meaningful way, either directly alone or synergistically with other components or even both.

This section summarises the known flavour effects of several of the more important components in beer.

Non-Volatile Components

(a) Bitterness

Bitterness flavour in beer is derived principally from iso-α-acids from hops, although oxidation products of β-acids (also produced during kettle boiling) can also provide bitterness character.

(b) Residual Sugars

Residual sugars impart **sweetness** and **mouthfeel** and **body** to beer flavour. It is unlikely that there will be any significant level of fermentable sugars present, especially in a fully attenuated beer, but some may persist. Alternatively, some beers have sugars added post-fermentation, not only for active secondary fermentation during maturation (or in final package for "traditional" cask-conditioned or bottle-conditioned beers).

The bulk of the residual sugars will be dextrins as such will not contribute much sweetness character, but will make a significant contribution to perceived **body**.

(c) Malt Components

Components derived malt and speciality malts can make significant contributions to beer flavour, in some cases (such as Black Malt or Roasted Barley in very dark beers, like Stouts) being the main over-riding character.

Differing levels of these colour and flavour compounds, such as melanoidins, etc. can contribute flavour characters such as: **Bready, Biscuity, Malty, Nutty, Chocolate, Toffee/Caramel, Roasted, Burnt, Astringent**.

(d) Inorganic Ions

Several ions have direct flavour effects, in addition to indirect effects (mainly by influence on pH) during wort production and on yeast metabolism during fermentation:-

- pH (or hydrogen ion concentration) if low enough, say less than pH 3.6, will progressively impart **Acidic** flavour to beer.
- Sodium at low levels imparts **Sweetness**, but tastes **Salty, Harsh** and **Sour.**
- Potassium will also taste **Salty.**
- Magnesium will contribute **Astringent** and **Bitter** flavours.
- Iron notoriously tastes **Metallic** at very low levels.
- Chloride imparts enhanced **Mouthfeel** and has a Smoothing effect on beer texture.
- Sulphate has a **Drying/Astringent** effect on beer palate and can enhance perceived **Bitterness.**

Many brewers pay particular attention to the balance between Chloride: Sulphate to ensure consistency of beer flavour.

Volatile Components

(a) Hop Oil

The essential oils in hops are the source of aroma compounds. These oils are volatile and will be almost entirely vaporised from the kettle if they are present from the start of a 60–90 minute boil, although some will be converted by heat or chemical reaction. To compensate for this, many brewers who want beer with a **hoppy** character add selected aroma varieties into the kettle between 5 and 20 minutes before the end of the boil. This gives sufficient time to extract the hop aroma but ensures that all the oil is not lost in the vapour.

Late hop character is often described as **floral** or **citrus**, but it can be unpleasant if present in too high a concentration. The variety of hop, the timing of the addition, as well as the kettle shape and the material of construction all have a major influence on the subtlety of the final beer aroma.

Hops can also be added to beer after fermentation, to the maturation vessel or to the cask to give beer a dry hop flavour - this is often described as **resinous**, **spicy** and **citrus**. As the α-acids are only slightly soluble in cold beer, there is hardly any increase in the bitterness of beer with dry hopping.

(b) Ethanol

Ethanol has little direct perceived flavour contribution, but enhances the perception of other volatile flavour components, especially at higher (say, greater than 5.0% v/v) levels.

The main flavour descriptor influenced directly by ethanol is described as **Alcohol warming**.

(c) Higher Alcohols

The concentration of individual higher alcohols (or fusel alcohols) rarely exceeds flavour thresholds, but collectively they all contribute to perceived **Alcohol warming** character and **Solvent** like aroma and taste.

d) Esters

Unlike higher alcohols, several esters exceed flavour thresholds and often are major contributors to perceived flavours, especially ethyl acetate (**ester, solvent**) and iso-amyl acetate (**fruity/bananas**).

Collectively, they all contribute to **fruity/ estery** characters.

(e) Vicinal Diketones

Usually regarded as an undesirable character in most lagers, diacetyl can be regarded as a positive flavour character in some ales, producing flavour effects, such as **Butterscotch, Buttery, Toffee/Caramel, Vanilla.** By contrast, 2,3-pentanedione rarely exceeds flavour threshold, but can be regarded as synergistically enhancing the perception of diacetyl.

(f) Dimethyl Sulphide and Other Sulphur Compounds

DMS is a flavour character either regarded as a positive character in some lagers or as a major flavour taint in others. It is rarely detectable in ales.

The perceived flavour is classically described as **Sweetcorn**, but also as **Cooked vegetable**.

Other sulphur compounds are usually regarded as flavour negative, such as hydrogen sulphide (**Rotten Eggs**), but some compounds, like thiol esters derived from hops make a positive contribution to some lager flavours.

(g) Carbon dioxide and Nitrogen

CO_2 can contribute to a flavour attribute described as **Tingle** or **Gassy**.

N_2 gas (as in so-called "widget" beers in can) at concentrations greater than 20 mg/l, will cause a palate softening or smoothing effect, also often described as Creamy. It is also considered that the smoothing of the nitrogen gas itself or as a consequence of the thicker, tighter, creamier foam that is usually produced reduces the perceived **bitterness** level.

Flavour Evaluation and Tasting

Professional assessment of beer flavour is an important analytical tool.

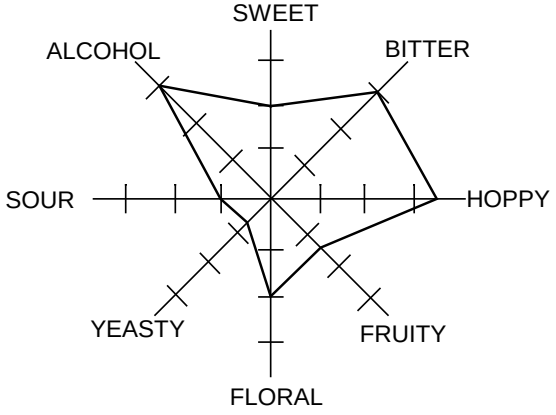
Beers are given **flavour profiles** so that tasting by trained tasters can be carried out during and after the production and packaging processes and they can judge whether a beer meets the required standards.

Each beer brand will have its own unique flavour profile which goes with its other unique specification values.

Trueness-to-Type.

A beer that is 'true to type' matches the standard flavour profile for that particular product or brand. Flavour profiles are produced by specifying a beer's typical flavours and intensities and documenting them, probably in a graphic form.

A typical flavour profile in the form of a spider diagram is shown below:-



Taste tests.

Beer must be tasted as part of normal quality control, the specification being the 'flavour profile'.

Flavour profiling is described as a "Descriptive" Taste Test, requiring trained tasters to be able to analyse the flavour of beer in considerable detail. Even the simplest tests should be carried out under controlled conditions or the results, because of an inability to reproduce them, will be worthless.

Because tasters – even trained and selected ones – vary in sensitivity to a particular flavour from 'blindness' to hyper-sensitivity, it is necessary to use several tasters to assess each beer. A suitable number for such a "Flavour Panel" is 8, and 5 should be regarded as absolute minimum.

If problems are encountered, an investigation could include a 'triangular taste test' or three-glass test, where three samples are tasted with one of the samples being different to the others.

This is described as a "Difference" test and is used to answer the questions 'Are the samples different?', or 'Do the samples differ on a specific attribute?'

They may also be used in the selection and training of tasters and for monitoring their performance.

If there is a notable difference between the samples, a statistically significant number of tasters will pick it out.

For statistically reliable results from a triangle taste test using untrained testers, it is usually recommended that a minimum of 25 assessors should be used.

The triangle test is recommended:-

- To detect slight differences between samples.
- When only a limited number of assessors is available.
- For the selection and training of assessors.

Some disadvantages of the test are that:-

- It is uneconomical for the assessment of a large number of samples.
- With intensely flavoured samples it may be more affected by sensory fatigue than the paired comparison test.
- It may be difficult to ensure that the two samples that are supposed to be the same are in fact identical.

In the Triangle Taste Test the assessor is presented with three beers, two of which are identical. The purpose of the test is to select the odd beer out of the three. The assessor is normally asked to express a preference between the beers and to indicate which attribute(s) were perceived as different in making the choice.

The beers should be arranged in random order so as to eliminate bias due to carry-over of flavours. (i.e. AAB, ABA, BAA, etc.). After tasting has ended, the number of correct answers is counted and compared with the number taking the test and the statistical significance of the results is determined.

Common Flavour Taints in Beer

(a) Sulphur Compounds

H_2S (**Rotten Eggs**) and SO_2 (**Burnt Matches**) are usually regarded as flavour taints, but sub-threshold levels of a whole range of sulphur compounds.

Various hop-derived thiol esters can all contribute to an ill-defined, so-called "Lager" character.

(b) Phenols

One of the most flavour-intense group of substances causing beer taint is the chlorinated phenols, such as TCP, generating flavour described as **Medicinal, Disinfectant**. The range of individual taster's sensitivity to these compounds can vary by several orders of magnitude, so that some individuals are virtually "taste blind" to chlorophenols.

These compounds are usually generated by reaction between chlorine (such as Towns Water disinfected with Cl_2, or inappropriate use of hypochlorite in beer vessels and mains) with phenols in water or beer (often contaminated steam, used for plant or container sterilisation); prolonged and excessive exposure of beer lines in draught beer installations to beer line cleaner is also a classic source of this beer taint.

Control is achieved by elimination or tightly controlled use of hypochlorite and carbon filtration of all relevant water supplies to remove any Cl_2 residues.

Related Phenolic taint can be due to wild yeast infection. In this case the flavour taint is described as **Medicinal** or **Cloves** and is usually due to the synthesis by the wild yeast of 4-vinyl guaiacol.

(c) Chloranisole

This compound is associated with the flavour character described as **Musty, Fungal** or **Wet Carpet**. It is caused usually by mould or bacterial infection in water supplies and is controlled by appropriate hygiene regimes.

(d) Metal Ions

Elevated levels of Iron and sometimes Copper and Aluminium can lead to flavour taints such as **Metallic**, **Rusty** and **Astringent**.

Some filter aids (diatomaceous earth) contain high levels of Iron and poor quality or corroded stainless steel in vessels and mains can also contribute.

Poorly lacquered cans and kegs can be a source of pick-up of aluminium.

(e) Plastic

Incompletely polymerised plastic (e.g. PET) beer containers (bottles or one trip kegs) or excessive plasticiser can be sources of **Plastic** taint.

In addition poorly cured lacquer linings in aluminium cans and kegs can contribute.

(f) Aldehydes

Oxidation of fatty acids and other lipids to aldehydes and other carbonyl compounds, such as trans-2-nonenal, is associated classically with stale flavour taints (**Papery, Cardboard**).

Qualifications

The General Certificate in Brewing (GCB)

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Section 12 Beer quality – Dissolved oxygen

Introduction

The quality of a beer changes continually. Beer is not completely stable in its final package even after packaging to the highest standards. Generally speaking, fermented beer will improve in quality during maturation, but will start to deteriorate once the beer has been filtered or clarified.
The two major factors in this change are the absence of yeast and the presence of oxygen.

- Yeast helps the beer to mature by absorbing some of the unpleasant flavour compounds like diacetyl and scavenging oxygen.
- Oxygen de-stabilises both the flavour and haze stability of the beer.

12.1 The spoilage of beer by oxygen

Sensitivity to oxygen

A very small amount of oxygen will cause problems because it only needs a small amount of protein/tannin to form a haze and only a small amount of oxidised lipid is needed to give an off flavour.

A DO_2 level of 0.5 parts per million will cause problems. To give a sense of scale, this is a thimble full of air in 500L.

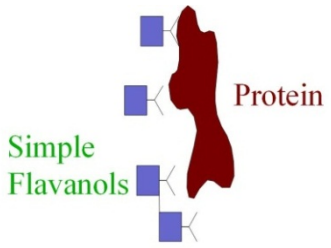
Most brewers try to maintain DO_2 levels below 100 ppb (0.1 ppm) in final package which means that oxygen levels pre-package are considerably less to allow for oxygen pickup during the packaging process.

Mechanisms of haze formation

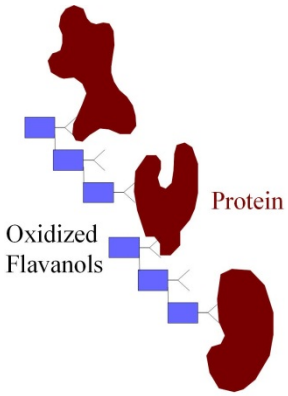
The build-up of visible haze particles is particularly rapid in the presence of dissolved oxygen and heavy metals. Polyphenols (tannins), from malt and hops are firstly oxidised. The oxidised polyphenols become linked with polypeptides (mainly from malt, but some from hops) firstly to create particles large enough to form haze and make the beer go cloudy.

Chill haze occurs when the bonds between the two compounds is reversible. The material comes out of solution because of the decreased solubility at low temperature.

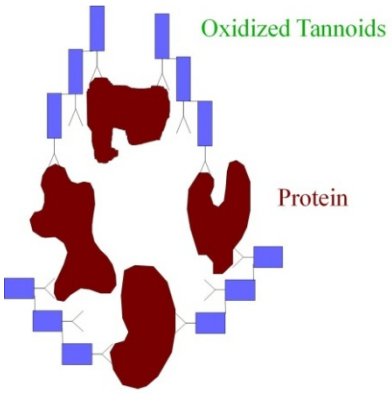
Permanent haze is characterised by the more durable, irreversible covalent bonds.



Haze free beer



Chill haze



Permanent haze

Oxidation reactions, flavour compounds & their descriptors

Most of the chemical changes during storage involve oxidation and will be accelerated if beer is allowed any contact with oxygen post fermentation.

The dissolved oxygen in beer rapidly disappears, although stale flavours may not develop immediately. However, oxidative reactions will have been initiated which will produce off-flavours subsequently.

When oxygen has dissolved in beer, lipids (fats) derived from malt are oxidised by enzymic and non-enzymic reactions to a range of oxidised compounds, which breakdown during the brewing process or in package to form aldehydes. For example, in the presence of the enzyme lipoxygenase, and oxygen, linoleic acid is converted to trans-2-nonenal. These compounds have a very unpleasant flavour. The flavour formed is often described as 'stale, papery or cardboard'. This reaction is speeded up at high temperatures. Thus the combination of high levels of oxygen and pasteurisation is disastrous.

The development of "ribes" or "catty" off-flavours in beer is classically associated with high dissolved oxygen content at packaging (high headspace air).

In general terms, the rate of development of oxidised flavours is inversely proportional to the strength of the beer (alcohol content) and the content of coloured malts in the original grist (higher level of reducing power). Consequently, strong stouts are much more flavour stable than light coloured lagers. Lagers will develop sweet, papery/cardboard and metallic notes, whereas ales tend to develop molasses/toffee and dried fruit or sherry characters.

Flavour term	Described as	Approximate flavour threshold	Typical conc^{n} in beer	Source
Diacetyl	Butterscotch buttery	0.05 – 0.2 mg/l	0.01 - 0.4 mg/l	By-product of amino synthesis
Caramel / Toffee	caramel, treacle	--------	--------	Oxidation with age Contamination of raw materials
Catty	catty, tom-cat urine, blackcurrant leaves	15 mg/l	--------	Oxidation with age Contamination of raw materials
Iso-valeric	cheesy	1 mg /l	0.2-1.5mg/l	Old hops Lipid oxidation
Metallic	tinny, blood-like, inky	1 mg/l	<0.5 mg/l	Contamination Oxidation
Papery	papery, cardboard	50-100 ng/l	50-0.2 µg/l	Staling during beer storage
Winey / Sherry	Vinous, Madeira, sherry			Oxidation

Additional note on diacetyl - may be apparent due to high oxygen pickup post fermentation whilst still in presence of active yeast, e.g. transfer from FV to MV. Alternatively may be due to contamination, so presence of diacetyl in package beer is not conclusive evidence of oxygen pickup.

Oxygen as a constituent of air

Oxygen forms approximately 21% by volume of atmospheric air. The remaining constituents do not give any real cause for concern as regards physical / chemical degradation of beer.

However, ingress of atmospheric air into beer also risks microbiological contamination by airborne yeasts and bacteria, giving a second reason for avoiding all forms of air pickup.

If the partial pressure of oxygen in the gas in contact with the air is greater than the partial pressure of oxygen dissolved in the beer, oxygen will pass from the gas into the beer in an attempt to equalise the partial pressures, up to the maximum solubility of oxygen in water, approximately 10 ppm.

It is essential that not only contact of beer with atmospheric air is avoided, but contact with any other oxygen contaminated gas, typically CO2 or nitrogen, is also avoided, because the oxygen in these gases will also attempt to reach equilibrium. Though the level of dissolved oxygen reached will invariably be less than that attained by contact with atmospheric air, it can still be sufficient to encourage oxidation flavour changes and haze formation.

Typical points of exposure to air

Air, or air contaminated process gases (CO_2, N_2) contains oxygen, so that any time the beer comes into contact with air, or water containing dissolved oxygen, it will pick up oxygen. The point of contamination is at the surface of the beer and this means that the larger the surface area, the more oxygen will be picked up. When the beer is agitated, a larger surface area is created and more oxygen can be dissolved.

- Impure process gases. This is a common problem with old, or poorly run CO2 recovery plants. These may be used as top pressure gas in tanks, or as injected gas for carbonation or for nitro-keg products.
- Pump seals, particularly the seal around the drive shaft.
- Valve seals – again typically these draw air in when on the low pressure, suction side of pumps, but leak outward on the high pressure discharge side. However, they can act rather like the fuel supply jet in a traditional carburettor, sucking air in through a small gap between the seal and the metal, or through holes in the seals.
- Joints, particularly between sections of main, or on instrument housings on the suction side of transfer pumps.

- Non-deaerated water e.g. that used for CIP final rinses.
- Inadequately deoxygenated water used for flushing out mains before and after transfers, or for diluting high gravity beers.
- Poorly deaerated transfer mains or filters. If insufficient time is given to flush out CIP rinse water, or the flow rates are insufficient to achieve turbulent flow, then pockets of gas or highly oxygenated water can remain.

12.2 Monitoring and controlling oxygen levels

Key control points

DO_2 levels will be zero in fermenting vessel at the end of fermentation. All oxygen has either been used by the yeast or purged out of the beer by the evolution of CO_2 during the fermentation.

High DO_2 levels in tank can be reduced by purging with an inert gas like CO_2 or nitrogen, but this could risk loss of beer foam proteins by causing fobbing.

Once the beer is in package, nothing can be done to improve out of specification DO_2 levels.

Thus it is useful to know on a regular basis, or at least have the ability to measure DO_2 levels at the following points:-

- In maturation tank.
- In the beer in line out of maturation tank (often at the pre-filter buffer tank inlet). DO_2 levels can rise at tank changeover.
- Pre filter – at the filter inlet.
- Post filter at the filter outlet – to help determine effectiveness of the pre-filter run de-oxygenation flush, and oxygen pickup from any additives.
- Post filter – again, often at the outlet of the buffer tank.
- Pre and post dilution and carbonation.
- In bright beer tank.
- At the inlet to the filler, especially if the supply system incorporates buffer tanks, pasteurisers etc.
- In final package – normally measure as TPO (Total in Package Oxygen) as this measures the total of the portion derived from the oxygen dissolved in the beer in the filler, and the portion derived from any oxygen in the headspace introduced as part of the filling process.

The significance of sampling time

It is important to measure for DO_2 immediately after potential contamination by air, for example immediately after transfer into a tank. This is because oxygen is used up in the oxidising process, so beer that has been transferred then stood and allowed to oxidise could have a considerably lower dissolved oxygen level than freshly transferred beer.

Tracking dissolved oxygen levels using in-line instruments with suitable recorders allows quick tracing of problems, for instance the oxygen spike that can occur when a valve changes state or a pump is energised. These spikes can make a large difference to the overall dissolved oxygen level.

It also allows alarm handling to be installed, so that no product is produced out of spec.

Operating a dissolved oxygen meter

Introduction

There are two main types of oxygen meter now in use:

- Electrochemical. This type of sensor has been in use since the mid 1970's. Electrochemical cells consist of a metal anode and a metal cathode dipped into an electrolyte solution. When a voltage is applied, current flows between the anode and the cathode. The electrodes and the electrolyte are separated from the gaseous or liquid sample by a membrane permeable to gas. Gas penetrating through the membrane into the cell dissolves in the electrolyte. It causes a measurable electric current to flow which is proportional to the amount of gas entering the cell, which in turn, is proportional to the amount of gas dissolved in the sample.
- Optical (quenching). This design has only been in use in breweries since about 2008. An oxygen sensor (sensor spot) is in contact with the liquid or gas for which the oxygen content is to be measured. The sensor spot is intensely illuminated by a blue light source for a short time. Depending of the oxygen content in the medium the sensor spot will give out a red light signal. A detector measures the intensity of the light signal and from it the oxygen content of the liquid or gas is calculated. Depending on the scan frequency, accurate results from an optical sensor are obtained more quickly than electrochemical sensors.

Operating guidelines

Both may be used as in line or off line (typical hand held or lab bench). Both types must be maintained and calibration checked regularly (cross check with other instruments), though Optical sensors, which are a comparatively new technology, appear to require less maintenance than electrochemical sensors.

In-line instruments should be installed in accordance with the manufacturer's guidelines.

When not actively being used to measure oxygen content, the instrument must be switched off to reduce unnecessary deterioration.

When measuring the DO2 of a liquid, the liquid should be flushed through the instrument at high flow rate to ensure that any entrained air bubbles or rinse water is removed. Once flushed through, the instrument should be switched on. Typically, optical instruments will give an accurate reading as soon as switched on, and the first pulse of light has been sent and measured. Electrochemical instruments take longer, typically more than 30 seconds due to the time required for the dissolve gas either side of the membrane to reach equilibrium. Sometimes, it may be necessary to leave the instrument on, flushing through with fluid for several minutes until a stable reading is achieved.

After use, if they have been used to measure a liquid, the instruments should be thoroughly rinsed out with cold clean water (de-mineralised preferred, but not essential).

Typical specified maximum levels

The following specs are based on current brewery good practice, not necessarily the best achievable, as these are generally only realistically achievable in large modern breweries. Note also that many (generally smaller) breweries may not be able to achieve these specifications either.

Note that particularly at very low levels of dissolved oxygen, specifications must reflect the possible accuracy of the instrument, and the sampling regime, so that although for instance, zero ppb may be desired, to allow for instrument / sampling error, a figure of say 10 ppb may be set.

- FV immediately prior to transfer (often not even specified) — not > 10 ppb
- MV immediately after filling — not > 100 ppb
- MV immediately before transfer — not > 50 ppb
- Bright beer tank (at high gravity) — not > 100 ppb
- Bright beer tank (at sales gravity) — not > 100 ppb
- In final package (TPO) — not > 150 ppb
- Deaerated water — not > 10 ppb

Good practices to avoid oxygen pickup

Beer should be stored as cold as possible, ideally at 0ºC. The Arrhenius equation predicts that the rate of chemical reactions double for every 10ºC rise in temperature. Therefore to reduce the rate of deterioration, beer should be stored as cold as possible (without freezing of course).

There are a number of ways of controlling DO_2 pickup:-

- Flush plant and pipes through with de-aerated water before running the beer through.
- Maintain an inert atmosphere (CO_2 or N_2) in maturation vessels and bright beer tanks.
- Ensure that any additions to beer are oxygen free. For example, use deaerated water to dilute beer and for mixing filter aid additions, and purge continuously with CO_2 or N_2.
- Ensure that recovered beer, yeast pressings etc. are oxygen free.
- Reduce the surface area where beer is in potential contact with air. Vertical tanks are best from this point of view than horizontal tanks.
- Add oxygen scavengers to the beer. This may not be possible, either due to legislation or due to customer concerns, and is an admission that other control methods are not being effective.
- Flush and counter pressure packaging containers with CO_2.
- The presence of small amounts of air in cask conditioned beer is not so destructive because of the activity of yeast.
- Ensure plant is maintained to minimise risk of oxygen pickup through pump, valve and other joint seals.
- Design pipes and plant so that beer turbulence is minimised. This means graduated bends etc.
- Fill tanks at a controlled speed (at just turbulent flow through the mains – typically circa 1.5 m/sec) from the base.
- Fill packaging containers with minimum beer turbulence.
- Monitor DO_2 levels and take corrective action where necessary.

The use of antioxidants / scavengers

- Sulphur dioxide is added to products like finings.
- O2 scavenging materials can be incorporated into bottle crown seals, e.g. sulphite and/or ascorbate.

Notes.

For a brewery that you are familiar with, write down details of dissolved oxygen levels at the different stages of production, and procedures for controlling them.

Qualifications

The General Certificate in Brewing (GCB)

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Section 13 Beer quality - microbiological contamination

13.1 Beer spoilage

Introduction

There are three main groups of contamination which can affect beer and the associated materials at any stage of the production process:-

- Chemical.
- Microbiological.
- Physical.
- Allergens.

There are a wide variety of sources of contamination, including the following:-

- With the raw materials. Examples of this type of contamination are:-
  - Pests such as weevils, moths or even rodents in malt deliveries.
  - Droppings from pests such as rodents.
  - 'Off flavours' and aroma chemicals absorbed by filter aids.
  - Dust and debris in empty cans.
  - Untreated surface water, nitrates or effluent in the water supply.
  - Loose or worn plant components.
  - Allergens such as wheat germ for brewing grist.

  These are monitored by identifying the most likely contaminants and either inspecting the material before delivery or agreeing specifications with a reliable supplier and monitoring and reporting back that supplier's performance.

- Cleaning chemicals. Product may be contaminated by plant cleaning chemicals, such as CIP detergents and sterilants, or chemicals used for environmental cleaning.

- Oil or grease. Only a small amount of oil will spoil a beer. It will taint the flavour and destroy the beer's foam stability. Oil or grease can get into the product via, for example, poorly maintained pump glands. Oil free gas including compressed air is essential for beer production and packaging.

- The use of unsuitable material for plant or package construction. Modern plant is generally constructed of stainless steel. However there are different grades of steel available. Some of these grades can corrode under certain brewing conditions (e.g. high chloride ion content in brewing liquor tanks), and therefore may not be suitable, even though classed as "stainless". Equipment manufacturing processes may also make even suitable grades for stainless steel liable to corrosion and creation of 'bug' traps.

- Hoses, joint rubbers, gaskets, valve and pump seals, and equipment used for manually handling materials such as mineral salts must be made of food grade material, resistant to scratching and breakdown by the materials being handled, or by the cleaning materials / temperatures.

- Microbiological contamination, which is covered throughout the following sections.

Sources of microbiological contamination

Micro-organisms will thrive in the most inhospitable conditions. When they are deprived of their nutritional requirements, bacteria can often form spores which are more difficult to destroy than the active live bacteria. Consequently, they can infect the beer from many different sources. The tables below identify the main sources of contamination.

Raw materials and packaging materials

Source of contamination	Comment
Water	Brewing water in wort will be boiled as part of the process, but additions later in the process (e.g. dilution water), cleaning final rinse water, pre and post beer transfer purging water, must all be sterile.
Brewing materials (malt, hops & adjuncts)	All naturally grown material harbours micro-organisms. These are unlikely to be a problem where added / used before wort boiling as this kills all flora and fauna present in the wort run into the kettle (copper).
Pitching yeast	Storage of yeast may allow growth of other micro-organisms already present in the yeast slurry. This is a major problem because an contamination can proliferate throughout the brewery unless controlled by effective plant cleaning and possibly acid washing.

Additives (filter aid etc.)	The powders and liquids as supplied are unlikely to be contaminated, but the additions make-up and dosing process, and the water used for mixing and purging can be a source of contamination.
Packages	New bottles and cans may contain dust and debris. Returnable bottles, casks and kegs may be heavily contaminated when returned from the trade because they contain small volumes of beer, which may have been in the container for a long time, allowing any contaminants time to grow on the remaining beer.

Equipment

Source of contamination	Comment
Brewhouse plant	Wort chillers and wort mains are important because of the nature of the wort, and high levels of fouling experienced, particularly in the heat exchangers, which can protect microorganisms if cleaning is inadequate. The wort is a rich medium for many micro-organisms to grown in, rich in sugars, proteins, minerals and oxygen from the wort aeration / oxygenation system.
Fermenting vessels	Difficult to clean because of the residue left by the yeast and hops. FVs are a major source of contamination because of the long time that the beer is in contact with them.
Yeast handling plant	This can be a source of contamination because of the nature of the yeast itself and the complexity of the plant makes it difficult to clean.
Maturation plant	Easier to clean than FVs but there is some yeast soil and again, the beer is in them for a long time.
Filtration plant	Difficult to clean because of the complex pipework and the design of the filter itself.
Bright beer vessels	Easy to clean because the beer in the tanks is bright and is likely to be nearly sterile.
Packaging plant	Difficult to clean because of the complex pipework and the design of the filler itself.

Product

Source of contamination	Comment
Wort	Wort is a perfect medium for micro-organisms to grown in. However, it will be sterile after boiling.
Beer in process	Beer will support micro-organisms but in itself it is unlikely to be a source of contamination. A more likely source is the plant. Beer from other breweries may contain more, or different contaminants, and should be treated with suspicion.
Recovered beer	Beer recovered from surplus yeast can be a major source of contamination because often the plant it has been processed in is not maintained to such high hygiene standards as say FVs. Any recycling operation needs special care because of the possibility of perpetuating an contamination. Beer recovered from packaging operations is also a major source of contamination.

Environment

Source of contamination	Comment
Insects and other pests	Storage areas for raw materials will encourage insects and other pests such as rodents unless maintained in a hygienic condition. They will carry contamination and must be kept away from open vessels.
Walls and floors	Contamination can be picked up from poorly maintained walls and floors especially in open vessels.

Aerobic growth

An aerobic organism or obligate aerobe is an organism that requires oxygen for growth, examples of which are: moulds (malt, empty cans) and yeast 'film formers' (*Pichia, Candida Mycoderma, Hansenula*)

Anaerobic growth

An anaerobic organism or anaerobe is any organism that does not require oxygen for growth. For practical purposes there are three categories:

- Obligate anaerobes, which cannot use oxygen for growth and are even harmed by it.
- Aero-tolerant organisms, which cannot use oxygen for growth, but tolerate the presence of it.
- Facultative anaerobes, which can grow without oxygen but can utilize oxygen if it is present.

Brewing yeasts are facultative anaerobes, requiring oxygen for healthy growth, but metabolise anaerobically during fermentation. Most contaminating micro-organisms in breweries are either aero-tolerant or facultative.

Spoilage products and effects on beer quality

For convenience, these two sub topics have been included in the following main topic.

13.2 Spoilage organisms

The principal categories of spoilage organisms

There are four main microbiological contaminants to consider:-

- Bacteria. Very small living organisms of which there are many varieties. Fortunately only a limited range will grow in beer and 'pathogenic' organisms (those that could give food poisoning) will not.

- Wild yeast. Small living organisms similar to, but different from the yeast that is used to ferment the beer. The difference being that wild yeasts will give quality problems, for example flavour or fining difficulties.

- Fungi or moulds.

- Water born organisms. Usually bacteria associated with contaminated water.

The following is a list of common contaminating micro-organisms, the stage of the brewing process they are most likely to be found, and the effects of contamination.

Stage
Unpitched wort

Infecting micro-organism	**Characteristics**	**Effects on beer**
Obesumbacteria. (Hafnia)	Grows along with the yeast in wort but dies off early in the fermentation. Presence indicates ineffective wort main or FV cleaning. Very common in top-fermenting yeasts but less common in lager yeasts.	Causes off flavours ("parsnips") in a very slow fermentation.
Escherichia	Grows in wort or partially fermented beer. Is an indicator of contamination of water supplied to brewery.	
Enterobacter	They do not grow below pH 4.3. They are generally unable to grow in beer but grow rapidly in wort. Some can metabolise nitrates to nitrites so increasing nitrosamines, particularly in lauter and mash tun residues	Can produce DMS and diacetyl, and flavours described as "herbal phenolic." Can result in increase in nitrosamines.

Stage
Pitching Yeast

Infecting micro-organism	Characteristics	Effects on beer
Pediococcus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey. Beer may go glutinous and "ropey".
Lactobacillus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey.
Wild yeast	Abnormal flavours (possibly acetic acid) and cloudy beer. May form a film on beer surface. Over attenuates.	

Stage
Fermentation

Infecting micro-organism	Characteristics	Effects on beer
Pediococcus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey. Beer may go glutinous and "ropey".
Lactobacillus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey.
Wild yeast		Abnormal flavours (possibly acetic acid) and cloudy beer. May form a film on beer surface. Over attenuates.

Stage
Maturation

Infecting micro-organism	Characteristics	Effects on beer
Pediococcus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey. Beer may go glutinous and "ropey".
Lactobacillus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey.
Wild yeast		Abnormal flavours (possibly acetic acid) and cloudy beer. May form a film on beer surface. Over attenuates.
Zymomonas		Cloudy beer, bad egg aroma.

Stage
Bright and Packaged Beer

Infecting micro-organism	Characteristics	Effects on beer
Pediococcus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey. Beer may go glutinous and "ropey".
Lactobacillus	Will also use any sugar left after fermentation.	Produces lactic acid and diacetyl. Beer goes cloudy and tastes sour, and smells of sour milk or honey.
Acetobacter	Most common in cask conditioned beer. Grow very quickly even at low pH.	Produces acetic acid in presence of air, and forms a skin on the surface of the beer. Beer goes cloudy and tastes of vinegar.
Zymomonas	Convert sugar into alcohol, acetaldehyde and hydrogen sulphide. Grow quickly in liquid sugars. Sometimes associated with 'primed' beers.	Beer goes very cloudy and smells of bad eggs. Beer may go glutinous and 'ropy'.
Megasphaera	Obligate anaerobe that thrives in extremely low DO levels found in modern bright beers; often associated throughout the brewery with biofilms. Produces considerable amounts of butyric and caproic acids and H_2S.	"Baby sick" and bad egg aromas. Cloudy beer.
Pectinatus	Obligate anaerobe. Produces considerable amounts of acetic acid and H_2S.	Bad egg aroma, vinegary. Cloudy beer.

Wild Yeast

The table below lists the main wild yeasts encountered in a brewery and effects that they have on the product:

Yeast	Effect on wort or beer
Pichia	Grows rapidly in the presence of air. Forms a film on the surface of the beer.
Candida mycoderma	Grows rapidly in the presence of air. Forms a film on the surface of the beer.
Saccharomyces diastaticus	Continues to ferment all carbohydrates so there is no control of attenuation. Also causes off flavours.
Torulopsis	Fails to sediment and causes hazes.
Brettanomyces	Very slow growing but it produces acid and causes off flavours. Note that some beers are intentionally pitched with Brettanomyces cultures to produce specific desired flavours, but these flavours are not considered desirable in the majority of beers.
Hansenula	Grows rapidly in the presence of air. Forms a film on the surface of the beer.

Cross contamination of pitching yeasts

Cross contamination of brewing yeast strains, for example a lager yeast contaminating an ale yeast, is normally considered as a wild yeast contamination, because quality problems such as abnormal flavours or an inability of the yeast to settle or fine properly may be experienced.

Moulds/ Fungi

Moulds or fungi do not normally grow in beer because they need air. However they can affect beer in a number of ways:-

- The malting ability of barley can be affected by the presence of mould.
- Some moulds which grow on / in barley can cause gushing (explosive gas breakout when a highly carbonated package is opened), e.g. fusarium, or in other cases (rare) are poisonous (ergot).
- Moulds will grow in empty beer packages (e.g. bottles) and in poorly cleaned plant. If this happens and the mould is not completely removed during washing prior to filling, the mould will probably affect the flavour of the beer.

Mouldy surfaces in buildings like fermenting rooms are difficult to clean and visible growths will harbour beer spoilage yeasts and bacteria.

Water borne organisms

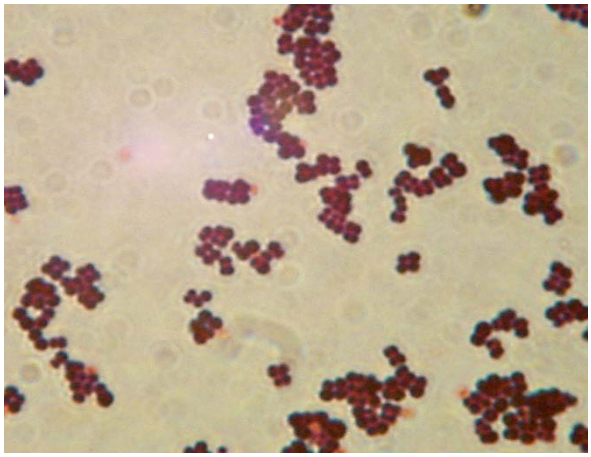
Water borne organisms are not very common but can cause serious problems.

Pathogenic bacteria that will not grow in beer will, however, grow in water.

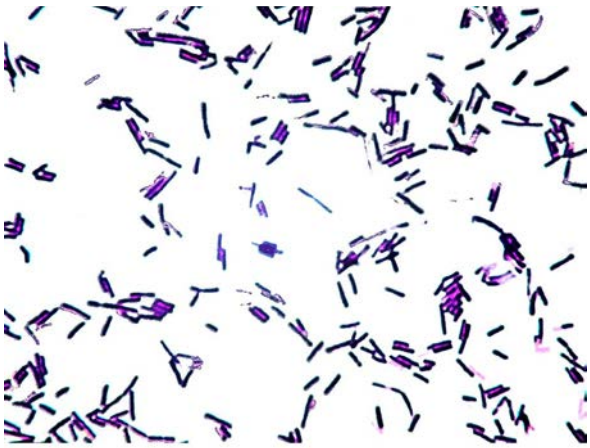
- The presence of Escherichia or Enterobacter may indicate that the supply is contaminated with untreated surface water or even sewage. Further investigation is recommended.
- Both Escherichia and Enterobacter grow readily in unfermented wort causing flavour problems when in high numbers.
- Legionella can cause serious illnesses. Usually the bacteria are transmitted when the water is in a mist form, for example from cooling towers (see Section 18, utilities).

Samples are examined using a microscope. The following show a few examples of micro-organisms.

Photomicrographs of typical bacteria found as brewing contaminants.

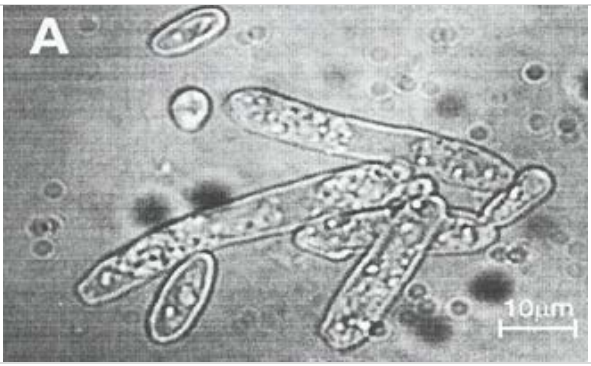


Pediococci (note the commonly seen tetrads)

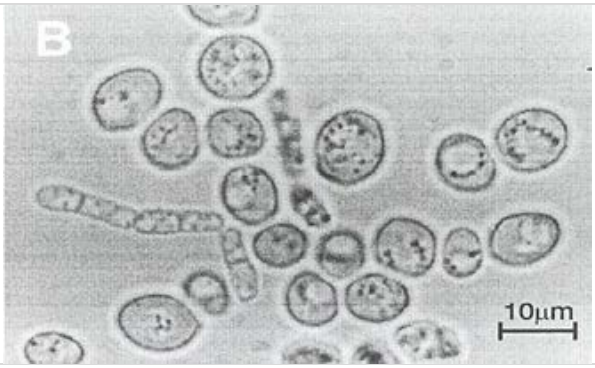


Lactobacilli

Photomicrographs of wild yeast and contaminated culture yeast



Wild yeast



Brewing yeast contaminated with wild yeast

13.3 Detection and monitoring

Methods of sampling

It is important to know the microbiological condition of the production plant, the product in process and of the raw materials. It is difficult to detect micro-organisms since they are not visible to the naked eye. Micro-organisms grow very rapidly in the correct condition therefore only a very small population of them is a potential risk. By the time they are noticed as haze or flavour taints, the contamination is already fully developed. But identifying a

small population is nearly impossible especially in a large volume of beer. This knowledge that the beer is contaminated can be used to improve the cleaning or production process as required.

It is therefore necessary to develop methods of detecting micro-organisms at a stage before they develop into a problem. This is achieved by:

- Visual examination - samples can be examined with the naked eye or viewed under a microscope.
  - Samples that have micro-organisms growing in them will usually be cloudy and an experienced person can tell from this if there is a problem. Also colonies can be seen on plates on which micro-organisms are growing.

- In order to carry out a detailed examination using forcing / plating / microscopic examination, it is necessary to take a suitable volume of representative sample which must be obtained using aseptic techniques to ensure it is uncontaminated by micro-organisms outside the bulk of material being sampled otherwise a false result is given. In aseptic sampling, the sampling equipment and the sample bottle are all sterile.

- Using ATP tests. The ATP test is a process of rapidly measuring actively growing microorganisms through detection of adenosine triphosphate. ATP is a molecule found in and around living cells only, and it gives a direct measure of biological concentration and health. ATP is quantified by measuring the light produced using a luminometer. The amount of light produced is directly proportional to the amount of living organisms present in the sample.

- Inspecting the sample through a microscope and identifying the foreign organisms (but often only useful after the micro-organisms have been grown).
  - More detail can be seen under the microscope as micro-organisms have different shapes and an experienced microbiologist can identify them.
  - A useful technique is to stain the sample to be examined, some bacteria take on the stain, others do not. A Gram stain colours 'Gram positive' bacteria like lactobacillus.

- Encouraging the micro-organisms to grow (with enriched media) so that they can be more easily detected and identified by plating out on growth media and counting the colonies which grow. By using a range of selective growth conditions, the micro-organism can be identified with sufficient accuracy to enable the brewery hygiene to be controlled at optimal cost. The conditions may be aerobic or anaerobic, according to the needs of the microbe being looked for.

- Forcing. This is where a bulk sample is taken, and the growth of micro-organisms is accelerated by culturing at relatively high temperatures, circa 30^{o}C for 3 to 5 days, for rapid growth. The sample may or may not have additional nutrients added prior to forcing, to encourage growth of the type of microbe being looked for. The conditions may be aerobic or anaerobic, according to the needs of the microbe being looked for.

- API analysis. This is a commercially available method for rapid manual identification of yeasts and Gram positive and Gram negative bacteria.

Beer for microbiological analysis can be sampled in a number of ways. These are shown in the table below along with the procedure's advantages or disadvantages:-

Sample point	Sampling procedure	Comment
Sample tap in a tank	Tap is sterilised, usually by heat. Sample is run into a sterile bottle.	Easy to operate. The tap is difficult to sterilise. The tap needs to be cleaned when the tank is cleaned.
Membrane sample point in a tank	A sterile needle is inserted into the membrane. Sample is run into a sterile bottle.	The membrane is easily cleaned when the tank is cleaned. The membrane needs to be replaced regularly.
Aseptic sample valve, e.g. Keofit	The valve body is arranged so that the internal sampling area can be sterilised before use. When the valve is closed it is possible to pass sterilising liquid through the top sample point and out through the bottom. This sterilises the entire internal surface of the valve.	

Continuous sampling from a process line	A sample is continuously 'dripped' into a sterile bottle from a sample point in, for example a filter line.	Representative of the whole batch of beer.
Swabbing	The plant is checked by rubbing with a sterile swab, normally wetted with saline solution. Sometimes the saline is added after swabbing. The saline solution is normally plated out using agar growth media.	Access to plant not always possible, especially in large automated breweries. The area being swabbed needs to be of consistent area and consistent location every time that item of plant is sampled.
Rinse samples	Samples of the final drainings of the final rinse water, or flush water are taken.	Can be difficult to obtain aseptically. Provides a snapshot of the hygiene at the time of the final rinse, but not necessarily say 48 hours later when the plant is used.

Sampling points

When beer is contaminated, it is usually necessary to identify the responsible organisms. It is to routine to check for microbiological contamination throughout the brewing process:

- Water and raw materials.
- All products and additions made to the wort and beer.
- Wort and beer in process.
- Hygiene and cleanliness of all vessels and pipework.
- Beer in package.

13.4 Control

Practices to protect against contamination

There are 5 main considerations in achieving a high standard of micro-biological control:-

- Design of plant for maximum hygiene and ease of cleaning.
- Effective plant cleaning and sterilisation, housekeeping.
- Product and raw material sterilisation, e.g. wort boiling, sterile filtration, pasteurisation.
- Creating conditions that inhibit microbiological growth, e.g. cold storage, low beer pH, acid washing of yeast, pasteurisation, filtration, regular fresh yeast cultures.
- Monitoring microbiological quality.

Plant design

Micro-organisms will persist on rough surfaces, in corners and it the 'dead ends' of pipework. The plant should be designed (e.g. smooth surfaces, no dead ends, cleanable pumps) to eliminate these problems (for more detail see Section 16).

Plant cleaning and sterilisation

The principles of effective cleaning are to remove soil and micro-organisms from the plant surface and then, if necessary sterilise to kill any remaining harmful bacteria or yeast, (for more detail see Section 15).

Good housekeeping and environmental cleaning form an essential part of creating hygienic brewing conditions.

Product sterilisation

- Wort is boiled in the brewhouse. One of the reasons for doing this is to sterilise it.
- Beer for packaging is often sterile filtered or pasteurised to improve microbiological stability.
- Beer recovered from surplus yeast or from packaging operations is often sterile filtered or pasteurised to improve microbiological stability.
- Pitching yeast is sometimes acid washed to kill off any contaminating micro-organisms. Bacteria are more vulnerable to acids because they have thinner cell walls.

Soak baths

Soak baths may be used to maintain the sterility of small fittings, such as swing bends and hoses when not in use for a production process. However, it is preferable to clean hoses and fittings as part of a CIP circuit and leave connected and isolated, full of sterilant or sterile rinse liquor unless in use. Key procedures for maintaining their effectiveness include:-

- Regular replacement of the sterilising solution with fresh sterilant solution.
- Removal of the hoses and fittings prior to cleaning and then refilling the bath with fresh sterilant, and rinsing prior to replacement.

- Thorough rinsing out of hoses and fittings prior to submersion in the sterilant solution.
- A schedule of replacement and regular checks to ensure the solution is being replaced properly.
- Correct placement of hoses and fittings in the soak bath to ensure there are no trapped air bubbles. Unless the sterilant is contact with the fitting, it cannot sterilise / keep the hose / fitting sterile.
- Do not allow the soak bath to be overloaded. All hoses / fittings must be fully submerged at all times.
- Ensure the hose linings are crack free.

Conditions that inhibit microbiological growth

Micro-organisms have optimum conditions for growth. Where possible, beer is kept in conditions that inhibit their growth. This means as low a temperature as practicable, close to minus 1°C. pH values in the range 3.6 - 4.4, typical of most beers, will inhibit the growth of many bacteria.

The same principles apply to yeast during its storage, but normally this is stored slightly warmer at circa 3°C.

Measures to combat known sources of contamination

The measures to combat known sources of contamination are virtually the same as practices to protect against the spread of contamination.

- Monitoring microbiological quality – to identify when and where contamination is present.
- Design of plant for maximum hygiene and ease of cleaning, e.g. smooth surfaces, no dead ends, and cleanable pumps.
- Effective plant cleaning and sterilisation, good housekeeping.
- Product and raw material sterilisation, e.g. wort boiling, sterile filtration, pasteurisation.
- Creating conditions that inhibit microbiological growth, e.g. cold storage, low beer pH, acid washing of yeast, pasteurisation, filtration, regular fresh yeast cultures.

Where a batch of product, whether raw material or product in process, including yeast, wort, beer, is known to be contaminated, then the priority is to prevent that batch from contaminating any other batches. Then, identify where and why the contamination has arisen. Any or all of the following actions may then be required to eliminate the spread of any contamination and to prevent re-introduction:-

- Disposal of the contaminated batch without further processing.
- Cleans before and after transfer of the contaminated batch.
- Disposal of contaminated yeast. Acid washing should not be considered a suitable process for eliminating all bacterial contamination and will not kill contaminating wild yeasts.
- Special cleans, for instance to remove beer stone that has built up without prior knowledge.
- Maintenance of equipment to stop leakage, or ingress through faulty seals, pin hole leaks etc.
- Change of detergent or sterilant as sometimes micro-organisms can become resistant to sterilants.
- Increase in detergent or sterilant strength if found to be below recommended concentrations.
- Increase in temperature of detergent / sterilant.
- Review of cleaning cycle times.

Notes

- *Identify the areas in a plant that you are familiar with where microbiological contamination is most likely.*
- *Specify the micro-organisms that cause problems in a brewery that you are familiar with.*
- *What problems do they cause and how are they eradicated?*
- *View a sample of yeast under the microscope at a range of magnifications and draw what you see.*
- *Give details of the procedures used to combat microbiological contamination in a brewery that you are familiar with.*
- *Give details of the microbiological sampling procedures and schedules in a brewery that you are familiar with.*

Qualifications

The General Certificate in Brewing (GCB)

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Section 14 Quality Assurance and Quality Management

14.1 Quality Management

*Candidates should have an understanding of the fundamental principles of Quality Management and be familiar with the methodology of **at least one quality system** appropriate to their region/country of operation.*

The Key Features of a Quality Management System are:-

- To understand precisely what is to be achieved.

  This means having **specifications** to meet and it means having **procedures** to follow.

  This also means that the procedures and specifications will have to be **documented**.

- To **monitor** actual performance against what is to be achieved.

  This means keeping records of performance and it means **auditing**.

- To correct things when they go wrong.

  This means having a system of initiating **corrective action**.

- To **review** the overall quality management system and to plan for **improvement**.

(a) Specifications.
Process and product specifications must detail all those parameters that are required to be measured, including flavour, and they must identify an ideal value together with an acceptable range for each parameter.

(b) Procedures.
Documented procedures are there to explain what has to be done and when and how it should be done. Procedures can cover a wide range of topics:-

- An explanation of the organisation and responsibilities.
- Procedures to be followed in the case of non-conformances.
- Procedures on how the processes are managed.
- Instructions on how to operate the plant.
- Procedures to be followed when auditing.

(c) Documentation.
Quality management systems rely on documents to ensure that procedures are followed.

The theory being that 'if it isn't written down, it isn't done'.

It is important that documents are 'controlled' so that people are confident that the document they are working to is current and valid.

(d) Monitoring.
Quality performance is monitored on a regular basis and the results can be presented in a way that highlights problems.

(e) Auditing.
The purpose of auditing is to check that the quality system is being followed.

Audits are concluded with a report back which usually identifies areas for improvement.

Auditing procedures have the advantage that they can be conducted internally.

Audits do not necessarily have to cover the whole quality system, often following a trail of evidence will reveal how rigorously procedures are being followed.

(f) Corrective Action.
Action must be taken to put things right and how this is done is usually covered by a procedure.

The procedure will ensure that the following areas are covered:-

- Detail of the problem.
- Nominating the person responsible for taking the action.
- When the corrective action will be completed.
- A review of the result of the corrective action taken.

(g) Review.
An overview is required so that it can be confirmed that, for example:-

- Corrective actions are being followed (implemented) in time.
- Audits are taking place as specified.
- The brewery's quality is meeting requirements.

The procedure for a review is specified and documented in the same way as all other procedures.

(h) Improvement.
It may be that an overall improvement in quality is required; many world class manufacturers have a 'zero defect' policy.

In this case a plan to achieve the required improvements is necessary. The quality management system will contain all the specification and monitoring procedures to enable an improvement plan to be implemented.

Total Quality Management (TQM)

A good quality system includes:-

- Motivated and well trained workforce.
- Well maintained plant.
- Adequate capacity for peak demand.
- Good plant cleanliness and housekeeping.
- Sufficient time for operations, cleaning and maintenance.
- Good relationships between suppliers and customers.

Typical Quality Management Systems include:

- **ISO 9000** - Quality Management.
- **ISO 14000** - Environmental Management.
- **GMP** - Good Manufacturing Practice.
- **GLP** - Good Laboratory Practice.
- **NAMAS** - National Accreditation of Measurement and Sampling.
- **HACCP** - Hazard Analysis Critical Control Points.

Notes.
Give details of a quality management system that you are aware of.

14.2. Roles and Responsibilities and Benefits

Individual Actions on Product and Service Quality

Quality is the responsibility of everyone working within an organisation. However, the following actions are required of a quality system:-

- It is the responsibility of top management to formulate the Company's quality policy and to ensure commitment at all levels to comply with the Quality System and to improve its effectiveness.
- Communication to all members of staff so that all understand it and are involved with its implementation.
- All staff members responsibilities and level of authority should be defined and understood.
- A management representative should be appointed as Quality Systems Manager, responsible for:
    - managing the requirements of the quality standard
    - issuing amendments to manuals
    - arranging audits
    - checking suppliers
    - taking minutes of quality meetings
    - investigating problems and initiating corrective actions
    - following up corrective actions
    - handling complaints

The Control of Documents

All quality systems require control of documentation. It is necessary to identify controlled documents (i.e. updated) and uncontrolled documents.

- Examples of Controlled documents include:-
    - Quality Policy
    - Quality Manual
    - Procedures
    - Work Instructions
    - Specifications
    - HACCP systems
    - Codes of Practice
- Controlled documents must be:-
    - approved before issue
    - reviewed and updated
    - changes identified
    - up-to-date
    - legible
    - external documents also controlled
    - obsolete documents removed
- Document control is usually achieved by:-
    - issuing on coloured paper or including colour logo

- no photocopying
- uniquely identified
- pages numbered (e.g. Page 1 of 10)
- maintaining distribution list of holders
- ensuring documents are not issued without authorisation
- only being available to staff who need to use them
- limiting number of copies issued

- Document change is controlled by:-
  - approval of changes before issue
  - issue of an amendment sheet so that changes are identified
  - keeping a master list of document numbers to ensure all staff use up-to-date copies
  - retrieval of obsolete copies as replacements issued
  - archiving one copy

The Maintenance of Conformity

Adherence to a well-established quality system will ensure that conformity of product quality and company operation is maintained.

However, all quality standards strive for improvement and this is often best achieved by regular management reviews of the quality system and appropriate communication to all staff, especially for changes to systems and regulations.

Regular quality review meetings should:

- review the Quality Policy and Quality System at defined intervals (at least annually).
- be additional to departmental or section quality meetings.
- be chaired by senior management.
- include QA staff, production managers, auditors, purchasing staff.
- review the operation of the quality system.
- ensure the policy and system are suitable and effective.
- recommend changes.
- record actions and responsibilities.
- meeting agenda should include:
  - audits (internal and external)
  - process performance
  - complaints
  - preventative and corrective actions
  - changes
  - training needs
  - supplier performance
  - future developments

Benefits

The control of quality through a 'Quality System' gives the following advantages over a 'Final Inspection' approach:-

- The use of documented procedures and specifications ensures that everybody knows what they are supposed to be doing.
- The responsibility for quality sits with the people who are operating the plant and making the beer.
- Quality problems will be identified as soon as they occur rather than much later when the process is over.

Maintenance of accurate records makes it easier to track back and investigate raw materials or processes so that 'due diligence' in manufacturing can be proved.

14.3 Product Safety

HACCP - Hazard Analysis, Critical Control Points

HACCP is a programme that provides food manufacturers with a systematic approach to address possible sources of contamination of foods and beverages that could adversely affect human health.

The concept was developed by NASA in the 1960s as part of research into 'astronaut well-being' for the American space programme, and more recently has evolved for the general food industry. HACCP, or its international version, iso 22,000, is now universally recognised by key legislative bodies as the internationally accepted food safety standard. The global brewing industry is obliged, both legally and morally, to provide safe and wholesome products for consumption and to assure food safety throughout the supply chain.

There are three types of hazard, namely **chemical**, **physical, allergens** and **microbiological**; it is important to note that hazards directly affecting quality, with no consumer safety implications. are not part of HACCP. Given that beer contains ethanol, and has a relatively low pH, and has limited available nutrient, the potential growth of any pathogenic organisms (harmful to human health) is limited, with only a few issues deriving from mycotoxins produced by certain moulds and specific flavour compounds produced by certain wild yeasts. However, contamination at successive stages of the process by various foreign bodies and chemicals such as detergent or coolant is a viable risk that needs to be addressed and controlled. The HACCP programme thus developed will address risk by prevention rather than by final product inspection.

Most countries have legal requirements for manufacturers to supply food that complies with food safety requirements and is of the nature, substance and quality demanded. Food

safety regulations demand that suppliers consider the potential food safety hazards throughout their operation, identify those steps where such hazards may occur, and put in place at these points monitoring and control procedures for any hazards deemed 'critical'. Other reasons to adopt a HACCP approach include customer expectations, cost control, especially in the prevention of product recalls, product integrity, and the need for accreditation to external auditing bodies.

A HACCP system consists of two main parts, namely individual HACCP studies on each separate process or production line, and so-called 'prerequisite programmes' normally contained within the mantle of Good Manufacturing Practice (GMP), covering elements such as Pest Control, COSHH, personal hygiene, workwear standards, equipment design, plant CIP, preventive maintenance programmes etc.

The HACCP process consists of nine essential steps (some companies base their processes on seven steps):-

- Agreeing the scope of the study.
- Conduct a hazard analysis by constructing a flow-diagram of the various process steps.
- Listing the hazards, rank them in order of 'risk', specify any control measures.
- Determine any critical control points.
- Establish critical limits.
- Set up monitoring of limits at each CCP.
- Establish any corrective actions.
- Set up documentation and record-keeping systems.
- Set up procedures to verify that the HACCP plan is working effectively.

In order to conduct an effective HACCP study, a multi-disciplined audit team involving operators, managers and technologists, must be assembled, containing the necessary engineering, technical and practical knowledge of the area to be covered by the study. The team leader should be qualified or experienced in HACCP principles.

Step 1 Define the scope of the HACCP study, i.e.

- The extent of the process covered, e.g. canning line from BBT outlet to ' full can' warehouse store
- Product description and its intended use
- Types of hazard considered, i.e. physical, chemical, microbiological
- Description of any prerequisite programmes

Step 2 Preparation and verification of the Process Flow Diagram

The flow diagram is a detailed description of the process under study produced by the team to enable them to identify any process hazards whilst conducting the analysis. The diagram must show each process step in sequence and indicate clearly each material addition and service. The HACCP team should verify the flow diagram for accuracy by walking the process with the associated operational teams and checking any relevant documentation (work instructions, engineering drawings etc.)

Step 3 Hazard analysis and identification of controls

The team should consider in turn each of the constituent process steps detailed on the flow diagram and conduct a hazard analysis to establish which hazards are present and if they present a risk to the consumer. Each hazard detected should be ranked in terms of' 'risk' on a scale of 1-3 according to:-

- Impact on the consumer (1= minor aversion; 3= serious injury/illness or even fatality).
- Likelihood of occurrence (1=remote, single batch affected ; 3 = multiple batches affected).

Hazard (Risk rating) = Impact x likelihood/probability, hence multiplied score can range from 1 to 9. Any hazard scoring 3 or more is deemed significant and should therefore be included in the HACCP study as a critical control point (CCP), the team identifying the appropriate 'control' to reduce the risk to an acceptable level and document it in the study.

Step 4 Establish any CCPs by using a decision tree which asks four key questions, viz:

- Are control measures in operation at this stage?
- Does this stage eliminate the hazard or reduce it to an acceptable level?
- Could contamination with the hazard occur at an unacceptable level?
- Will a subsequent process stage eliminate the hazard or reduce it to an unacceptable level?

If the answers to these questions are respectively either:-

Yes, Yes, or

Yes, No, Yes, No

Then the hazard point is a CCP.

Step 5 Establish critical limits for each CCP.

The critical limits define the difference between a 'safe' or 'unsafe' process, so if the limit is exceeded, the process is out of control and the safety of the product is compromised. For example, the critical limit for a trap filter

on the beer supply line to the can filler is “filter of correct mesh size in place and checked weekly for security and integrity” Such Critical Limits are simple to install and thereby implement corrective action.

Step 6 Establish monitoring for each CCP

The monitoring procedure must state:-

- The frequency of monitoring.
- The person responsible for carrying out the monitoring.
- The monitoring procedure.

The frequency of monitoring is such that any loss of control of a CCP is detected and rectified before any product deemed at risk leaves site: for example, putting a series of test bottles weekly through the empty bottle inspector (EBI) on a bottling line would require quarantining of a week’s production should the test fail. As ever, all monitoring results should be recorded.

Step 7 Set up any necessary corrective actions

When a critical limit is exceeded appropriate ‘corrective action’ needs to be implemented to bring the CCP back into control: it must stipulate ‘what to do’ both to restore the CCP to control and to deal with any affected stock produced since the last ‘good’ monitoring result. Again, all corrective actions should be documented. As an example, any stock at risk because of an EBI test bottle failure should be quarantined by the team leader, ‘sorted’ for possible glass defects, the test bottles checked, the test re-run immediately and any sources of potential defects within the empty bottle supply to the EBI highlighted and eliminated before production resumes.

Step 8 Create appropriate documentation and records

Each study should yield a HACCP plan, defining hazards, causes, risk rating, control, monitoring and corrective actions, which can serve both as a work instruction and a training document.

Step 9 implementation, verification and review

Having documented all the CCPs and their ensuing critical limits, monitoring and corrective actions, the appropriate responsible people must be trained. Verification procedures should then be established to ensure that the controls implemented are sufficient to manage any risks identified. An example is a regular review of small-pack consumer complaints, where the incidence of flavour defects and foreign bodies will serve as a measure of the effectiveness of ‘chemical’ and ‘physical’ CCP control on small-pack production lines . A review of the HACCP plan should occur at least annually, together with auditing of the CCP monitoring and corrective actions.

In summary, HACCP is all about:-

- Meeting legal, customer and consumer requirements.
- Preventing the risk of illness or injury to consumers.
- Ensuring due diligence and avoiding liability.
- Saving money.
- Preventing brand damage.

Qualifications

The General Certificate in Brewing (GCB)

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Section 15 Plant Cleaning – Detergents and Sterilants

Plant cleaning - Introduction

The objective of any cleaning and sanitising programme is the control of microbiological growth.

Growth control can be effected by:-

- limiting microbial growth by the removal of nutrients or protective materials and films in the forms of scales and biofilms (cleaning).
- by removing all viable microbes by either total removal (sterilisation) or removal of vegetative cells only (commonly known as sanitisation) by the application of agents (e.g. biocides) to kill microbes or by the application of agents that, in continued presence, prevent growth (e.g. bacteriostats).

Typically, control measures follow the cycles of:-

- soil removal (or cleaning).
- disinfection or sanitisation (chemical agents or heat) to prevent growth or eliminate viable microbes.
- sterilisation to prevent the growth of any surviving organism including spore formers (by use of chemical agents or heat) thus preventing spoilage.

The purpose of cleaning is to remove permanently all the soil from the surfaces of the plant and to leave it in a condition suitable for use.

The purpose of sanitisation or sterilising is to kill any micro-organisms that remain on the internal surfaces of the plant after cleaning so that the wort, beer or yeast is not spoiled due to infection by any remaining viable organisms.

(a) Microbiology of Cleaning

The degree of cleanliness required for a processing plant is defined by the potential impact of the soil or microbes on the resultant product. This is largely determined by the type of product being produced in that particular plant.

Products that are sensitive to spoilage require higher degrees of cleanliness (hygiene) than those that are not as susceptible; therefore knowledge of the products propensity to spoil is essential in determining an appropriate cleaning sequence.

This may or may not include a sanitisation / sterilisation step.

- 'Clean conditions' are defined as those following the removal of all soils but not all vegetative cells. Thus the higher the required degree of cleanliness the more robust the cleaning process has to be, and the more important it becomes to ensure that the plant is designed for effective cleaning.
- 'Hygienic conditions' for brewing and other beverage plants are defined as a degree of cleanliness which has been achieved by elimination of vegetative forms of life, making it suitable for most aspects of beer brewing or other beverage production.
- 'Disinfection or sanitisation' may be defined as the destruction of micro-organisms, but not usually bacterial spores. It does not necessarily kill all micro-organisms, but reduces them to a level acceptable for a defined purpose, i.e. a level which is harmful neither to health nor to the quality of perishable goods (in this case beer, cider etc.).
- 'Sterilisation' is defined as the elimination of all forms of life including microbial spores. Typically this is most effectively achieved with live steam at a minimum temperature of 122°C for a contact time of at least 15 minutes. These conditions are found most typically in the pharmaceutical manufacturing environment, but in breweries most commonly in a microbiological laboratory autoclave for preparing growth media, etc.

(b) Detergents

A detergent is a blend of chemicals, which is put together to help solubilise soil, remove it from the surface and ensure that it does not re-deposit itself back on the cleaned surface.

(c) Sterilants (sanitisers)

Sterilants (sanitisers) are formulated to kill microbes and bring micro-organism load to an acceptable level and work by:-

- Creating the conditions of temperature, pH, chemical or surface activity that destroy (kill) micro-organisms.

15.1 Detergents

Detergents help the cleaning process by:-

- Penetrating the soil, usually by increasing the wetting power of the cleaning liquid.
- Dissolving soluble soil material.

- Dispersing insoluble soil and holding it in suspension so that it does not re-deposit.

- Carrying the soil away as the cleaning liquid is rinsed off.

A detergent is made using an acid or an alkali as the basis. Therefore the chemical properties of the detergent are acidic or alkaline.

In a brewery, the organic soils are best removed using an alkaline cleaner. Acids are used to remove inorganic deposits such as hard water deposits.

Formulated detergents used in the beverage industry comprise:-

- A base dissolving material, which is either alkali or acidic. These form the main dispersing agent of the detergent.

- Surface active molecules as wetting agents (surfactants).

- Chelating agents or sequestrants.

- Rinsing agents.

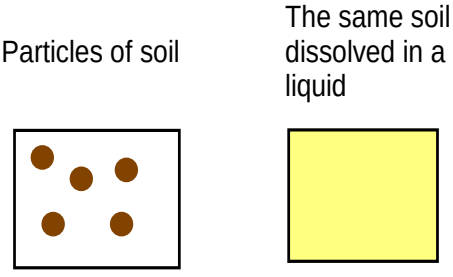
- Oxidising agents (sometimes).

Constituents of detergents and their functions

Water
Water acts as the principal solvent that breaks up soil particles after the surfactants reduce the surface tension and allow the water to penetrate soil (water is commonly referred to as "the universal solvent").

Water also aids in the suspension and anti-redeposition of soils. Once the soil has been dissolved and emulsified away from the surface, any redeposition should be prevented. Water keeps the soil suspended away from the clean surface so that it can be carried away easily during the rinsing process. It is clear that without this water, the cleaning formulae would be much less effective.

Base material (dissolving agent)
When a substance is dissolved, it becomes chemically bound into the liquid and the liquid is usually clear. If the soil can be dissolved in the detergent liquid, not only can it be removed from the plant surface, it can also be carried away easily.



There are two main types of soil that need to be removed from the surface of brewing and packaging plant:-

- Organic soil which includes yeast, protein, fat and sugar. Plant which has a lot of organic soil that needs to be removed should be cleaned with a detergent that contains compounds that can dissolve it. Alkalis like caustic soda dissolve organic soil and caustic solutions are often used to clean fermenting vessels and brewhouse plant.

- Inorganic soil which includes hard water scale and 'beerstone'. Plant in some breweries becomes scaled up quite quickly, especially in hard water areas. This plant needs to be cleaned regularly with a detergent that dissolves scale.

Caustic & other alkalis
Caustic detergents are made of caustic soda (sodium hydroxide) as the main ingredient. Caustic or alkali detergents can be chlorinated.

To clean surfaces where caustic is not allowed, detergents are used which use sodium metasilicate as a base. Sometimes soda ash or phosphate salts are used as alkali source with builder (sequestering) properties.

To deal with stubborn dirt, chlorinated caustics or chlorinated alkalis are sometimes used. The amount of available chlorine of the working solution should not exceed 200ppm, and the pH should be greater than 11, i.e. highly alkaline, to protect stainless steel from pitting and/or stress corrosion.

Acids
Acid detergents are also used specifically for descaling. The scale is made of metal salts of oxalates, phosphates, carbonates, silicates, etc. The acid detergent should be able to penetrate scale, for which a strong acid component such as nitric acid is required. To facilitate the removal of scale, an acid such as phosphoric acid is required that will attach itself to metal ions and act as a sequestrant. Acid detergents are often made of a blend of phosphoric acid and nitric acid to a 1.2:1 ratio.

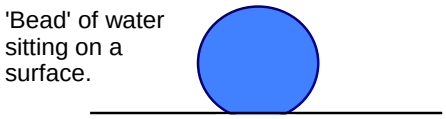
Adding wetting agents in acid detergent improves penetration and removal of scale especially when the scale is not only inorganic soil.

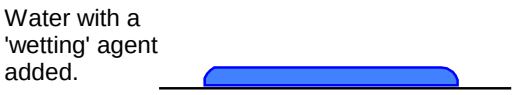
Acids with a higher level of nitric acid than phosphoric acid are recommended for passivation of stainless steel.

Wetting agents (surfactants)
In breweries, water is always used as the medium for carrying the detergents used to clean brewing plant. However, water has a relatively high surface tension and forms 'beads' on a surface rather than wetting it.

Most detergents contain substances that reduce the

surface tension and so increase the detergent's wetting power. Surfactants have a hydrophobic (water repellent) part and a hydrophilic ('water loving') part. Dependent on the nature of the hydrophilic part the surfactants are classified as an-ionic, non-ionic, cat-ionic or amphoteric.





Surface-active molecules act as wetting agents that assist with penetration of water into the dirt, otherwise water clings to itself due to the bipolar nature of the water molecule. During cleaning of organic soil such as proteins, surface-active molecules are created out of hydrolysed proteins, hence the creation of foam during cleaning. Because of this tendency to foam, detergents are often supplemented with an antifoaming agent.

Chelating (Sequestering) agents

Water is made "hard" by the presence of calcium, magnesium, iron and manganese metal ions. These metal ions interfere with the cleaning ability of detergents. The metal ions act like dirt and "use up" the surfactants, making them unavailable to act on the surface to be cleaned.

A chelating agent (pronounced *keelating*) combines itself with these disruptive metal ions in the water. The chelated metal ions remain tied up in solution in a harmless state where they will not use up the surfactants.

The choice of chelating agents or sequestrants depends on the pH of the working solution. Their effectiveness is pH dependant. Some common chelating agents used in industrial cleaning compounds include phosphates, sodium gluconate/heptonate or amino tris (methylenephosphonic acid) EDTA (ethylene diamine tetra acetate), sodium citrate, sodium polyphosphates and zeolite compounds.

Rinsing agents

It is important that at the completion of a cleaning cycle, no detergent and accompanying soil remains on the plant surface. In other words, the detergent must be 'rinsable'.

Thus to be effective, a detergent must be capable of adhering to the plant surface being cleaned; when the job is done, however it must be rinsed away.

Rinsing agents are added to the detergent to enable these two incompatible actions to take place.

Oxidising agents

These enhance soil breakdown and removal by the mechanical action of the O2 gas release, or more normally by the oxidation of the soil. These are generally added to the caustic based detergent just before the point of use as the oxiding agent breaks down so quickly, particularly at high temperatures. Common usage areas include wort copper heating surfaces and liquid hop extract addition equipment.

The table below summarises the details of the most **common constituents** and their contribution to the **effectiveness** of the **detergent**:-

Constituent	Effects	Benefit/problem
Caustic soda	Dissolves organic matter. Sterilises especially when hot.	Does not rinse well. Very hazardous and cannot be used by hand. Dissolves aluminium. Denatured by CO2. Spraying a tank containing CO2 with caustic can create a vacuum and collapse the tank.
Other alkalis e.g. silicates	Dissolve organic matter.	Less aggressive than caustic soda. Very good dispersants.
Oxidants e.g. Hypochlorite	Help dissolve protein. Sterilise.	Very corrosive unless at high pH.
Phosphates	Soil removal.	Very good rinsing properties.
Acids (nitric, phosphoric)	Dissolve scale.	Corrosive in high concentrations. Not denatured by CO2.
Wetting agents e.g. teepol	Reduce surface tension.	May cause the detergent to foam.
Sequestering agents e.g. EDTA	Prevent the formation of scale.	Expensive.

Factors affecting the selection of detergents

Legal aspects
Is the material legally allowed to be used in this situation?

Nature of the soil
In the brewery, the soil will generally be a combination of proteins, carbohydrates, and fats. In filtered beer packaging, the soil will consist largely of light deposits of minerals and proteins.

Corrosivity
The detergent used for cleaning the production plant material must not corrode the brewing / packaging plant or the building materials.

Composition / residues
What is the composition of the material, both before use and as a result of any breakdown during use or storage? How will these affect the product?

Hardness of the water
The degree of water hardness may make it necessary to add a chelating (sequestering) agent to the water.

Temperature
Is it possible to use hot detergent solution? This can often improve and shorten the cleaning process. However, see later notes on use of hot detergent.

Cleaning method
How is the material to be used? E.g. contact time, temperature, concentration. When manual cleaning is used, the detergent should not be aggressive to the skin. With mechanical or automatic cleaning, the quantity of foam that is produced may be a limiting factor.

Safety aspects
How safe is it to handle? What precautions must be taken to protect personnel who are handling the material directly, or working in the vicinity of the material in concentrated or usable form? Particularly when working with concentrated detergents and hot detergents, it is necessary to take measures to protect personnel. Plant may need to be specifically designed to cope with hot cleaning.

Product integrity
The detergent should not affect the taste and flavour of wort and beer, and should not contain any odorous matter. In working solutions the detergents should not affect the head retention and the colloidal stability of the beer. If, in spite of the precautions taken, traces of a detergent should enter the wort or the beer, the toxicity of the detergent is very important. All cleaning materials must be approved for use in the food industry, and must not exceed the permitted concentrations.

Environmental aspects
What is the impact on the environment, including buildings, the drainage systems and environmental air? Because detergents ultimately end up in the waste water, the various components should be bio-degradable, and not have a significant adverse influence on the biological degradation processes which take place in a wastewater treatment plant.

Solubility
The detergent must be fully water soluble.

Costs
The aim is to keep costs as low as possible. To achieve this, the various products will have to be compared on a cost-effectiveness basis, and not on a price per kg basis, including of raw materials and disposal, and any additional handling or storage requirements. The reason for doing this is that the costs of labour and equipment account in most situations for the bulk of the cleaning costs. An important aspect in this context is whether the detergent can be re-used or regenerated.

Analysis methods
How easy is it to monitor and maintain strengths during the cleaning process? Are any special chemicals or equipment required for both in line and off line analysis?

Caustic / alkaline detergents

- Caustic soda based products are easily controlled on conductivity, but when they are contaminated with carbonates, which contribute to conductivity, the control using purely conductivity is not accurate.
- Caustic soda based products react with carbon dioxide, producing sodium carbonate then sodium bi-carbonate, reducing cleaning efficiency. When cleaning vessels this situation creates the potential for implosion of the vessel.
- Caustic solutions provide bacteriological action at high pH, particularly when used hot e.g. at 65^{O} C.
- They will corrode aluminium rapidly, and copper and brass to a lesser extent.

Acid detergents

- Acidic products are used to remove inorganic soils such as mineral films (from hard water) and stones (e.g. calcium oxalate) from brewing.
- They are most effective at pH < 2.5.
- They are free rinsing and help to remove inorganic soil.
- Anionic surfactants can be added to improve soil & scale penetration.
- They do not react with water hardness or carbon dioxide.
- They are generally easily controlled using conductivity instruments.
- They require formulation with “non oxidising biocides” to deliver concurrent cleaning and sanitising, and to maintain hygiene in the recovered acid detergent tank.

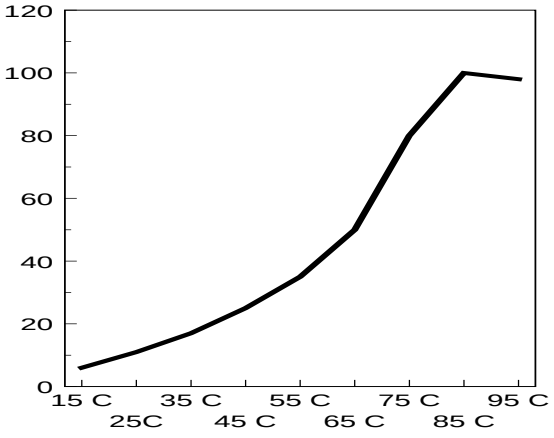
The table below gives details of the types of detergent used to clean in the various situations encountered in breweries and packaging plants:-

Plant to be cleaned.	Detergents often used.
Brewhouse e.g. coppers/kettles. * High level of organic soil.	Caustic soda with wetting / rinsing agents. Used at high temperature.
Fermenting vessels (CIP) * High level of organic soil. * Atmosphere of CO2. * Requirement for sterility.	Caustic soda with wetting/rinsing/sequestering agents. May be used at high temperature if the plant is suitable. Effectiveness may be reduced because of effect of CO2. High usage. Acid with wetting/rinsing agents, but this is less effective than caustic unless high pressure jets are used. Compromise of caustic pre-wash followed by a rinse, then acid recirculation is increasingly being used because of problems with CO2 atmospheres and energy requirements when cold or hot caustic alone used.
Yeast handling plant. * Extremely high levels of organic soil. * Complexity means it is difficult to clean. * Requirement for sterility.	Caustic soda with wetting/rinsing/sequestering agents. May be used at high temperature if the plant is suitable. Caustic pre-wash followed by a rinse, then acid recirculation is increasingly being used.
Maturation/conditioning vessels. * Medium level of organic soil. * Inert gas atmosphere. * Requirement for sterility.	Acid with wetting / rinsing agents. Substitute acid for every 10th clean with caustic soda solution.
Bright beer tanks. * Low level of soil. * Inert gas atmosphere. * Requirement for sterility.	Acid with wetting / rinsing agents.
Process pipework. * Variable levels of soil. * Complexity means it is difficult to clean.	Caustic soda with wetting/rinsing/sequestering agents. Normally cleaned at elevated temperature - ca. 65 ^{O}C is typical.
Packaging plant. * Low level of soil. * Complexity means it is difficult to clean. * Requirement for sterility.	Caustic soda with wetting/rinsing/sequestering agents. May be used at high temperature if the plant is suitable. Cold acid detergent also used - either as normal clean or regular descaling clean.
Returnable cask/kegs. * Care with materials of construction. * High levels of organic soil. * Need for good rinsability.	Caustic soda with wetting/rinsing/sequestering agents. Will be used at high temperature. Must use non-caustic detergents with aluminium.

Temperature

The temperature that a detergent operates at influences its effectiveness. The action of caustic soda, for example is much more powerful at high temperatures than at low temperatures. So called neutral detergents such as silicate based materials are often used hot, particularly for keg and cask cleaning. It is not common to use hot acid detergents.

The graph (below) illustrates how caustic soda reaches maximum effectiveness at 85°C.



Where hot detergents are used, the equipment, whether production or packaging, or reusable packages such as kegs, including any sealing joints / gaskets must be capable of withstanding:-

- The additional corrosiveness during the hot cycle.
- The changes in expansion of enclosed gases when the temperature changes from cold pre-rinses to hot detergent, and from hot detergent to cold post detergent rinses.
- The physical expansion / contraction of the plant itself.

The changes due to use of hot detergent must not adversely affect operation staff or the product.

The temperature used is a compromise between safety of the plant, personnel and product, and the speed and effectiveness of the cleaning and sterilising processes.

Note that hot caustic detergent in the presence of CO2 can create insoluble calcium carbonate deposits on the equipment surfaces.

Notes:-

Identify the detergents used in the following areas of your brewery:-

Brewhouse. *Fermenting vessels.*
Maturation/conditioning tanks. *Bright beer tanks.*
Packaging machines. *Container washing machines.*

15.2 Sterilants (sanitisers)

Introduction

- Disinfection or sanitisation may be defined as the destruction of micro-organisms, but not usually bacterial spores. It does not necessarily kill all micro-organisms, but reduces them to a level acceptable for a defined purpose, i.e. a level which is harmful neither to health nor to the quality of perishable goods (in this case beer, cider etc.)

- Sterilisation is defined as the elimination of all forms of life including microbial spores. This is most effectively achieved in the brewing industry by using steam at a minimum temperature of 122°C for a contact time of at least 15 minutes. These conditions are common in the pharmaceutical manufacturing environment, but in breweries usually only in a microbiological laboratory autoclave for preparing growth media etc. and sometimes in yeast culture plant.

There are several different types of sanitising / sterilising agent. However many are toxic, corrosive, or likely to taint the beer.

Types of sterilants (sanitisers) as defined by active agent

The main types of chemical sterilant are:-

- The 'halogens' like chlorine, bromine and iodine. Chlorine is often used in the form of sodium hypochlorite or chlorine dioxide. Iodine can be used in the form of an iodophor.
- Formaldehyde.
- Ammonia in the form of quaternary ammonia compounds.
- Hydrogen peroxide.
- Peracetic acid.
- Ampholytic surfactants.
- Ozone.

Some of the above are not now considered acceptable for use, for a number of different reasons.

Some sterilants (sanitisers) are considered by many to be suitable for non-rinse application. Peracetic acid is widely considered to be one such material. Most sterilants require rinsing off with sterile water before the equipment may be used.

Sterilants for <u>non-rinse</u> application

Oxygen releasing sterilants
These are peroxyacetic (peracetic) acid (PAA) and hydrogen peroxide based sterilants. They are made from the blending of acetic acid and hydrogen peroxide in the presence of a stabilising agent. When used, the breakdown products are oxygen and water from hydrogen peroxide and acetic acid and oxygen from peroxyacetic acid.

These types of sanitisers break down in the presence of metal ions. Apart from being used in vessel sanitation, they are also used in sanitiser baths and in environmental sterilant formulation.

Hydrogen peroxide
- Not very effective on own.
- Will not affect beer flavour at volumes / levels normally remaining after effective scavenging.
- Safe to use but strong oxidising agent and could be a fire hazard.

Peroxyacetic acids
- Effective over wide temperature range, though contact time may be long at low temperatures.
- Broad spectrum of bactericidal activity.
- Non corrosive to stainless steel.
- Safe at working strength, but dangerous in more concentrated form.
- Larger contaminating volumes / concentrations considered to affect beer / cider flavour, therefore many users prefer to rinse off.

- Unstable unless combined with hydrogen peroxide.
- Considered by many not to affect beer flavour volumes / levels normally remaining after effective vessel scavenging.
- However, many users require a final rinse due to possible flavour effects when in contact with beer or cider.

Sterilants requiring rinsing off after use for plant sterilization

Chlorine dioxide

Chlorine dioxide has gained popularity as an effective, safe to use sterilant. It is effective against a wide spectrum of micro-organisms and in removing biofilms. It is tolerant of small amounts of organic matter.

Chlorine dioxide does not chlorinate, therefore there is minimal risk of flavour taints the low (but still effective) concentrations used for sterilising final rinse waters (circa 0.2 ppm), but risks remain if used as a terminal sterilant (circa 5ppm) and this high level must be rinsed off with sterile water.

However, there is greater risk if the pre-addition chlorine level is high. This often occurs when the liquor has not been de-chlorinated prior to ClO2 addition. The breakdown products of chlorine dioxide are chlorite and chloride.

Chlorine dioxide is used for disinfection in many areas:-

- water disinfection.
- post or final rinse sanitiser.
- biocide for cooling towers and tunnel pasteurisers.

Some brewers have concerns over safety of handling of the raw materials and the accuracy of chemical dosing.

Chlorine releasing compounds

Hypochlorites are widely used as a source of chlorine. These must be kept at low concentrations, typically 150 to 200 ppm chlorine, with high pH to reduce the evolution of free chlorine. The free chlorine attacks the surface of the stainless steel, leading to corrosion which can eventually perforate or crack the steel. It is commonly used in caustic solutions for aggressive "one off" cleans. Chlorine:-

- Is very effective, hard water tolerant and effective at low temperatures.
- Is cheap in most forms.
- Is dangerous as a gas and must be kept away from acids to prevent gaseous chlorine formation.
- Is corrosive to plant.
- Is less effective in the presence of organic matter.
- Leaves a very strong and lingering taint if it contaminates beer or cider.
- Must be rinsed off.

Iodine releasing compounds

Iodine releasing compounds, e.g. iodophors, used to be widely used as both CIP and soak bath sterilants. However use for CIP is comparatively uncommon nowadays, but they are more widely used for sterilant soak baths.

Iodophors combine elemental iodine with surface-active compounds. Acid is added to stabilise the product. Iodine:-

- Is effective across a broad spectrum of micro-organisms.
- Has an effective pH range greater than chlorine (2 to 8).
- Is somewhat less irritating than chlorine.
- Is dangerous as a gas.
- Is corrosive, particularly at high temperatures (don't use above 50^{o}C.).
- Has a long, stable shelf life.
- Loses effectiveness at low temperatures or in presence of organic matter.
- Leaves a very strong and lingering taint if it contaminates the beer.
- Must be rinsed off.

Quaternary ammonium compounds

- Non corrosive, effective at low temperatures and temperature stable.
- Effective at low concentrations.
- Solutions prone to foam formation.
- Adverse effect on beer foam stability.
- Must be rinsed off.

Sterilants for <u>sterilant (soak) baths</u>

Iodophors

Iodophors are used in sanitiser baths because their presence can be easily be detected with brownish red colour. Iodophors can taint the product when not handled properly and if not rinsed off thoroughly before use. Where a fear of tainting exists, peroxide/peracetic acid based sterilants may be used instead.

Chlorine releasing compounds

Hypochlorites are widely used as a source of chlorine for soak-baths. These must be kept at low concentrations, typically 150 to 200 ppm chlorine. To ease safety issues when handling the liquid, tablets of the material are now available, allowing easy, accurate and relatively safe addition of the sterilant to the soak bath water.

Peroxyacetic acids
Peroxyacetic acids may be used for soakbaths. They do however have to be changed regularly, even if the equipment being soaked is not changed for long periods. This is due to the rapid degradation of the PAA to acetic acid and oxygen, particularly in warm environments. It is not possible to determine if there is sufficient active ingredient in the solution simply by looking or smelling, or using a test strip.

Environmental sterilants

Environmental sterilants are used for sanitising floors, walls, external surfaces of tanks and pipes and cleaning of drains. For these to work effectively on surfaces, they must be able to cling to the surface to allow for extended contact time. When rinsed off the walls, they must be easily removed. Because the risk of contact with the product is low, there is a wider choice of ingredients that can be used.

Quaternary ammonium compound (QAC) sterilants
These work by surface action. The QAC formulations contain non-ionic surfactants like ethoxylated fatty alcohols to boost foaming properties of the product. In order that micro-organisms do not develop a resistance to sanitisers, different types should be used over specific periods of time.

Gluteraldehydes
These are commercially available as acidic solutions and they are activated before use by making them alkaline. They have a wide spectrum activity against different micro-organisms.

Biguanides and Chlorhexidines
These have widespread bactericidal properties. For the product to foam, non-ionic surfactants are added. Anionic compounds deactivate these sanitisers. They are also not compatible with phosphate, borate, chloride or carbonate ions because they form salts, which are insoluble so making the active ingredients unavailable.

Chlorine releasing compounds. e.g. sodium hypochlorite
Possibly the most popular sanitiser for drains is sodium hypochlorite solution that has been diluted to contain about 5% available chlorine during use. This must be kept separate from stainless steel equipment (or drain gullys!), as the free chlorine corrodes the stainless. It must also be kept away from acids to prevent gaseous chlorine formation.

Ozone
Although this compound has been successfully used as a sterilant during CIP, it is more commonly used for treating wash-down and rinse water, and therefore has been included as sterilant used for environmental cleaning. Typical use is for packaging wash-down hoses and bottle filler external (glass removal) rinse systems and can filler external rinse systems.

- Ozone is active against bacteria, viruses, fungi and spores.
- Effectiveness of ozone is pH sensitive. It is unstable at both high and low pH.
- The effectiveness at pH 6 – 8.5 is equivalent or better than peracetic acid.
- It is safe to use with stainless steel, but corrosive to soft metals, rubbers and some plastics.
- Low oxygen pickup. 350 ppb ozone resulted in 1.44 ppm increase in dissolved oxygen in rinse water. But it is therefore not suitable for sterilizing deaerated water.
- It has a “half-life” of 10 minutes and so needs to be made at point of use.

Note that because of safety risks, it is not approved for use in all countries.

Ultra violet light
Although not strictly a sterilant for production plant, Ultra Violet (UV) light is widely used to sterilise clear water for rinse waters and high gravity beer dilution water. Once the water has been treated, there is no residual biocidal activity, hence its non-use as a terminal sterilant during cleaning. It is ineffective on turbid water, so cannot be used for hygiene maintenance of detergents or pre-rinse waters.

Criteria for choice of sterilant

The choice of sterilant depends on a number of factors:-

Is a sterilant required?
The microbiological condition of the plant may be suitable for its purpose after the standard clean, particularly those where hot caustic detergents are used. Note also that many acid detergents are now formulated to contain a sterilant, and a separate sterilant cycle is not normally then required.

Legal aspects
Is the material legally allowed to be used in this situation?

Corrosivity
The sterilant used for sanitising the production plant material must not corrode the brewing / packaging plant or buildings.

Composition / residues
What is the composition of the material, both before use and as a result of any breakdown during use or storage? Would a residual ‘taint’ affect the beer quality? If so, it will probably be considered necessary to rinse off.

Cleaning method
How is the material to be used? E.g. contact time, temperature, concentration. When manual cleaning is used, the sterilant should not be overly aggressive to the skin. With mechanical or automatic cleaning, the quantity of foam that is produced may be a limiting factor.

Safety aspects
How safe is it to handle? What precautions must be taken to protect personnel who are handling the material directly, or working in the vicinity of the material in concentrated or usable form? Particularly when working with concentrated sterilants, it is necessary to take measures to protect personnel.

Product integrity
The working strength sterilant residues should ideally not affect the taste and flavour of wort and beer, and should not contain any odorous matter. In working solutions the sterilants should not affect the head retention and the colloidal stability of the beer. If, in spite of the precautions taken, traces of a sterilant should enter the wort or the beer, the toxicity of the material is very important. All cleaning materials must be approved for use in the food industry, and must not exceed the permitted concentrations.

Environmental aspects
What is the impact on the environment, including buildings, the drainage systems and environmental air? Because sterilants or their residues ultimately end up in the waste water, the various components should be bio-degradable, and not have a significant adverse influence on the biological degradation processes which take place in a wastewater treatment plant.

Solubility
The sterilant must be fully water soluble to allow easy rinsing.

Costs
The aim is to keep costs as low as possible. To achieve this, the various products will have to be compared on a cost-effectiveness basis, and not on a price per kg basis, including of raw materials and disposal, and any additional handling or storage requirements. The reason for doing this is that the costs of labour and equipment account in most situations for the bulk of the cleaning costs. An important aspect in this context is whether the sterilant can be largely re-used or is used as a "single shot".

Analysis methods
How easy is it to monitor and maintain strengths during the cleaning process? Are any special chemicals or equipment required for both in line and off line analysis?

Effect of sterilant residues on beer quality

Please refer to the paragraphs above, which summarise the key properties of the various types of sterilant.

Notes.
Give details of the detergents and sterilants used in a cleaning regime that you are familiar with.

Why have those particular materials been chosen?

15.3 Heat sterilization

There is a maximum permissible temperature for growth and survival of any organism, and exceeding this will result in death (macro-molecules lose their structure and cease to function). This is a result of the combination of time and temperature.

Heat is used at different temperatures and for different times to achieve different levels of hygiene.

Lowest temperatures are those used during beer pasteurisation, e.g. 65 ^{O}C for 20 minutes in a smallpack tunnel pasteuriser, or 73^{O}C for 15 seconds in a flash pasteuriser. However neither of these temperatures / times are suitable for plant sanitisation. Pasteurisation is discussed in more detail in the General Certificate in Packaging.

The uses of steam & hot water as sterilants

Hot water is widely used for sterilisation of mains, where very high levels of hygiene, approaching absolute sterility is required. Brewing equipment commonly sterilised using hot water includes:-

- Wort mains and wort chillers.
- Yeast propagation mains.
- Pasteuriser mains and pasteurisers in recovered beer areas.
- Filters – KG, PVPP, cross flow and trap filters.
- Yeast propagation equipment (though other methods are also widely used).

It is important to note that all "corners" of the plant must reach the required minimum temperature for the minimum time. Temperature probes are typically set at the system return, and will only initiate timers once a degree or two above the minimum to ensure the complete plant is at the minimum temperature. It is essential that turbulent flow in pipework is achieved during sterilisation to minimise risk of cold spots. The water is normally recirculated through a heat exchanger to reduce water wastage.

Brewing equipment commonly sterilised using steam includes:-

- Gas supply mains.
- Gas particulate trap and sterilising filters.
- Product trap filters.
- Product mains, such as yeast propagation transfer mains (less common).
- Propagation tanks (less common).

The steam needs to be food grade, filtered to ensure it is free of particulate matter, and "wet", i.e. supersaturated as it is the heat given up during the condensation of steam into water that kills the micro-organisms. The moisture makes the high temperature much more effective at killing

micro-organisms as it contacts the micro-organisms resulting in rapid heat transfer.

The effects of time and temperature

Heat is very effective as long as the plant is held at high temperature, for an adequate time

When sterilising with hot water, a typical specification is for the temperature at the system return to be greater than 85 ^{O}C for not less than 20 minutes.

To achieve total sterilisation using steam requires contact at 120^{O}C for at least 15 minutes (as in a laboratory autoclave) However, for practical purposes for plant or for bulk pack container sanitising, contact time with steam usually only requires 2 – 3 minutes to achieve the necessary level of hygiene.

Dry Heat	
(Superheated steam)	
Temp ^{O}C	**Time**
120	8 hours
140	2.5 hours
160	1 hour
170	40 minutes
180	20 minutes

Moist Heat	
(Saturated steam)	
Temp ^{O}C	**Time**
100	20 hours
110	2.5 hours
115	50 minutes
121	15 minutes
125	6.5 minutes
130	2.5 minutes

15.4 Safety

Detergents are designed to dissolve organic matter, and sterilants are designed to kill microorganisms. Consequently, these are dangerous materials for people to handle.

In the most countries, under the **C**ontrol **O**f **S**ubstances **H**azardous to **H**ealth (C.O.S.H.H.) legislation (or similar outside the UK), manufacturers are required to issue technical information on any cleaning materials they supply. This information (including the MSDS – Material Safety Data Sheets) covers recommended usage concentrations and actions to be taken in case of accidents.

Hazards of detergents and sterilants

Cleaning of tanks and pipe lines require the use of aggressive chemicals which are strong acids and strong bases designed to remove soils:-

- Strong alkalis degrade organic materials like fat and protein.
- Strong acids degrade inorganic materials like scale and stone.
- Oxidising agents such as chlorine, oxygen, bromine react with proteins and fats in particular. Safety precautions, as required by Occupational Health and Safety legislations (ISO 18000), have to be considered when using these chemicals.
- The use of hot chemicals can exacerbate the damage caused, in a similar manner to the way hot cleans are more aggressive than cold cleans.

We are made of these organic and inorganic materials too, and can therefore be damaged by both dilute and concentrated chemicals or by heat from the diluted chemicals, or hot water or steam used for heating or sterilisation.

Components of these chemicals may have short or long-term effect on the health of the employees. Some components can affect the health of the consumer at parts per million levels.

Additionally, all these materials can damage the environment, including buildings, the brewing plant itself and effluent systems. The products used have to comply with environmental legislation with respect to handling of spillage.

Read all labels and ensure you understand what the material is to be used for, under what conditions, and the hazards associate with that material. Ensure suitable precautions are taken in response to this information.

Every material used must be accompanied by **Material Safety Data Sheet (MSDS).**

An **MSDS** should disclose the following:-

- Manufacturer's details.
- Product identification.
- Composition information on ingredient.
- Hazards identification.
- Safety first measures.
- Firefighting measures.
- Accidental release measures.
- Handling and storage.
- Exposure control and personal protection.

- Physical and chemical properties.
- Stability and reactivity.
- Toxicological information.
- Ecological information.

The MSDS is meant to give enough data about the product that assist the user to make an informed technical decision. A user will only know about this safety information if the information provided is read and, if necessary, the supplier is questioned to clarify.

Good practices for chemical storage

- Chemicals must be stored in a secure, cool, dry area, with adequate and appropriate ventilation.
- Chemicals must be clearly labelled, and the Material Safety Data Sheets (MSDS) and usage information be readily available and understood.
- Chemical storage areas must be fitted with safety showers and eye wash stations.
- Chemicals must be separated by type, and if liquid, stored in bunded areas to prevent accidents to personnel, property, plant or the environment.
- Overstocking must be minimised.
- Good stock rotation must be employed.
- Ensure that when in the proximity of detergents and sterilants people use appropriate personal protective equipment especially eye protection (goggles), gloves, boots and overalls.

- Acids – avoid splashes and contact with fumes.

- Caustic substances – mixing caustic with water generates heat. Splashes can cause severe burns. When diluting, add caustic to water, not the other way round (automated systems greatly reduce the risk).

The use of PPE (Personal Protective Equipment)

- PPE is a last resort as it does nothing to prevent the original exposure to the substance.
- PPE must be suitable for the task and the user.
- Training in the use of PPE is required. If you are not trained, then the task must not be carried out.
- Regular cleaning and maintenance of PPE is required – and always after use.
- Replace PPE when it is no longer fit for purpose, or if it doesn't fit properly.

- Wear safety glasses with side protection at locations where chemicals, steam or hot water can be released (for example at chemical dosing points)
- Wear face mask protective clothing and safety boots when handling chemicals
- Wear whatever PPE is required by local laws if the requirements exceed the above recommendations
- Make sure you know the location of the nearest safety shower / eye wash station
- To protect eyes:-
    - Safety glasses.
    - Goggles offer the best protection for the eyes.
    - Face shield. A face shield protects the whole face.
- To protecting the body:-
    - Apron.
    - Gloves.
    - Boots.
    - Smock.
    - Rain suit.
- Normally, sleeves and trouser legs should be worn on the outside of boots and gloves.

Procedures in case of chemical spillage or discharge

When tackling any spillage or environmental incident the first priority is to:-

- Ensure the safety of yourself and others
- Wear appropriate Personal Protective Equipment (PPE).
- Determine what the spillage is:-
    - Check for any labels or hazard warnings look at MSDS or COSHH sheets.
    - Is it foaming, fuming or burning?

- Determine if the spillage is:-
    - Safe to tackle (minor spillages).
    - Not safe to tackle on your own, i.e. you need assistance (major spillages).

Generally the inclination is to flush spillages to drain with water.

- STOP – CONSULT – THINK – ACT.
- If you flush a chlorinated product into drain water that is acidic it will release chlorine gas.
- Concentrated detergents and sanitisers may kill effluent treatment plants.
- Consult the MSDS (there is a section on spillages) – think and then act.

MINOR SPILLAGES

Tackle only if you feel it is safe to do so:-

- Determine what it is.
- Wear appropriate protective clothing.
- Protect drains.
- Contain or stop the leak.
- Clean up spill.
- Dispose of clean-up materials in appropriate disposal skips / drums etc.
- The spillage may need reporting to appropriate authorities.

- A major priority is protecting the drains.
- Eliminate (i.e. remove the source of the spillage).
- Isolate the spillage (e.g. shut off leaking valves).
- Contain (e.g. drain mats / bunding materials).
- Clean up the spill to prevent further contamination.
- If available, use the absorbent material from the appropriate spill kit (larger sites may have separate kits specifically for oils or chemicals).

MAJOR SPILLAGES

Spillages you feel are unsafe to tackle:-

- Get away & keep a safe distance.
- Determine what the spillage material is and obtain MSDS if possible.
- Seal off area.
- Alert others.
- Look for injured people but only if possible and safe to do so.
- Get help.
- With suitable help contain & clean up, or contact Emergency Services to assist.

Notes.

What type of detergents and sterilants are used in your plant?

What safety precautions during both storage and use are employed in this plant?

Chemical Hazard Identification -

The following symbols for chemical hazard identification are commonly seen in different regions:-

Highly Flammable (F)

Flammable

Flammable

Extremely Flammable (F+)

Harmful (Xn)

Health Danger and Irritant

Health Hazard

Irritant (Xi)

Irritant

Corrosive (C)

Corrosive

Corrosive

Toxic (T)

Poison

Toxic

Oxidising (O)

Self-Ignition

Oxidising

Very Toxic (T+)

Explosive (E)

Explosive

Explosive

Dangerous for the Environment (N)

Environmentally Damaging

Qualifications

The General Certificate in Brewing (GCB)

Learning Material © Institute of Brewing and Distilling 2016

Section 16 Plant cleaning – Cleaning In Place systems

Introduction

Cleaning in place of brewing and packaging plant has largely replaced traditional methods where plant was dismantled for manual cleaning, or personnel had to enter vessels and manually clean them. Effective CIP systems, when used in conjunction with correctly designed beer production or packaging equipment can deliver higher hygiene standards than can be achieved with manual cleaning, with less risk of damage to the equipment or risk to personnel from manual handling, cleaning chemicals or dangerous gases.

In many countries, increasing costs have necessitated reductions in manpower and the time required for manual cleaning operations. For improved economics, the use of larger batch sizes requires larger vessels and mains, which are not able to be easily cleaned manually, if at all.

CIP is the circulation of detergents, water rinses and sterilants through fixed plant without dismantling. In order to achieve this, tanks have to be fitted with spray balls/heads and pipework has to be linked into a 'ring' main.

16.1 Types of CIP system

Comparison of single use & recovery systems

A Single Use (total loss) system doses concentrated detergent or sterilant into the delivery line and although they are recirculated during that specific cycle, e.g. detergent recirculation, at the end of the cycle, the cleaning fluids are run to waste. In their simplest form, these systems do not even recover post detergent and post sterilant rinses, but use fresh water for all rinses.

A recovery CIP system consists of tanks where supplies of detergent and sometimes sterilant are held at the required concentration for use. Cleaning fluids are delivered from the tanks and returned to them both during and at the end of the cycle. Detergent (and sterilant) strength and temperature is maintained in the tank.

A recovery system can be designed with more than one CIP supply and return, to be run simultaneously, using common detergent and recovered rinse tanks for example, so reducing capital costs.

The benefits and problems associated with 'Recovery' and 'Total Loss' systems are identified in the following table:-

Recovery system	Single use system
Capital costs are higher because separate (often large) tanks are required for detergent, recovered rinse water and sometimes sterilant	Lower capital cost because only a single recirculation buffer tank, which is used for all stages of the clean is required
Running costs are lower because • chemicals are recovered • final rinse water is normally reused for pre-rinsing • where hot detergent is used, this is recovered, saving heating energy	Higher running costs because • chemicals are always run to drain • these chemicals may also affect effluent costs • water is run to drain after a single use • heating energy when hot cleaning is usually wasted
Good practice CIP sets are only able to clean one type of plant from a cleaning unit, e.g. unfiltered beer in FVs & MVs or BBTs	One cleaning unit can clean different types of plant, for example rough beer and bright beer tanks, though this functionality is not generally considered to be acceptable.
The time required to clean is reduced because the detergents and sterilants can be prepared prior to use – no separate makeup time is required	The cleaning time is usually longer because • the detergents and sterilants have to be made up to strength fresh each time • if hot cleaning, additional time is required to heat up the recirculating CIP fluids
Effluent produced is generally less because most of the detergent, and sometimes sterilant is recovered at the end of the recirculation cycle.	Volume and strengths of chemicals generally higher than recovery systems.
Automation control is generally more complex due to additional tanks and separate sequences for make-up, and the actual plant cleaning cycles	Simpler due to single recirculation "buffer" tank, and detergent / sterilant makeup integral to the plant cleaning cycles.

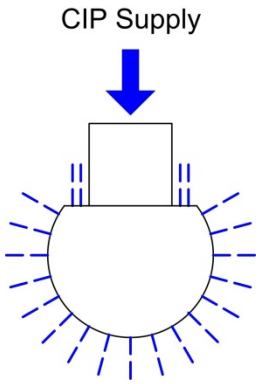
Types of cleaning head used and reasons for their choice

There are two main types of spray head, the fixed spray head and the rotating spray head.

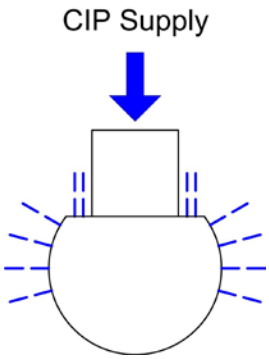
Fixed spray ball

Fixed sprayballs are drilled to a number of different designs appropriate for the vessel they are being used to clean.

The spray pattern of a nominal 360 degree ball is shown below. These may be used on small vessels.



The spray pattern of a nominal 180 degree ball is shown below. These are widely used on vertical cylindrical tanks.



They use large volumes of cleaning liquid at low pressure. Effective cleaning relies on the cleaning liquid flowing over the surface of the tank at sufficient depth and speed to clean effectively. Therefore the whole surface must be wetted thoroughly by correct positioning of a suitably designed sprayhead.

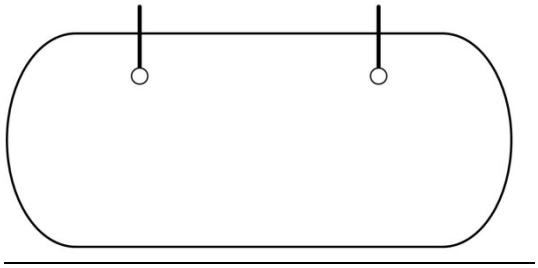
Burst delivery is often used because the delivery flow rate is so high that often the scavenge system cannot prevent a pond developing in the bottom of the tank. This is particularly a problem with dish bottom vessels or horizontal vessels. If a pond develops, the flooded portion of the tank is not cleaned because the cleaning liquid does not flow over the surface at sufficient speed to develop turbulent flow.

Spray balls are relatively cheap and they are easy to maintain although they can block up, especially if the cleaning liquid is unfiltered.

The dimension of the vessel dictates the number of, size of the ball(s) and the drill pattern required for total coverage of the entire surface during the clean. The hole pattern in the sprayball is designed to direct the bulk of the flow of the fluid onto the area where most of the soil is located, e.g. at the yeast ring in a fermentation vessel. The areas not wetted by direct contact are wetted by the drainage of the fluid from these areas

The fluid runs down the side of the walls of the vessel in a continuous curtain to create turbulent flow, contributing to the effect of the chemicals, time and temperature to assure a clean surface.

Vertical tanks typically have only one installed, but horizontal tanks usually require two or more to give adequate coverage.



The choice of spray balls or rotating spray cleaners is a key factor in the effective design and operation of a CIP system for tank cleaning.

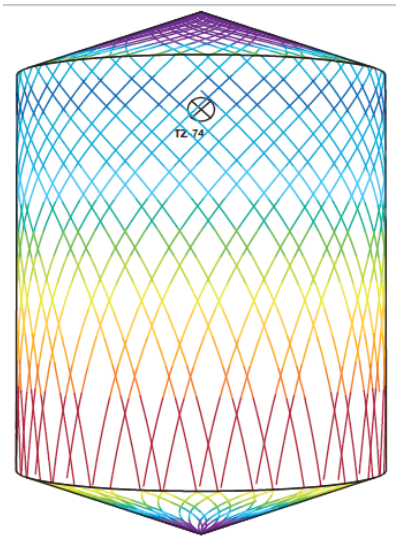
Rotating spray heads

The rotating spray head, for example, the Sani Magnum show below, rotates at high speed, spraying the vessel wall with a sheet of CIP fluid rather than a jet.

The turbodisc head rotates at high speed and sprays a fan of fluid on to the vessel wall. This type of head tends to be used for small vessels only, or for cask washing.

The high pressure jet, for example the TZ74 shown below rotates at slow speed, with a number of jets impacting the walls, floor and top of the vessel.

TZ74 cleaning pattern, partial cycle only shown:-



High pressure cleaning heads, e.g. Toftejorg TZ74. These are mechanically driven heads that rotate to direct high-pressure jets to the tank surface, in a pattern to ensure that the entire surface is jetted. This principle means that it takes a defined time to complete the pattern and cover all surfaces.

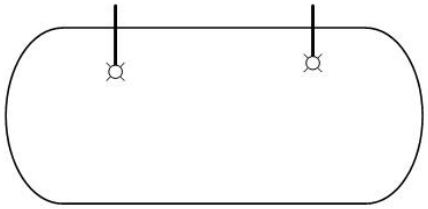
Rotating jet cleaners require a high pressure supply to direct the fluid onto the surface of the vessel to create. The rotating jets have a higher impact force on the surface, giving much higher physical cleaning effect on the soil or scale than the flooding low pressure system applied on fixed spray balls. The mechanical force is a powerful aid to the cleaning process and the system can use colder and or less aggressive detergent, and often shorter cycle times than sprayballs. The fluid flowing down the rest of the surface continues to clean in a similar manner to that of fluid from a sprayball.

The jets on a rotating mechanism direct the fluid on forming a narrow track, and rotate a specified number of times for a complete cycle, at the end of which the entire surface will have had direct impingement from the high pressure jet.

Rotating spray heads are relatively expensive and are made up of moving parts, therefore there is wear and tear during use. Rotating spray heads are often fitted with rotation sensors linked to the alarm handling of the CIP automation because a stationary head will only clean a very small section of the tank. Filters in the CIP delivery are essential to reduce the risk of blockage and wear of the rotation turbine.

Although high pressure heads are expensive compared to sprayballs, the reduced water usage arising will often pay back this cost within a few months, and so are becoming increasing popular. When using caustic detergent in atmospheres containing CO2, the detergent is subject to slower degradation by the CO2.

Vertical tanks typically have only one installed, but horizontal tanks often require two, to give adequate coverage. They are considered to be far more effective in horizontal tanks than sprayballs, and are frequently installed as replacements.

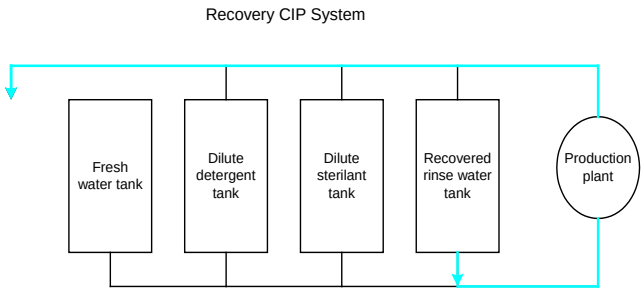


Notes:
Write down the type of cleaning heads fitted to a tank installation that you are familiar with.
Why was that type of cleaning head selected?

Operating principles of CIP systems

RECOVERY (REUSE) SYSTEM

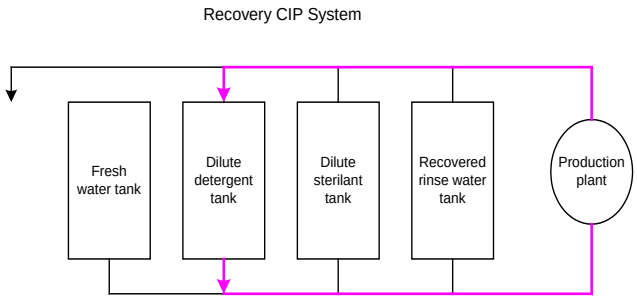
1. First rinse:-



Fresh, or more normally, rinse water recovered from the post detergent and post sterilant rinse cycles is delivered to the plant and returned to drain. If the buffer tank is too small, the rinse may be supplemented with fresh water. When cleaning tanks with spray balls, burst rinsing is often used to allow the tank to drain between bursts, so improving the cleaning affect at the bottom of the tank.

The time taken for these rinses will depend on the design of the plant and therefore how easy it is to clean.

2. Detergent circulation:-

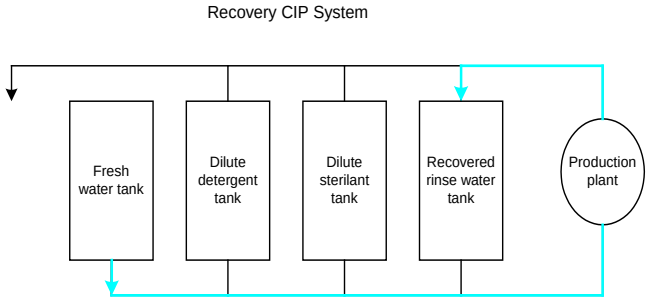


The dilute detergent tank is maintained at the correct strength and its contents are circulated through the plant. At the start of the detergent cycle, the plant will contain pre-rinse water, and the return will be run to drain until detergent is detected to reduce dilution of the detergent.

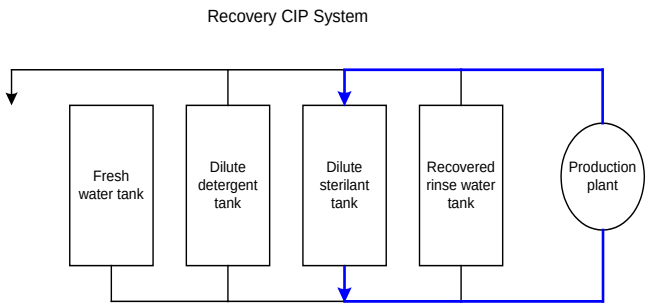
The time of recirculation will depend on the level of soil in the plant, but times of 20 to 30 minutes are common.

3. Second (post detergent) rinse:-

Fresh water is delivered to the plant and normally recovered to a recovered rinse water tank. As the plant contains detergent, at the start of this cycle, the return is recovered to the detergent tank until the rinse water is detected. The water from the post detergent rinse is usually collected and used as the pre- rinse when the next piece of plant is cleaned.



4. Sterilisation:-



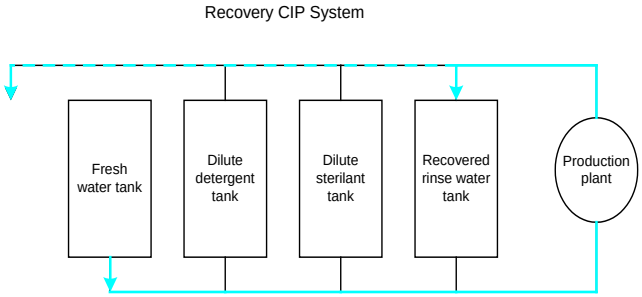
If the sterilant is suitable for re-use, the dilute sterilant tank is maintained at the correct strength and its contents are circulated through the plant for a programmed time. At the start of the cycle, because the plant contains rinse water, the return is run to drain until the interface is detected to reduce dilution the sterilant in the tank.

The diagram assumes use of recovered / reused sterilant

Many systems use sterilant once only in a single use system. Fresh water is recirculated through the system, and dosed up with sterilant until the required strength is achieved, and then the system is recirculated for a programmed time.

The time of sterilisation will depend on the effectiveness of the sterilant under those conditions, and the level of microbiological contamination in the plant, but times of 10 to 30 minutes are common.

5. Final rinse:-



If it is considered, however, that residual traces of the sterilant will not harm the product, the final rinse may be omitted.

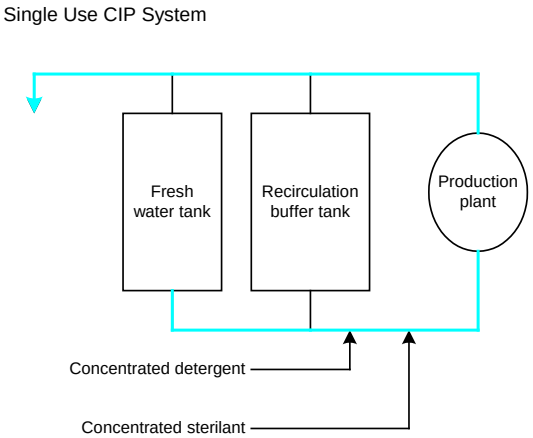
This is similar to the initial rinse although the water that is used must be of potable quality, i.e. free from microbiological or chemical contamination.

The water from the final rinse is usually collected and used as an initial rinse when the next piece of plant is cleaned.

TOTAL LOSS (SINGLE USE) SYSTEM

It has been assumed for these drawings that there is no recovered rinse water tank built into the system.

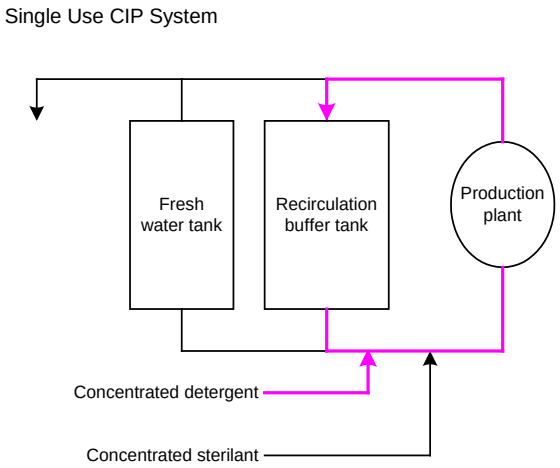
1. First rinse:-



Fresh water is delivered to the plant and returned to drain. When cleaning tanks with spray balls, burst rinsing is often used to allow the tank to drain between bursts, so improving the cleaning effect at the bottom of the tank.

The time taken for these rinses will depend on the design of the plant and therefore how easy it is to clean.

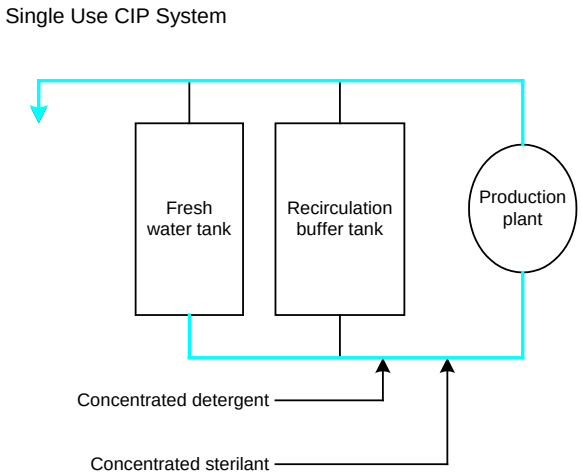
2. Detergent clean:-



Fresh water is delivered to the plant and dosed with detergent, ideally at a rate that achieves the required concentration in a single pass. If the detergent is to be used hot, then the recirculating fluid will be heated at the same time as the detergent is being dosed. When all the recirculating fluid is at the correct concentration and temperature, the detergent is circulated back to and from the buffer tank for a programmed time. Normally no further additions of detergent will be made, but if necessary, but it will continue to be heated if necessary.

The time of recirculation will depend on the level of soil in the plant, but times of 20 to 30 minutes are common.

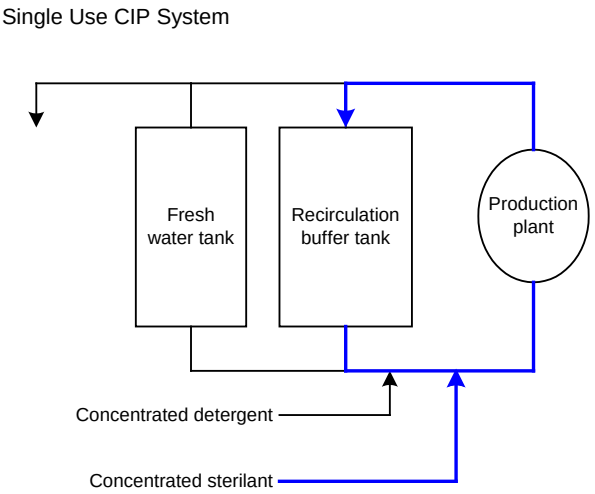
3. Second rinse:-



Fresh water is delivered to the plant and returned to drain. The buffer tank is drained and rinsed out as part of this cycle.

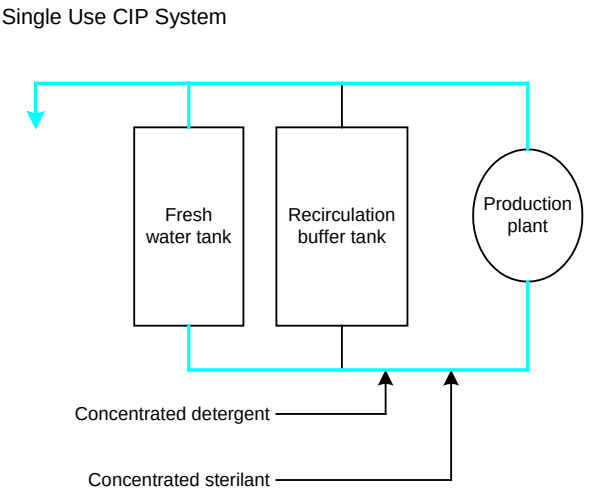
4. Sterilisation:-

Fresh water is delivered to the plant and dosed with sterilant, ideally at a rate that achieves the required concentration in use in a single pass. When all the recirculating fluid is at the correct concentration, the sterilant is circulated back to and from the buffer tank for a programmed time. Normally no further additions of sterilant will be made.



The time of sterilisation will depend on the effectiveness of the sterilant under those conditions, and the level of microbiological contamination in the plant, but times of 10 to 30 minutes are common.

5. Final rinse:-



If it is considered, however, that residual traces of the sterilant will not harm the product, the final rinse may be omitted.

The water that is used must be of potable quality, i.e. free from microbiological or chemical contamination.

16.2 CIP cleaning cycles

Typical cleaning programmes and cycle times

CIP programmes vary from one area of the brewery to another, depending on the soil loading and the microbiological standards required. Example CIP programmes are given below for a number of different areas.

Brewhouse:

- Hot (or sometimes cold) pre-rinse (ideally recovered final rinse water).
- Detergent (normally hot caustic) recirculation
- Hot water post detergent rinse.

Fermenting, maturation vessels and yeast vessels:

The following is one of the more traditional CIP cycle sequences:-

- Pre-rinse with hot or cold water (ideally recovered from post detergent or post sterilant rinse).
- Hot caustic detergent recirculation.
- Post detergent fresh water rinse.
- Sterilant recirculation.
- Post sterilant fresh water rinse.

An increasing number of breweries are using the following sequence

- There is no pre-rinse.
- Sacrificial cold caustic detergent burst rinsing.
- Post caustic detergent fresh water rinse (to drain).
- Cold acid detergent recirculation.
- Post detergent fresh water rinse.
- Sterilant recirculation.
- Post sterilant fresh water rinse.

Note that the separate sterilant recirculation and post sterilant rinse may be omitted because many if not most acid detergents are now combined detergent & sanitisers.

Bright beer tanks and similar vessels:

- Pre-rinse with cold recovered water.
- Cold acid detergent recirculation.
- Post detergent fresh water rinse.
- Sterilant recirculation.
- Post sterilant fresh water rinse.

Again, the separate sterilant recirculation and post sterilant rinse may be omitted because many if not most acid detergents are now combined detergent & sanitiser.

Also note that good practice requires regular periodic caustic cleaning of the BBTs etc.

Mains:

- Pre-rinse with hot or cold water (ideally recovered from post detergent or post sterilant rinse)
- Hot caustic detergent recirculation
- Post detergent fresh water rinse

Depending on the quality of the hot detergent cycle, in particular the temperature, there may be a need for a sterilant recirculation and final rinse cycle in addition to the above.

The pre-rinse cycle times are very dependent upon the soil loading.

- For instance, in the brewhouse, the pre-rinse cycle may last for 10 – 15 minutes or more, because the soil loading is so high, and because rotary high pressure cleaning heads are often used.
- In the FVs, the cycle will vary depending on the spray head used, the soil loading and whether sacrificial caustic rinses are used. If sacrificial caustic rinses are used, pre-rinses are best not carried out as they reduce the effectiveness of the caustic rinses.
- In MVs and yeast vessels, the yeast / hop debris ring is virtually absent, and the vessels are often free rinsing. If this is the case, the rinse cycle may be reduced to a few minutes only.
- Bright beer tanks may be rinsed for 5 to 10 minutes.
- Mains are typically rinsed for perhaps ½ a circuit volume only, except in the brewhouse, where the soil residues may be very high. All product transfers should have been flushed out with clean water, and the soil loading should be very low. There is no need to waste additional water flushing out where no residues remain.

Detergent recirculation times vary somewhat, according to the soil loading and the cleaning head used.

- In the brewhouse, 20 to 30 minutes is typically used.
- In FVs, MVs and yeast vessels using hot caustic recirculation, typical times are 20 to 30 minutes.
- In FVs, MVs and yeast vessels using a sacrificial caustic prewash cycle, this can take up to 30 minutes, mainly because of the soak time after each burst delivery cycle. A rinse of perhaps 5 minutes follows. The acid detergent cycle which then follows lasts for 15 to 20 minutes.
- Mains detergent recirculation is typically 20 to 30 minutes, but this varies according to the complexity of the circuit.

Post detergent rinse (and post sterilant rinse) cycles are as short as possible to minimise water usage. The cycle time commences once the interface between detergent and water has been detected at the CIP set, and the rinse times can be very short after this if a clean interface, i.e. efficient rinsing is achieved. For vessels, only one or two minutes after the interface is detected is normal. For mains, it can be as short as ¼ of a circuit.

Sterilant recirculation cycles are dependent upon the type of sanitiser being used, but typical times are between 10 and 20 minutes. A long duration should not be required as the detergent cycles will have removed or killed the vast majority of micro-organisms.

The function of each of the cycle stages

The **pre-rinse** removes as much water soluble and loose soil as possible and flushes this to drain.

The **detergent recirculation** cleans the plant by loosening and suspending solid materials, which may include yeasts, bacteria, protein from malt and hops, oils and resins from hops, and dissolving soluble materials. This leaves the surface free of material that might cover yeast or bacteria. Most detergents are also effective at killing yeasts and bacteria.

Where a sacrificial caustic cycle is used when cleaning FVs, MVs and yeast vessels, this is to remove the high levels of organic material present in the form of yeasts, hop debris etc. Acid detergents are not as good as this and are far more expensive. It is cheaper and more effective to sacrifice a small quantity of caustic than a similar quantity of acid detergent.

The post detergent rinse removes traces of detergent and any loosened soil residues.

The sanitisation cycle destroys any remaining micro-organisms left on the surface of the physically clean plant.

The post sterilant rinse removes traces of sterilant if it is decided that no sterilant should remain in the plant and be capable of contaminating the product.

Notes:
Write down details of a CIP programme for a piece of plant that you are familiar with. For all rinse, detergent and sterilisation cycles include

- *times,*
- *temperatures*
- *chemical strengths*
- *flow rates.*

What precautions are taken to ensure that the plant is not re-contaminated before re-use?

Quality assurance of cleaning operations

Quality assurance of CIP is provided by a number of methods

- CIP and production plant process automation and management information systems.
- Visual inspection.
- Swabbing Techniques.
  - Conventional Techniques.
  - Rapid Methods.
- Rinse Water Analysis.

CIP and production plant process automation
Providing the systems are programmed correctly, the repeatability of automated CIP processes and the interface with the production plant provides a high degree of assurance that the plant is being cleaned as specified. The process specifications for a number of key parameters including those below may be specified:-

- Times.
- Temperatures – delivery & return.
- Flow rates.
- Delivery pressures.
- Detergent strengths.
- Sterilant strengths.
- Numbers of pulse pause delivery cycles.
- Product tank empty checks.
- Rotation checks on high pressure cleaning heads.

These specifications may be cross checked against the real time values, and if out of range may alarm hold the clean so corrective action can be taken.

The frequency of cleaning may be determined by advanced management information systems, with automatic start of clean when a plant item becomes dirty.

Similarly, automated plant, before it can be used for a production process can be set so it has to be clean / sterile before the production process will be allowed to start.

Management information systems will allow regular reviews of cleaning frequency and reviews of problems, particularly if repeated. This allows corrective action to be taken as required.

What this automation and management information does not do is provide assurance that the programme specified is fit for purpose. Other methods are required for this aspect, as outlined below.

Visual inspection
Wherever possible, both production and CIP plant should be visually inspected at least annually. This is probably best carried out when other essential planned maintenance / insurance inspections are carried out. Where pipes are broken for maintenance or as part of the routine set up for production / CIP, the internal surfaces should be inspected. Whenever possible, open up the production tanks and inspect the spray balls for scale blockage: this can be done remotely by using sound waves.

If visible soiling is present, it must be assumed that microbial contamination is also present, hidden in the soiling. Special cleans may be required to bring the plant back to the required state, but in addition, the root cause of the problem must be resolved, either by appropriate maintenance, or by changes to the CIP programme.

Laboratory sampling / analysis
Methods carried out by the lab include conventional and rapid result analysis of microbiological swabs of production equipment wherever this is possible, either as routine validation, or as “one offs”. In most cases, it is considered essential to re-clean or re-sterilise following swabbing, especially if the plant has had to be opened up by breaking joints or opening access doorways.

Where equipment forms a closed circuit and is impossible to carry out regular swabs, final rinse water samples may be taken and analysed.

In all cases, the beer which has been processed by the production plant should be checked for increased levels of contamination. Any major increase suggests the plant itself is contaminated.

16.3 Hygienic plant design

Introduction
Effective cleaning is the result of a combination of four factors:-

- **Time**. How long is the cleaning agent/detergent in contact with the plant? More heavily fouled plant normally requires longer to clean than less heavily fouled plant.

- **Temperature**. How hot is the cleaning agent/detergent? Cleaning effectiveness rises as the temperature increases up to an optimum for each chemical.

- **Chemical activity**. How strong/effective is the cleaning agent/detergent? Generally, the stronger the detergent, the greater the cleaning power. Note that at very high concentrations, cleaning effectiveness will drop off, and there may be problems rinsing, or high wastage which makes high concentrations non cost effective. There may also be safety issues with higher concentrations.

- **Physical activity**. How vigorously is the cleaning agent/detergent applied to the plant? The greater the physical force, the more effective the cleaning. Thus high pressure cleaning heads are increasingly used for tanks.

If one of these factors is reduced, for example if the plant has to be cleaned quickly, then another factor must be increased to compensate, for example hot instead of cold detergent could be used.

Plant design needs to take this concept into consideration in the following ways:-

- The plant capacity needs to be large enough to allow time for cleaning.
- The parts of the plant where very high standards of hygiene and sterility are normally required to be capable of being cleaned hot.
- The materials of construction should be capable of withstanding strong detergents such as caustic soda or phosphoric / nitric acids.
- The plant needs to be able to withstand oxidising agents such as peracetic acids which are used as sterilants. This is particularly applicable to valve rubbers and joint gaskets.
- The plant design should either allow access for manual cleaning or more commonly, ensure that detergent can flow over the surface at the speed required to give turbulent flow, and thus clean effectively.

Design features to minimize soil accumulation

Effective cleaning is a major consideration when designing brewing equipment. The main areas for consideration are:-

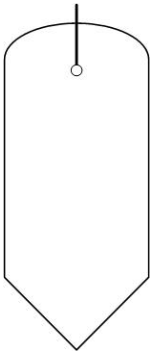
- No encumbrances (intrusions) in vessels if possible.
- Vessels must drain well.
- There must be no ‘dead legs’ in the pipework.
- There should be no ‘U’ bends or ‘goalposts’ in the pipework. Where these are necessary, then cleaning processes must ensure they are cleaned effectively (principally by using high flow rates).
- Pipes must be designed for fast flow of fluids during cleaning.
- Spray heads must be of suitable design and sited in the correct position.
- The plant must be accessible for external cleaning and maintenance.

(a) Vessel design

Vessels in modern breweries are designed for being cleaned in place, i.e. by using spray heads rather than manually with personnel having to enter and clean. They must drain well and have no internal encumbrances.

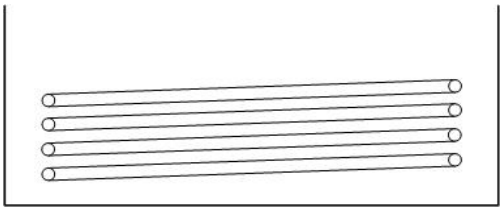
Cylindroconical vessel

- Drain freely and completely.
- Smooth walls.
- No or minimal intrusions (e.g. temperature probes) .
- Sprayball or high pressure head.



Open square FV

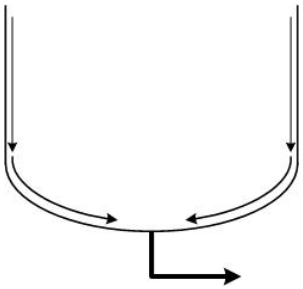
- Poor drainage due to flat floor.
- Attemperation coils difficult to clean, either manually or using CIP techniques.
- Normally manually cleaned.



(b) Vessel drainage

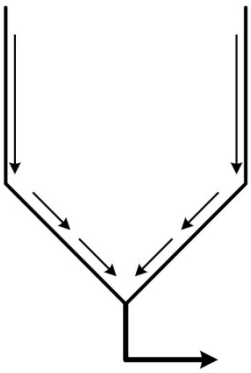
Good drainage:
Fast flow of liquid cleans surface, and scours away soil from side walls and dish bottom Often requires burst delivery to achieve effective scouring of the vessel bottom dish surface on a regular basis throughout the clean.

Vortex breakers are often fitted to improve the flow rate at the outlet, and so reduce the scavenging time.



The bottom section of the cylindroconical vessel shown below is the most easily drained.

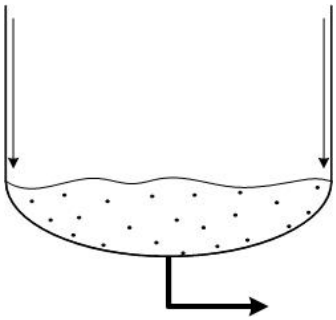
They are only very rarely fitted with vortex breakers, and providing the CIP return pump is fast enough, only rarely need burst delivery to ensure the lower cone vessel walls are scoured effectively at all times.



Poor drainage

Very low (non-turbulent) flow in the ponded area doesn't clean the surface of the dish bottom.

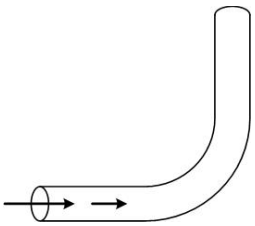
Soil removed from higher up the vessel may be re-deposited on the dish area.



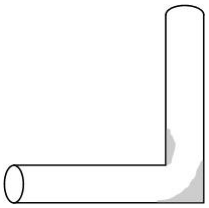
(c) Pipework design

Pipes and mains in modern breweries are designed to be cleaned in place. They have smooth bends and no 'dead legs'. Flow of cleaning fluids is fast through all the pipework, 2 meters per second giving turbulent flow and effective cleaning.

Pipe with smooth, swept bends are cleanable.

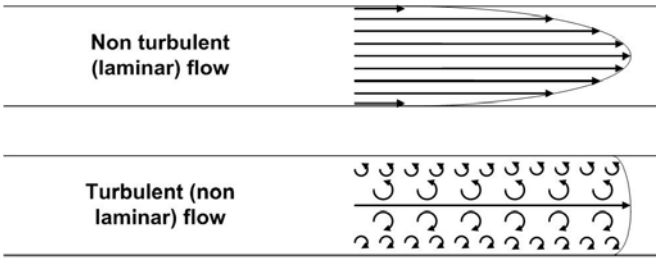


Pipes with sharply angled bends are difficult to clean, leaving soil build up in the areas shown.

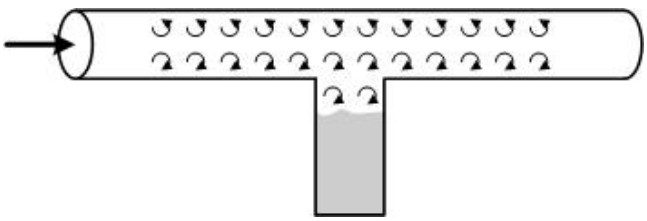


Slow flow of cleaning fluid through a pipe (typically less than 1.5 metres / sec, see diagram) is ineffective because the flow is not turbulent, or laminar, and there is no scrubbing action. The times required for rinsing will also be excessive, leading to high water usage and long cleaning times.

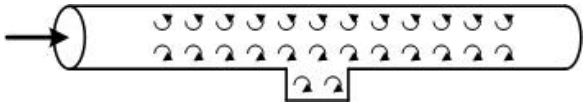
Adequately fast flow of cleaning fluid through a pipe (typically more than 1.5 - 2.0 metres / sec, see lower diagram) causes turbulent flow, and generates a good scrubbing action.



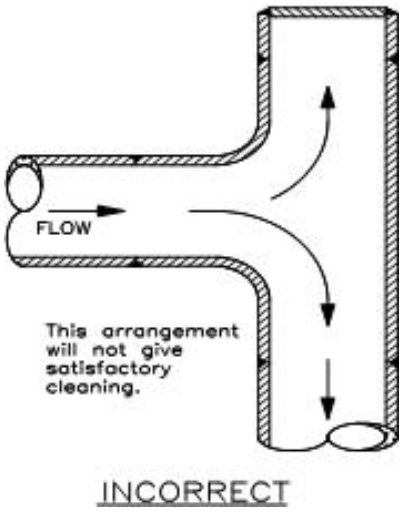
Long dead legs (> 1.5 times the pipework diameter) never get cleaned, even with good turbulent flow through the main section of pipework, and irrespective of the direction in which they point. .



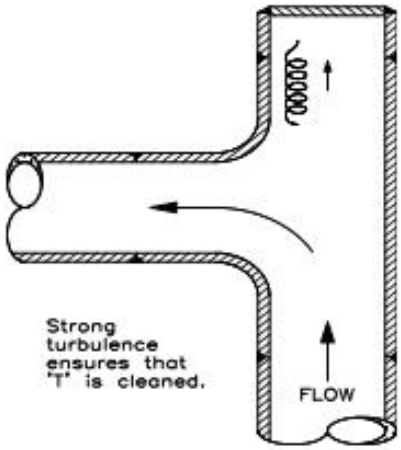
Short dead legs are cleanable providing there is good turbulent flow through the main sections of pipework.



Because Tee pieces are inevitable, particularly with equipment that is manually set up, it is essential that the direction of flow is correct to maximise the ability to clean.



INCORRECT



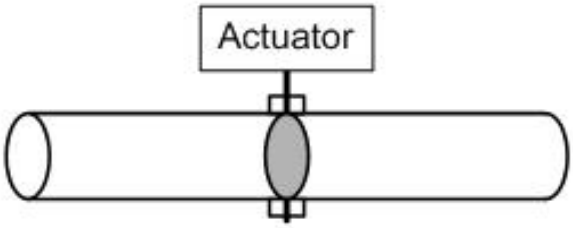
CORRECT

A pipe circuit for CIP should consist of pipes of the same diameter. If there are different pipework sizes, the flow rate must be suitable for the largest pipe diameter, otherwise the flow may be too slow to clean.

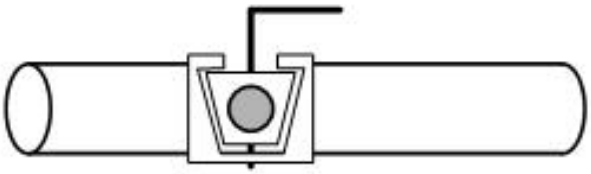
(d) Valve design

Valves in modern breweries are designed so that they can be cleaned in place as part of the pipework cleaning cycle.

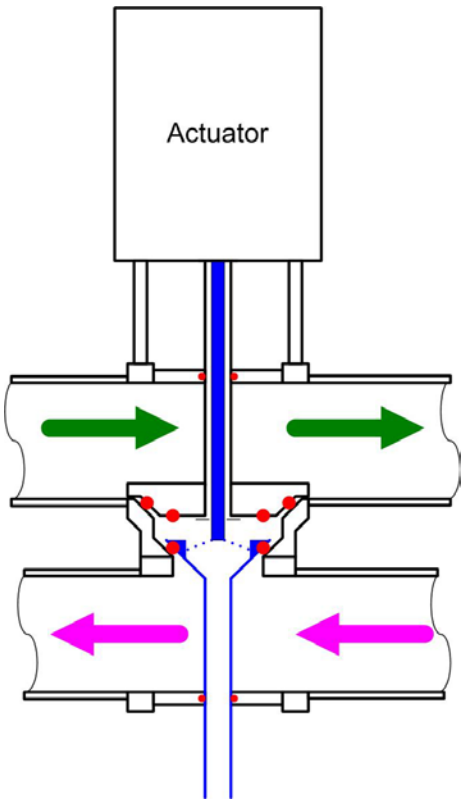
A butterfly valve is easy to clean. It has a smooth finish, hygienic glands to seal around the spindle, and when the seal is in good condition has minimal areas where soil and bacteria can build up. They can be manually controlled or automated.

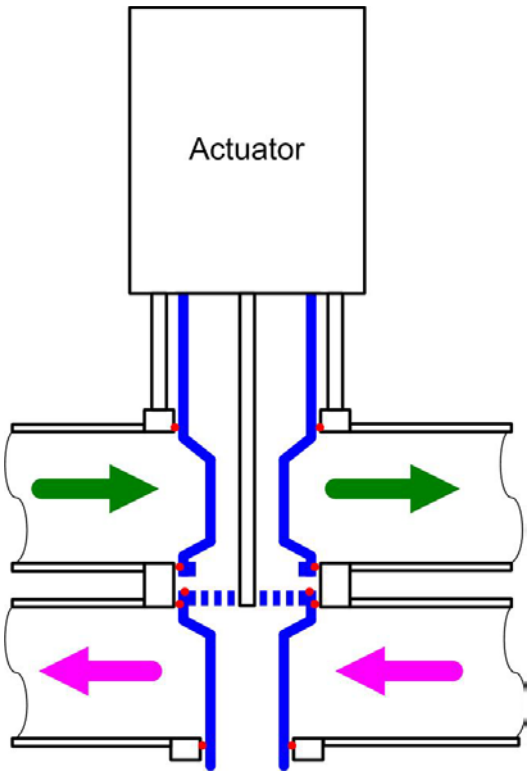


Plug valves are virtually impossible to clean as part of a CIP circuit. The housing surrounding the plug allows soil and microorganism build up. They can only be cleaned properly by dismantling. Typically they are manually controlled, but may be controlled automatically.



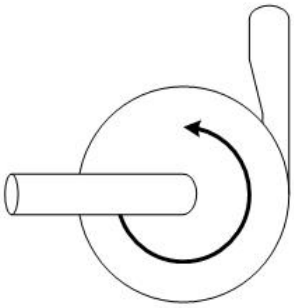
Double seat valves are widely used in critical areas. These designs are effectively two separate hygienic blocking valves combined, with interseat drainage for leak detection. To clean the interseat space and seals, they are fitted with interseat cleaning, or are designed to lift a single seat a time, leaving the other seat sealed. This design minimises the risk of cross contamination between different products or CIP fluid and product. Two styles of 4 port valve are shown here:-



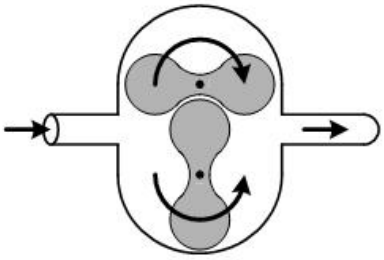


(e) Pump design

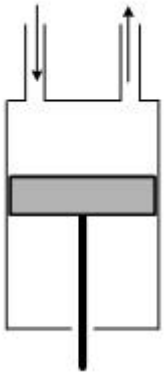
A centrifugal pump, e.g. for beer transfer, are easy to clean. The impeller creates turbulence. There are only two seals with no "hard to clean" corners.



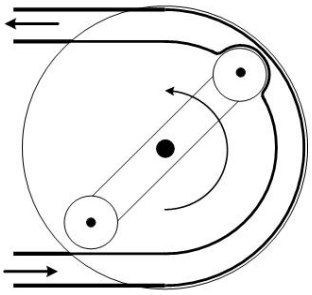
Stainless steel lobe pumps, e.g. for yeast cropping, are reasonably easy to keep clean. The internal surfaces are polished. However, a bypass is essential to allow the remainder of the pipework to be cleaned at the correct flow rate.



Piston pumps, e.g. for accurate dosing of additives, are difficult to clean. A film of soil on the cylinder wall and the non-return valves is difficult to remove due to the low flow rates through the pump. A bypass is essential to allow the remainder of the pipework to be cleaned at the correct flow rate.



Peristaltic pumps, e.g. for yeast cropping, are reasonably easy to keep clean. The internal hose is flexed by the compression wheel or shoe and helps top loosen any soil. However, a bypass is essential to allow the remainder of the pipework to be cleaned at the correct flow rate.



Sometimes pumps, particularly positive displacement pumps such as lobe and piston pumps are fitted with pressure relief by-pass systems. This by-pass must be opened during the cleaning programme whilst the pump runs to maximise cleaning effectiveness.

Design features of CIP sets and brewing plant to facilitate CIP

The key features to be considered when designing a CIP system include:-

Product tank

- Size and design, e.g. cylindroconical, dish end vertical, dish end horizontal.
- Tank material, e.g. stainless steel, epoxy resin, copper, aluminium.

Pipework

- Diameter and length of cleaning circuit.
- Pipework material. Typically in new or recent developments this will be stainless steel, but old plant may still contain copper and brass.

Fouling

- The type of fouling.
- The degree of fouling.

For instance, brewhouse plant will get fouled more easily, and heavily than bright beer tanks and mains.

The factors noted above will determine:-

- The flow rates and pressures to tank cleaning heads, and from the tank outlets.
- The flow rate to clean the pipework.
- The choice of cleaning/sterilising chemicals (see Section 15).
- The detergent recirculation temperature
- The CIP programme or sequence of cleaning cycles to ensure the plant is cleaned.

The following factors also need to be considered:-

- The number of individual routes (plant items) in the same are that require cleaning
- The cleaning frequency of each route (plant item)
- The likely duration of each of these cleans

These factors will then help determine if the CIP system is to be a 'recovery' or a 'total loss' system, the number of independent channels installed, the tank sizes and the type of and level of automation and monitoring. This will then determine the capital and revenue (running) costs.

Whichever type of system is installed, it should be capable of being cleaned periodically to remove any debris removed from the production plant and subsequently deposited in the tanks. Note that in the following diagrams, no facility to clean the CIP tanks themselves is shown.

Hot cleaning

Some plant is designed to be cleaned at high temperatures because of the importance of hygiene and sterility. The yeast culture vessels are common examples. Plant design features that allow high temperature cleaning of tanks are:-

- Strong construction, for example thick walls to a vessel.
- The presence of a pressure relief valve, which must be regularly tested.
- Vacuum relief system, to prevent the collapse of the vessel due to the very low pressures that will occur if the vessel cools quickly.

Mains are normally cleaned hot. The layout must be designed to allow expansion and contraction of longer runs without damage to fixed items of plant such as valve blocks or supporting brackets.

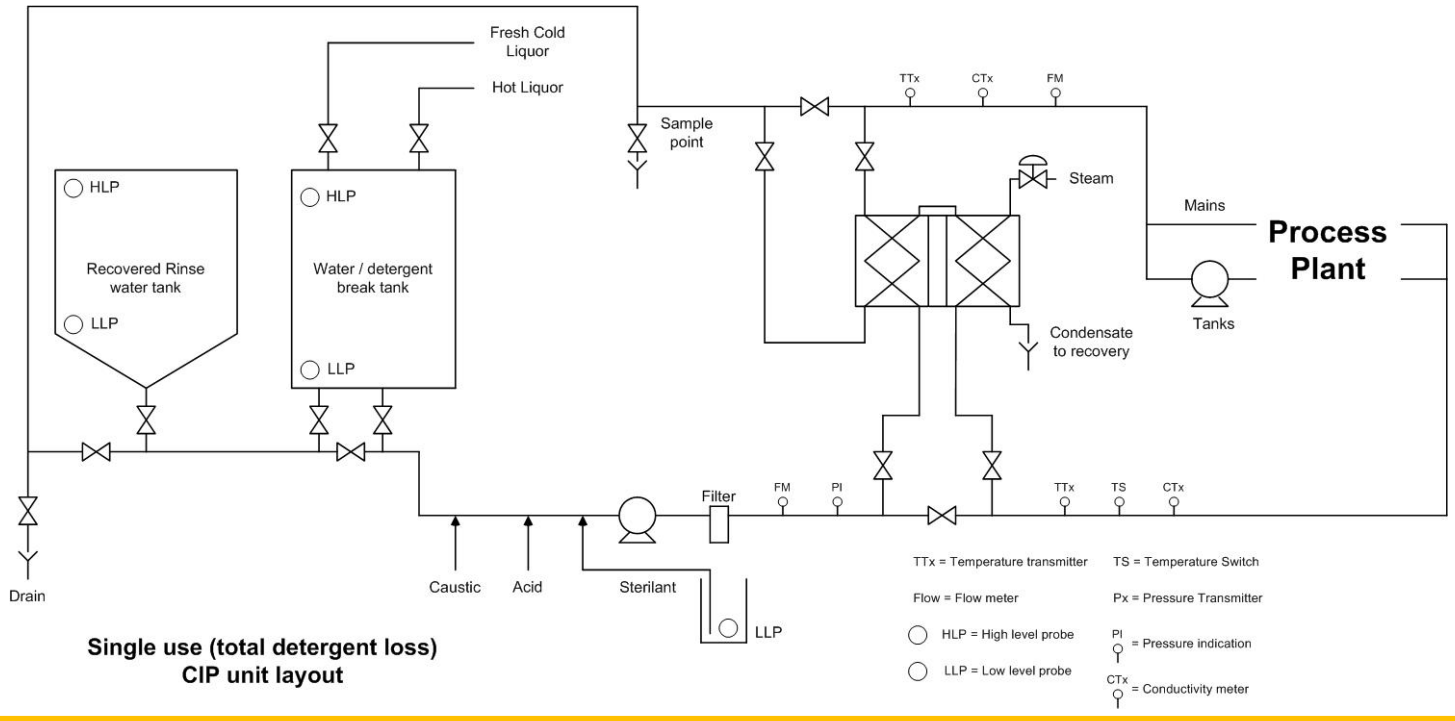
Construction materials

The choice of material that the plant is made from needs to allow for the detergents and sterilants that are going to be used.

Most modern plant is constructed of a suitable quality of stainless steel. However, pump glands, hoses, valves and sensing equipment such as thermometers, must also be compatible with what might be very corrosive substances. Some of the more common problems are listed below:-

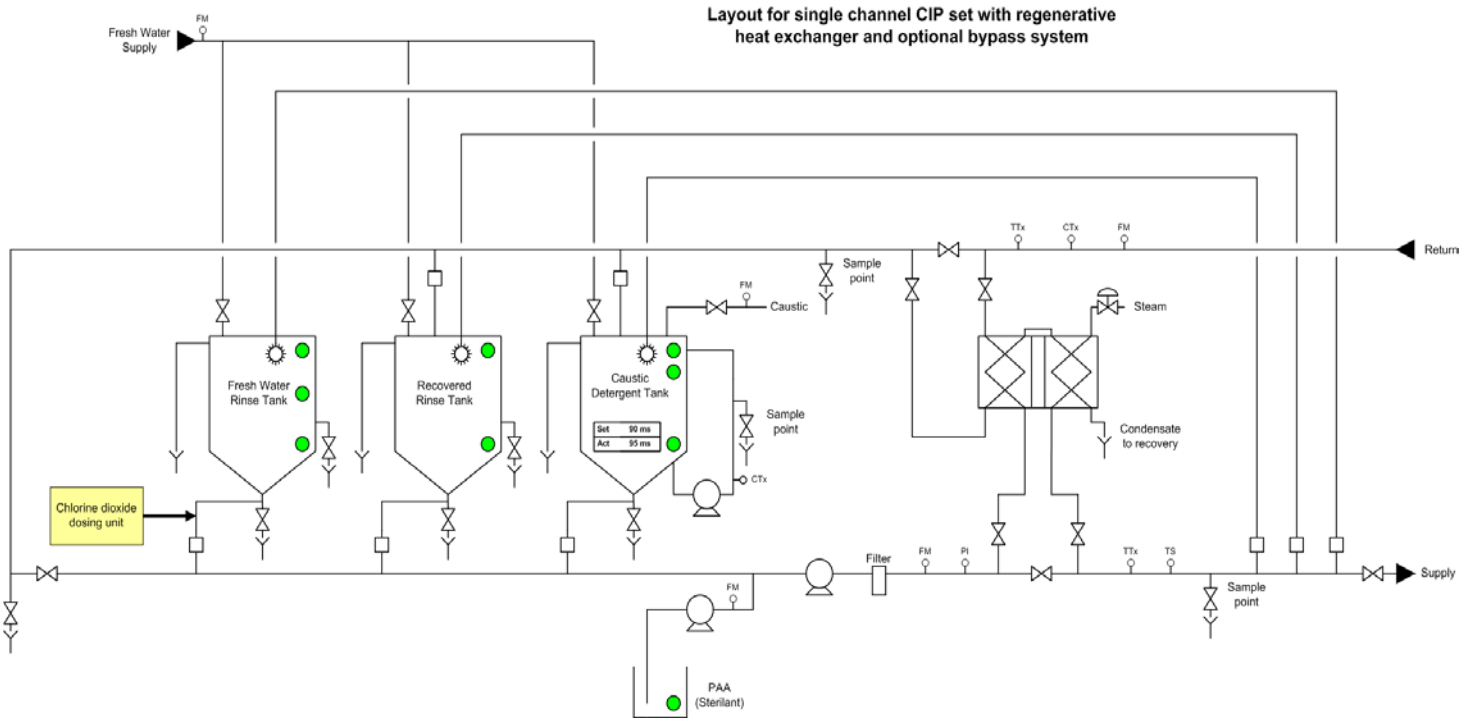
- Caustic soda will dissolve aluminium.
- Chlorine is a very strong oxidising agent and will corrode most metals.
- Acids will seriously damage concrete.
- Dilute sulphuric acid corrodes many grades of stainless steel.
- Hoses and rubber seals, for example plate heat exchanger gaskets can pick up taints from sterilising agents, e.g. chlorine and iodine.
- If gaskets become worn, it is possible for small detergent volume to be trapped between rubber and plate, thereby setting up a corrosion cell.

Example of a single use (total loss) CIP set



Single use (total detergent loss) CIP unit layout

Example of a recovery CIP set using caustic detergent only



Features included in the two more detailed layouts for CIP sets include:-

- Level switches or gauges on the individual CIP set tanks, to ensure the tanks do not run out of CIP fluids during a clean, or overflow causing dangerous spillages.
- Temperature sensors immediately after the heat exchanger, to ensure the delivery temperature is correct.
- Temperature sensor on the return line, to ensure the minimum temperature has been achieved throughout the plant being cleaned.
- Conductivity sensors on the recirculation loop to ensure the detergent or sterilant strength is correct at all times.
- Pressure sensors and indicators to ensure that the required pressure is achieved where this is a specific requirement, e.g. for high pressure cleaning heads, or to indicate blockages of, or damage to filters and heat exchangers.
- Flow meters to ensure the flow rates are correct for the item of plant being cleaned.
- A filter in the delivery line to ensure that large particles which might block spray heads, or damage other equipment are removed.
- A heat exchanger to ensure the temperature of the CIP fluid is correct at all times (only required if warm or hot cleans required).

Automation and monitoring

Complex CIP systems are ideally controlled using automation, the advantages being:-

- Individual cleaning programmes can be designed and fine tuned when the plant is commissioned to maximise cleaning effectiveness, and minimise revenue costs. This programme will be consistently adhered to subsequently.
- Cleans can run unsupervised.
- Automated records of cycle times, detergent strengths, temperatures and flow rates can be implemented.
- The clean can be suspended if a problem is detected.
- Detergent and sterilant strengths can be optimised.
- Sensors can detect detergent / sterilant strengths on the return line and direct the return to tank or drain reducing chemical and water costs.
- The CIP set automation can be linked to the process plant automation to ensure the plant is available for cleaning at the start of a clean, and available for production at the end of a clean.
- Flow rates and supply pressures can be adjusted automatically (using variable speed pumps) to suit the type of plant being cleaned.
- Interlocks can be built in to assure plant, product and personnel safety.

Notes:

Draw an automated CIP system that you are familiar with and specify the pieces of equipment that are automatically controlled.

Design features for the working environment

Room and building finishes

The buildings that house brewing and packaging plant should be designed with the following hygienic design features:-

- The floors can be cleaned easily. This means good drainage and chemical and temperature resistant impermeable floors, tiled or of suitable material that is durable and has an impermeable surface that will allow for regular cleaning and sanitation.
- Floors of the process and packaging areas must be made from materials that resist the chemicals at the concentrations found in the operational areas.
- Where areas are earmarked for storage of the concentrated forms of detergents and other materials, the floors and walls should be able to resist those materials.
- Floors must have a good fall towards the drains to prevent ponding of water after spillages or hosing down. 1.5% is often considered the minimum fall.
- Drainage systems should be dimensioned (size and falls) to allow for effective discharge of effluent with solids without having any blockages.
- All drains in the process areas and packaging areas should have appropriate airlocks.
- Drain covers in the packaging areas should be constructed with baskets to retain glass or other debris.
- Skirting of the wall to floor joints must be adequate, generally considered to be at least 100mm high and of the same material as the floor finish.
- The walls must be easy to clean. Walls in the process areas should be tiled to the ceiling or coated with a durable and washable coating. Ceilings should be painted with durable and washable coating. Where possible, anti-mould coatings should be used.
- The plant can be accessed for maintenance, ideally without the need for scaffolding.
- There is adequate lighting with access for maintenance.
- There is good ventilation or air-conditioning should supply sufficient air movement to reduce the risk of a damp atmosphere, which can result in mould growth and to eliminate odours.
- Walkways and hand rails should be made of corrosive resistant material or coated with a suitable corrosion resistant material.
- No protrusions should be allowed on walls and windows should have sills facing the outside. Any internal protrusion or beams should have at least a 30° fall to reduce dust from accumulating and to facilitate cleaning.
- All holes to the exterior should be covered by plastic bird and or fly netting.
- All process areas should be protected against entry of insects, vermin, dirt and dust. All floors and walls should be repaired promptly should they be damaged.
- Hot and cold water points should be positioned strategically around the plant for hand cleaning and cleaning of equipment, walls and floors.
- Toilets and changing areas must be positioned away from the process area and be fitted with suitable lockers, showers, washbasins and other required sanitary fittings.

16.4 General plant cleaning

16.4.1 Cleaning plant surfaces, walls & floors

General requirements

- Suitable bins to hold all waste material should be positioned around the plant.
- Only nylon (i.e. **not** natural bristle) brooms and brushes should be used to sweep and clean floors etc.
- Foam cleaning systems are increasingly being used as these allow quick, and more importantly effective and regular cleaning of intricate areas, with reduced manual handling hazards for personnel.
- Squeegees can be used to push excess water from the floors.
- Sufficient hoses and hose points are required to allow cleaning of walls, floors and equipment.
- Special brushes may be required for cleaning surfaces of the plant. Care must be taken not to scratch inside and outside surfaces of stainless steel plant.
- Personnel performing cleaning duties should wear appropriate personal protective equipment.
- Suitable detergents should be used for general cleaning of all surfaces. The choice of the detergents must take account of the fact that chlorine based chemicals are corrosive to stainless steel equipment.
- MSDS certificates must be available for all materials on site.

Constituents of foam cleaning agents

A typical foam cleaner contains a blend of caustic alkali, sequestrants and high foaming surfactants/wetting agents. Some foam detergents also contain hypochlorite for use in particularly heavily soiled areas.

- When selecting the type of foam cleaning material to be used, consideration should be given not only to the soil to be removed but also the materials of construction that the foam detergent will come into contact with.
- **Alkaline** based foams are the most common used for cleaning in the food industry. They will range from approximately pH8 to pH12 (in use) and are effective on most types of soil encountered. Some alkaline foams are inhibited and may be safe to use on soft metal such as aluminium, tin, brass etc. Uninhibited alkaline foams may cause some corrosion to soft metals.
- **Chlorinated** foams are alkaline based with a chlorine "donor". They are usually very powerful detergents. The introduction of hypochlorite in the formulation is to assist with protein removal rather than acting as a biocide.
- **Acid based** foams are used for the removal of mineral scale and protein build up. They may be used in hard water areas (usually more than 200ppm). They will range from pH1 to pH4, are aggressive and care should be taken on soft metals such as aluminium, tin, brass, copper and zinc.
- **QAC (Quaternary Ammonium Compound)** foams are used mainly for light to medium cleaning tasks such as break cleaning and product changeovers.
- **Neutral** foam detergents are by description approximately pH7. They are usually used where soft metals are present or to reduce the hazards of cleaning and therefore reduce the need for Personal Protective Equipment.

The use of foaming systems

Foam cleaning refers to the cleaning process where the main detergent is applied as foam, and Gel cleaning where the main detergent is applied as a gel. Gels can also be aerated during application; this is called a mousse. Foam or gel application is followed by a water rinse. This rinse this can be of low, medium or high pressure.

Foam cleaning has proven to be a very effective, efficient and popular method for cleaning of rooms and equipment. The improvement in foam technology, such as long cling foams, and the introduction of different types of foam detergents have made it a process that can be used, with benefit, in many situations. Air pressure must be sufficiently high to generate a dry, and hence adhesive, foam.

Foam is created by mixing water, detergent and air together and applying it via a hose with a special nozzle or lance onto the surfaces and equipment. The foam detergent will typically be applied at 3 to 5% v/v, depending on the soil to be removed and water hardness. The main advantages of foam and gel cleaning in comparison to manual cleaning are:

- The detergent solution can be applied to large and difficult to reach areas in a short period of time.
- The can be an extended detergent contact time between the soil and the detergent.
- There is normally a reduction in the time required to clean equipment, particularly complex equipment such as pie racks and valve blocks.
- Less manpower is therefore required.
- Detergent use can be carefully controlled.
- Application of hazardous detergents can be made safer, allowing use of stronger detergents for effective cleaning.

A common misconception of foam and gel cleaning is that it removes the need for any type of physical action (such as scrubbing with a brush or scourer). Physical energy must still be applied after suitable detergent contact time. The physical energy can be applied by either scrubbing or by energy from a water jet, usually at high or medium pressure.

All wash-down systems whether low, medium or high pressure will cause overspray and / or aerosols, which can lead to cross contamination if no controls are put in place.

Notes:
Draw a diagram of a piece of plant with which you are familiar:

- *Identify parts that are easy to clean.*
- *Identify parts that are difficult to clean.*

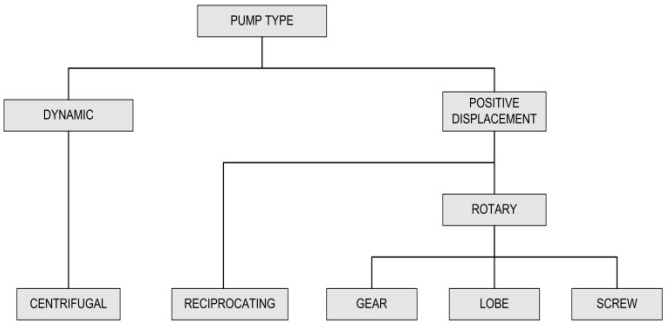
Qualifications

The General Certificate in Brewing (GCB)

Learning Material © Institute of Brewing and Distilling 2016

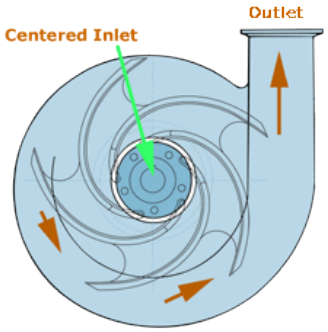
17.1 Engineering Basics

PUMPS



Centrifugal pumps

They are excellent pumps for general transfer applications of low viscosity liquids such as wort, beer, water. Centrifugal pumps handle high volumes with a smooth, non-pulsating flow.



Liquid enters the central inlet port of pump. The level of liquid must be high enough above pump, or the supply pressurised to push the liquid into the pump. The rotating impeller moves the liquid to the outside of the impeller, into the casing and towards the discharge port. The pressure is dependent on the design of the impeller and the casing. The flow rate is dependent upon restrictions in the inlet and outlet piping and the height that the liquid needs to be moved.

Straight bladed impellers are very inefficient. The capacity of the pump can be controlled by either trimming the diameter of the impeller or restricting the discharge of the pump with a partially closed valve but these can cause unnecessary damage to the product. Curved impellers are much more efficient and substantially reduce turbulence and damage to the product.

Reasonably priced variable frequency drive (VFD), also known as variable speed drive (VSD) speed controls are widely available. With a VFD you can use a larger diameter impeller so that the pump is capable of pumping at a range of different flow rates, whilst operating at its best efficiency. The required flow rate can be achieved without excess turbulence, wasted energy or damage to the pump.

Applications - closed impeller

- Most common type of impeller.
- Handles liquid with low levels of solids.
- Wort, beer, water transfer.
- Flash pasteurisation.
- Filter precoating powders.
- CIP delivery and scavenge.

Applications - open impeller

- Where liquids contain higher levels of solids.
- Wort transfer from lauter tun.
- Trub transfer.
- Thin yeast slurry transfer (though not best pump for this duty) .

Advantages

- Comparatively inexpensive.
- Smaller than other designs with similar capacity
- Easy to clean.
- Easy to install due to compact size and the ability to rotate the discharge port to various positions for ease of piping.
- Less expensive to maintain. They are easily disassembled for quick service, and have few moving parts.
- Wear due to operation is minimal.
- Will handle fine solids (but will wear pump material if solids are hard & abrasive such as KG powder).
- Valves in discharge line may be closed with minimal risk of damage to pump in short term.
- No pressure relief by-pass valve required in discharge main.

Disadvantages

- Damages fragile products such as mash, so most are unsuitable for this purpose.
- Can't easily handle solids or thick products such as yeast slurries.
- Easily gas locked.
- Not normally self-priming.

Hygienic properties

- Minimal risk of blockage due to open design.
- All surfaces are accessible and can be polished to any surface quality.
- All internally wetted areas are actively flushed by product flow.
- No enclosed or low flow areas within the pump or impeller.
- Self- cleaning.

Positive displacement pumps

All positive displacement pumps take a fixed portion of product (the amount that fits between the rotors or vanes or in the housing) and physically moves that product from the inlet to the outlet side of the pump. The pump impellers

move slowly (typically 300 - 500 rpm for rotary) and there is very little slippage, especially if pumping a thick product like mash.

Advantages:

- Can pump thick products such as mash, yeast, trub.
- Gentler on the product, especially thick products.
- Can produce high pressure.

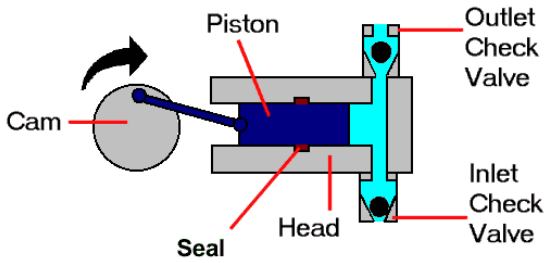
Disadvantages:

- Many designs produce pulsing flow.
- Hard to clean.
- Lower flow rates, bigger and more expensive than equivalent capacity centrifugal pump.
- Can be more expensive to maintain.
- Can build high pressure if blocked, so normally have pressure relief system fitted at outlet].

Piston pumps

A motor-driven cam pulls the piston back and forth in the pump head. A flexible seal around the periphery of the piston prevents leakage of liquid from the back of the pump. Check valves mounted in the head open and close in response to small changes in pressure to maintain a one-way flow of the liquid.

The capacity of the pump is determined by the plunger diameter, the stroke length and the number of strokes per unit of time. The combined adjustment of stroke length and speed allows metering as a function of the two variables. A piston pump is independent of head against which it is pumping.



Applications

- Filtration – bodyfeed dosing.
- Additives dosing, e.g. colour, priming sugar, finings.
- CIP – concentrated detergents and sterilants.

Diaphragm pumps

A diaphragm pump is a positive displacement pump that uses a combination of the reciprocating action of a rubber, Teflon or similar diaphragm and suitable non-return check valves to pump a fluid. This type of pump is sometimes also called a membrane pump.

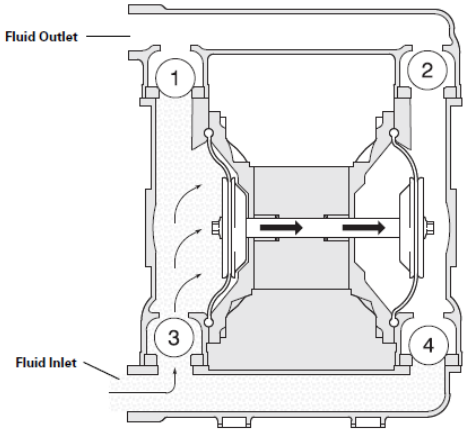
There are two main types of diaphragm pumps used in breweries:-

- In the first type, the diaphragm is sealed with one side in the fluid to be pumped, and the other in air or hydraulic fluid. The diaphragm is flexed, causing the volume of the pump chamber to increase and decrease. A pair of non-return check valves prevents the reverse flow of the fluid.
- As described above, the second type of diaphragm pump works with volumetric positive displacement, but differs in that the prime mover of the diaphragm is neither oil nor air; but is electro-mechanical, working through a crank or geared motor drive. This method flexes the diaphragm through simple mechanical action, and one side of the diaphragm is open to air.

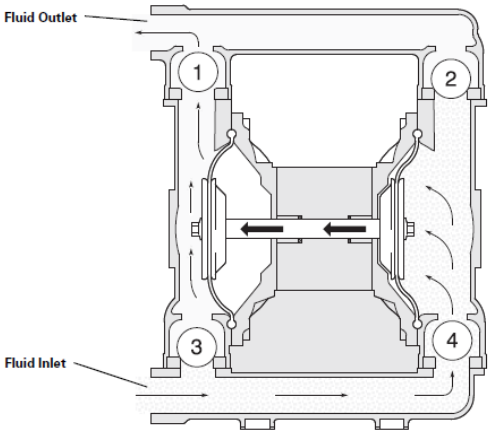
Operation of a double diaphragm pump

The double diaphragm pump is perhaps the most commonly used type of diaphragm pump in breweries, and so only this type is described.

Compressed air flows into the right air chamber, causing the right diaphragm to flex. This expansion creates a high pressure in the right fluid housing equal to the air pressure applied to the pump. The inlet check valve (4) of the right fluid housing closes, the outlet valve (2) opens, and the fluid is pumped through the outlet manifold. The pump shaft moves right creating a vacuum in the left fluid housing. The left inlet check valve (3) opens, the left outlet valve (1) closes, and the fluid flows into the left fluid housing.



At the end of the pump stroke the air valve switches and compressed air will flow into the left air chamber, causing the left diaphragm to flex. The inlet check valve (3) of the left fluid housing closes, the outlet valve (1) opens, and the fluid is pumped through the outlet manifold. The pump shaft moves left creating a vacuum in the right fluid housing. The right outlet valve (2) closes, the right inlet check valve (4) opens, and the fluid flows into the right fluid housing.



Applications

- Yeast slurry transfers from tank to tank.
- Trub slurry transfer.
- Yeast and bottoms transfer to presses for beer recovery.

Advantages of diaphragm pumps

- They do not depend on pumped liquid for lubrication, thus can be run dry without damage.
- They are self-priming.
- They can have single or multiple chambers, with more chambers resulting in smoother flow.
- They can pump fluids with fine solids, though the solids may affect the seals (ball valves in the diagrams).
- They are pressure balanced. They stall if discharge is closed and restart when discharge is opened so avoiding heat build-up and component wear.
- They have minimum product agitation.
- If air driven, they are safe in hazardous areas, no sparking.

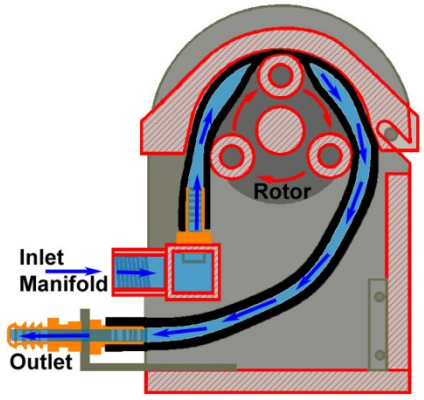
Disadvantages

- They generally have a low throughput.
- If mechanically driven, they need a pressure relief valve on the outlet if there is a risk of dead-ending (not applicable to air driven pumps as these will stall).
- Pulsating flow (though they can be smoothed to some extent).

Peristaltic pumps

Peristaltic pumps work using the process of peristalsis to pump products through a hose, in the same way that food is pumped through the small and large intestine.

- The hose sits around a rotor which, when turning, compresses a segment of the hose almost flat.
- This compression is released as the rotor moves around the hose with the hose reinforcements causing it to spring back to its round shape, thus creating a partial vacuum refilling the hose.
- This compression creates a seal and, as the rotor turns, any product on the discharge side of the rotor is propelled forward and displaced from the pump.
- Combining this suction and discharge action results in a self-priming positive displacement pump.



Applications

- Filtration – bodyfeed dosing.
- Additives dosing, e.g. colour, priming sugar, finings.
- CIP – concentrated detergents and sterilants dosing.
- Laboratory equipment.
- Yeast cropping and transfer.
- Trub slurry transfer.
- Yeast and bottoms delivery to presses for beer recovery.
- Re-slurried filter cake transfer to waste.

Advantages

- Seal-less design. The main feature of the peristaltic pump is the tube/hose. Because this is the only part of the pump to come in contact with the product it means the pump avoids corrosion and is leak-free.
- Dry running. Many pump users face difficulties when the pump runs dry. Note that in many designs the outside of the tube & the rotor are immersed in lubricating oil.
- Self-priming. The pumps are capable of self-priming and can handle products that are likely to suffer gas breakout.
- Gentle pumping action. Because of the tube/hose and the pumps' gentle action, the product being pumped is not damaged in the process thus making peristaltic pumps ideal for shear sensitive or viscous liquids or suspensions such as yeast slurry.
- High discharge pressure. The pumps can provide high discharge pressures meaning they are suitable for use where the product being pumped is viscous and develops high back pressure (e.g. yeast slurry), or is being pumped into an areas of high pressure (e.g. kieselguhr dosing).
- Accurate dosing. The pumps are accurate in dosing, with repeatability of circa ±0.5% and metering capabilities of circa ±2%.
- Enhanced hose life & abrasion resistant. Tube/hose life is not related to a product's abrasive qualities. The tube/hose only fails due to fatigue or chemical action.

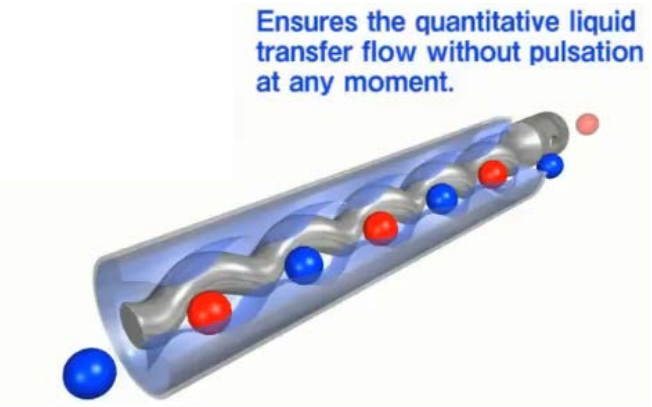
Progressive cavity pumps

These are a type of positive displacement pump. They may be known by a variety of similar names including Moineau (after the inventor), Mono pump, Moyno pump and Mohno pump They are also known as progressing cavity pumps, eccentric screw pumps or cavity pumps.

The progressing cavity pump uses the helical rotor pumping principle. There is a single helix metal rotor which rotates eccentrically within a double helix resilient stator. The rotor of circular cross section creates a continuously forming cavity as it rotates. The cavity progresses towards the discharge end, carrying the pumped material with it. As the stator open cross sectional area is always constant the flow rate is continuous without pulsation.

The volumetric flow rate is proportional to the rotation rate.

The pumps are suitable for fluid metering and pumping of viscous or shear-sensitive materials. The cavities taper down toward their ends and overlap with their neighbours, so that, in general, no flow pulsing is caused other than that caused by compression of the fluid.



Applications

- Yeast slurry transfer (more commonly waste yeast).
- Trub slurry transfer.
- Re-slurried filter cake transfer.

Advantages

- Capacity is proportional to speed.
- Self-priming even with entrained air.
- Can handle a variety of viscous materials.
- Minimal damage to shear sensitive products.
- Can handle liquids containing solids or abrasive particles.
- Pulsation free operation.
- Positive displacement.

Disadvantages

- Reduced pressure developed with thin liquids such as beer.
- Needs pressure relief valve on outlet if there is a risk of dead-ending.

Lobe pumps

These pumps offer a variety of lobe options including single, bi-wing, tri-lobe (shown), and multi-lobe. Rotary lobe pumps are able to handle slurries, pastes, and a wide variety of other liquids. If wetted, they offer self-priming performance. A gentle pumping action minimizes product degradation. They also offer reversible flows and can operate dry for long periods of time. Flow is relatively independent of changes in process pressure, so output is constant and continuous.

Lobe pumps are similar to external gear pumps in operation in that fluid flows around the interior of the casing.

- As the lobes come out of mesh, they create expanding volume on the inlet side of the pump. Liquid flows into the cavity and is trapped by the lobes as they rotate.
- Liquid travels around the interior of the casing in the pockets between the lobes and the casing -- it does not pass between the lobes.
- Finally, the meshing of the lobes forces liquid through the outlet port under pressure.

Lobe pumps can handle solids such as yeast slurry without damaging the product. Particle sizes pumped can be much larger in lobe pumps than in other PD types. Since the lobes do not make contact, and clearances are not as close as in other PD pumps, this design handles low viscosity liquids with reduced performance. Slip in a rotary lobe pump is the amount of liquid which escapes from the high pressure side of the pump to the low pressure side. Slip occurs between the two lobes, between the lobes and the rotor case walls and between the lobes and the front and back of the rotor case.

Applications

- Yeast cropping and transfer.
- Yeast and bottoms presses for beer recovery.

Advantages

- Can handle fine solids such as yeast slurries.
- No metal-to-metal contact.
- Good CIP capabilities.
- Long term dry run (providing there is lubrication to seals).
- Non-pulsating discharge.
- The flow can be bi-directional, though is rarely if ever used in brewing.
- Relatively quiet operation.

Disadvantages

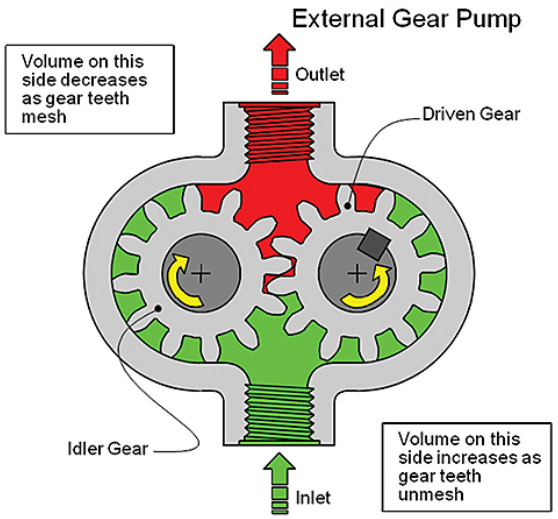
- Reduced pressure developed with thin liquids such as beer.
- Needs pressure relief valve on outlet if there is a risk of dead-ending.

Gear pumps

The simplest gear-type pump, most commonly used in the brewing industry, uses a pair of mating gears rotating in an oval chamber to produce flow. As the gears rotate, the changing size of the chambers created by the meshing and un-meshing of the teeth provides the pumping action.

Another design (not shown) uses an external rotating ring with internal gear teeth that mesh with an internal gear as it rotates. As the inner gear rotates, the tooth engagement creates chambers of diminishing size between the inlet and outlet positions to create flow.

Slip in a gear pump is the amount of liquid which escapes from the high pressure side of the pump to the low pressure side. Slip occurs between the two gears, between the gears and the rotor case walls and between the gears and the front and back of the rotor case.



Applications

- Yeast cropping and transfer.
- Yeast and bottoms presses for beer recovery.

Advantages

- The flow can be bi-directional, though is rarely if ever used in brewing.
- Gear pumps are capable of self-priming because the rotating gears evacuate gas in the suction line.
- Can be relatively high speed.
- High pressure.
- Relatively quiet operation.
- Design accommodates wide variety of materials.
- Good CIP capabilities.
- Non-pulsating discharge.

Disadvantages

- No solids allowed, though they can be used for yeast slurries.
- Fixed end clearances so potential for considerable slippage.

VALVES

Butterfly valves

A hygienic butterfly valve suitable for use with beer, cider etc. has a short circular body, a round disc, metal-to-soft seat seal, top and bottom shaft bearings, and a stuffing box. The construction of a butterfly valve body varies. A commonly used design is the wafer type that fits between two flanges. Another type, the lug wafer design, is held in place between two flanges by bolts that join the two flanges and pass through holes in the valve's outer casing. Butterfly valves are available with flanged, threaded or butt welding ends.

A circular disc, of the same internal diameter as the pipe is pivoted in the pipeline. When the axis is parallel to the flow, it is fully open. When the axis is at right angles to the flow, it is fully closed. The rim of the disc and the circumference of the pipe at the point of contact are generally fitted with sealing rings to provide complete shutoff.

The maintenance costs are usually low because there are a minimal number of moving parts and there are no pockets to trap fluids.

They are especially well-suited for the handling of large flows of liquids or gases at relatively low pressures and for the handling of slurries or liquids with large amounts of suspended solids.

They can be automatic or hand operated. Seat materials can be specified to suit the particular duty. They are relatively cheap and provide good “shut off”. They are not suitable for controlling flow rates accurately, though are often found “locked” partially closed for crude flow control.

Non hygienic butterfly valve – to demonstate basic design only.

Advantages

- Compact design requires considerably less space, compared to other valves.
- Light in weight.
- Quick operation requires less time to open or close
- Available in very large sizes.
- Low-pressure drop and high-pressure recovery.

Disadvantages

- Throttling service is limited to low differential pressure
- Cavitation and choked flow are two potential concerns
- Disc movement is unguided and affected by flow turbulence
- Butterfly valves require special seal for tight shutoff.

Gate valves

Gate valves are primarily designed to start or stop flow, and when a straight-line flow of fluid and minimum flow restriction are needed. In service, these valves generally are either fully open or fully closed.

The disk of a gate valve is fully drawn up into the valve bonnet when the valve is fully open. This leaves an opening for flow through the valve at the same inside diameter as the pipe system in which the valve is installed.

A gate valve can be used for a wide range of liquids and provides a tight seal when closed.

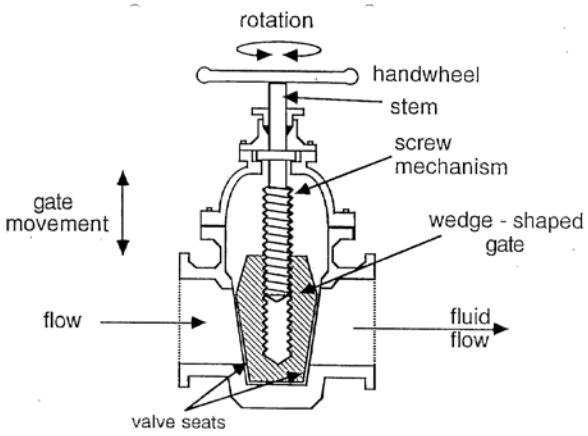
Advantages

- Good shut-off features.
- Gate valves are bidirectional and therefore they can be used in two directions.
- Pressure loss through the valve is minimal.

Disadvantages

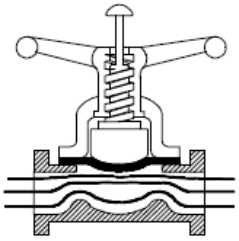
- They are not hygienic and so must not be used for product.
- They cannot be quickly opened or closed.
- Gate valves are not suitable for accurate control of flow rates.
- They are sensitive to vibration in the open state.

The disc or gate travels normal to the direction of flow of the liquid and causes a rapid change in the area of the orifice. Sizes up to 12" (30cm) are common.

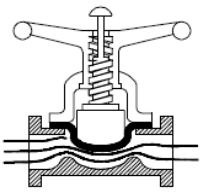


Diaphragm valves

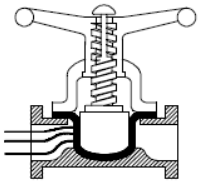
A resilient, flexible diaphragm is connected to a compression system by a stud moulded into the diaphragm. The compressor is moved up and down by the valve stem. Hence, the diaphragm lifts when the compressor is raised. As the compressor is lowered, the diaphragm is pressed against the contoured bottom in the straight through valve or the body weir in the weir-type. A straight through type of diaphragm valve is shown below.



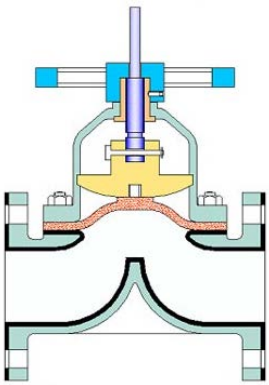
Open



Throttling



Closed



Weir type valve

Applications

- Air and other gases
- Steam supply

Advantages

- A weir-type diaphragm valve can be used to control small flows.
- Diaphragm valves are particularly suited for the handling of corrosive fluids or other fluids that must remain free from contamination.
- The operating mechanism of a diaphragm valve is not exposed to the media within the pipeline. Sticky or viscous fluids cannot interfere with the operating mechanism.
- Many fluids that would clog, corrode, or gum up the working parts of most other types of valves will pass through a diaphragm valve without causing problems. Conversely, lubricants used for the operating mechanism cannot be allowed to contaminate the fluid being handled.
- There are no packing glands to maintain and no possibility of stem leakage in valves.

Disadvantages

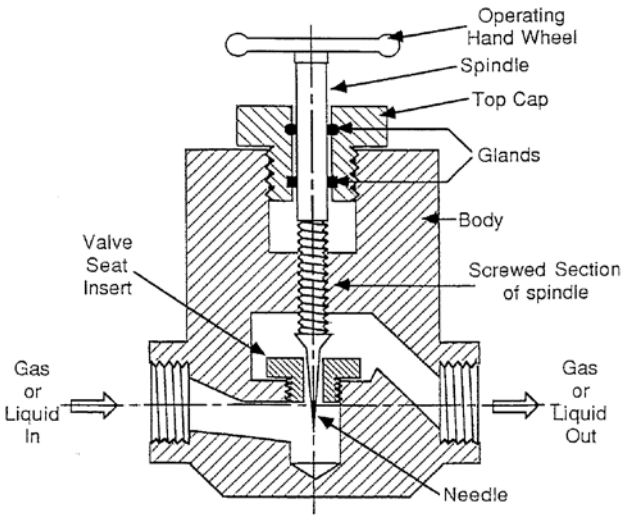
- Generally these are unhygienic and must not be used with product (beer / cider etc., where the mains require cleaning)

Needle valve

A needle valve has a relatively small orifice with a long, tapered seat, and a needle-shaped plunger, on the end of a screw, which exactly fits this seat. As the screw is turned and the plunger retracted, flow between the seat and the plunger is possible. However, until the plunger is completely retracted the fluid (or gas) flow is significantly impeded. Since it takes many turns of the fine-threaded screw to retract the plunger, precise regulation of the flow rate is possible.

Needle valves are commonly used when a precise control of gas flow is required, at low pressure such as wort oxygenation or small scale carbonation.

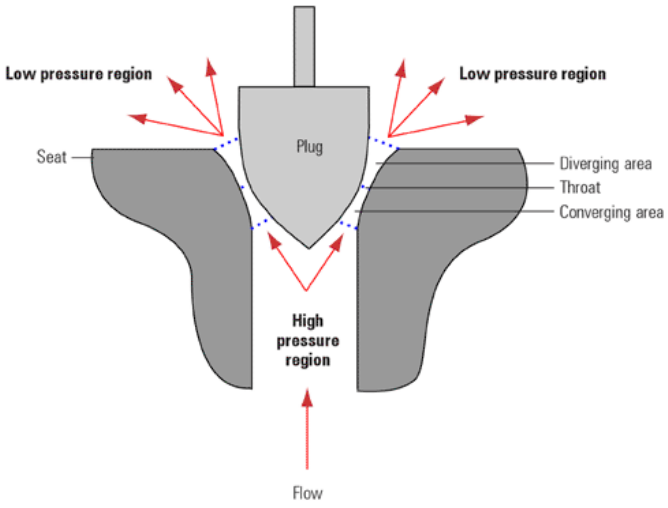
Since flow rates are low and many turns of the valve stem are required to completely open or close, needle valves are not used for simple shutoff applications. It may also be necessary to force the needle into the orifice resulting in damage to the needle or the orifice surface.



Applications

- Flow control of air, CO_2 and other gases

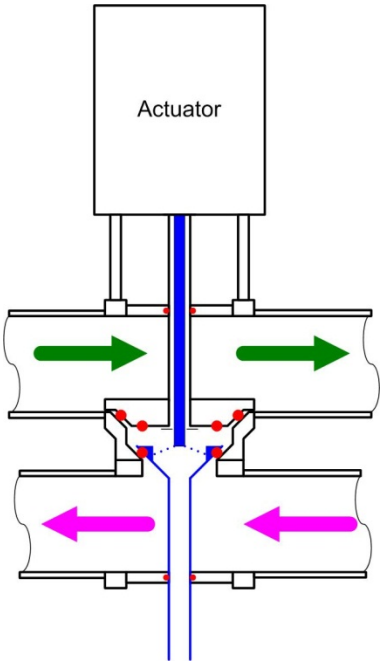
Larger variable flow control valves operate on a similar principle, but use wider "plugs" instead of a needle. The principle of operation is shown below.



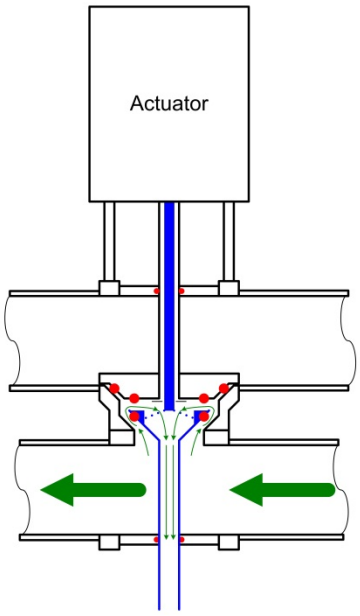
Double seat valves

These are commonly used on larger installations where for instance, a number of tanks are connected to a number of different filling, emptying and CIP lines and are used to ensure the complete separation of incompatible products in automatic process plants. The closed valve avoids mixing the two liquids by having two independent valve seats with depressurized leakage discharge between them. In case of a damaged sealing, the process medium escapes from the valve into the depressurized area. The leakage space can be cleaned by lifting the upper valve disk or lowering the lower valve disk respectively, or less efficiently by spaying CIP fluids into the space between the upper and lower seats.

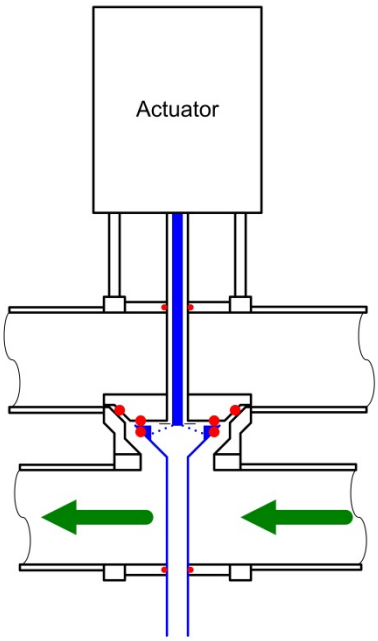
The following diagrams show the phases of opening of a typical double seat valve.



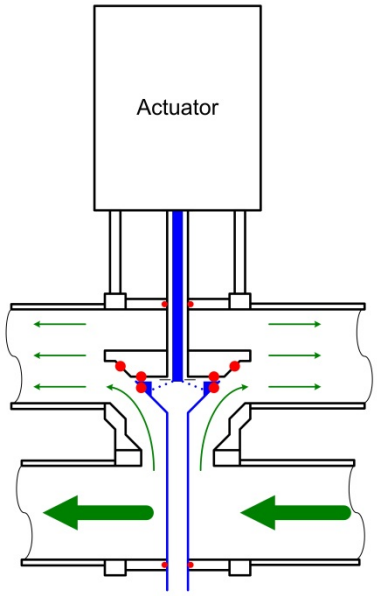
Typical separated flows – CIP & Beer



Bottom seat lifting – slight beer leakage



Bottom and top seats sealed – leakage stops



Seats fully lifted – flow from bottom to upper main

Ball valves

A ball valve is a quarter-turn rotational motion valve that uses a ball-shaped disk to stop or start flow. If the valve is opened, the ball rotates to a point where the hole through the ball is in line with the valve body inlet and outlet. If the valve is closed, the ball is rotated so that the hole is perpendicular to the flow openings of the valve body and the flow is stopped.

Applications

- Air, gaseous, and liquid applications
- Drains and vents in liquid, gaseous, and other fluid services
- Steam service

Advantages

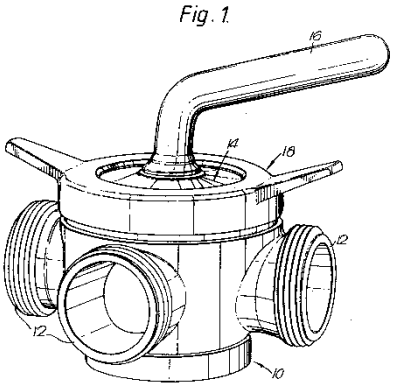
- Quick quarter turn on-off operation
- Tight sealing with low torque
- Smaller in size than most other valves

Disadvantages

- Generally these are unhygienic and must not be used with product
- Some suppliers claim to have hygienic ball valves, but these still have a portion of the ball surface and the housing which is does not come into contact with CIP fluids and must therefore be considered unhygienic
- Conventional ball valves have poor throttling properties
- In slurry or other applications, the suspended particles can settle and become trapped in body cavities causing wear, leakage, or valve failure.

Plug valves

Plug valves are valves with cylindrical or conically-tapered "plugs" which can be rotated inside the valve body to control flow through the valve, in a similar manner to ball valves. The plugs in plug valves have one or more hollow passageways going sideways through the plug, so that fluid can flow through the plug when the valve is open. An advantage of these types of valves is that they are excellent for quick shutoff. The following diagram shows a three way valve.



3 way plug valve

Applications

- They are not hygienic as the surfaces cannot be fully exposed to CIP fluids, and therefore are not suitable for beer or cider production.

Pressure Relief Valves

A pressure relief valve (PRV) is a safety device designed to protect a pressurized vessel or system during an overpressure event, i.e. any condition which would cause pressure in a vessel or system to increase beyond the specified design pressure or maximum allowable working pressure (MAWP). The primary purpose of a pressure relief valve is protection of life and property by venting fluid or gas from an over-pressurized vessel. There is normally a statutory requirement to test these valves regularly.

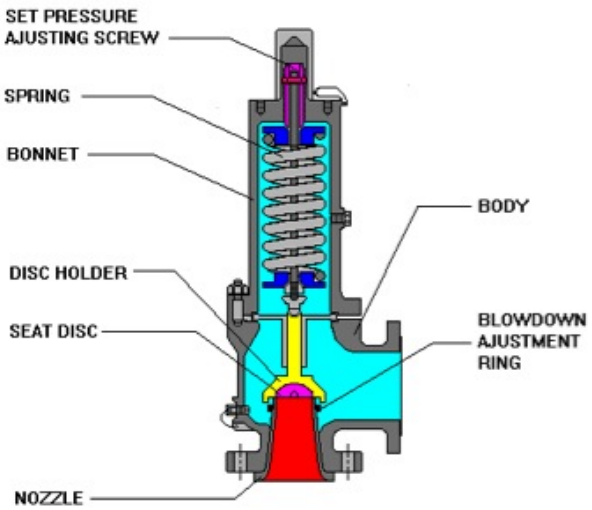
Spring loaded PRV

The basic spring loaded PRV has been developed to meet the need for a simple, reliable, system actuated device to provide overpressure protection.

The image on the right shows the construction of a spring loaded PRV.

The valve consists of a valve inlet or nozzle mounted on the pressurized system, a disc held against the nozzle to prevent flow under normal system operating conditions, a spring to hold the disc closed, and a body/bonnet to contain the operating elements. The spring load is adjustable to vary the pressure at which the valve will open.

When a pressure relief valve begins to lift, the spring force increases. Thus system pressure must increase if lift is to continue. For this reason PRVs are allowed an overpressure allowance to reach full lift. This allowable overpressure is generally 10% for non-actuated valves. This margin is relatively small and some means must be provided to assist in the lift effort.

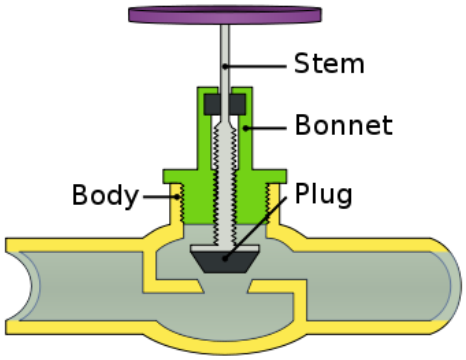


Applications

- They are used for gases and liquids, though the exact internal design will differ for each application.

Globe Valves

A globe valve is a type of valve used for regulating flow in a pipeline, consisting of a movable disk-type element and a stationary ring seat in a generally spherical body. The valve can have a stem or a cage, similar to ball valves, that moves the plug into and out of the globe. The fluid's flow characteristics can be controlled by the design of the plug being used in the valve. A seal is used to stop leakage through the valve. Globe valves are designed to be easily maintained. They usually have a top that can be easily removed, exposing the plug and seal. Globe valves are good for on, off, and accurate throttling purposes but especially for situations when noise and cavitation are factors.

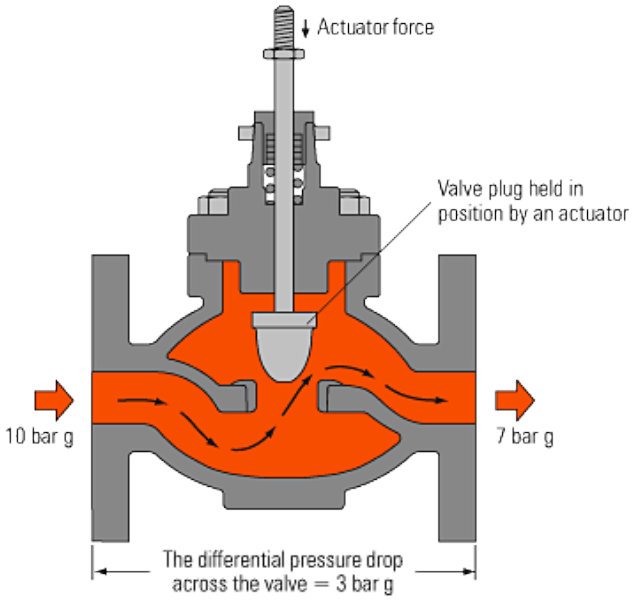


Applications

- They are used for liquids and steam, though the exact internal design will differ for each application.

Pressure regulating (control or reducing) valve

These are installed on services such as gas supplies to control the downstream pressure in the system at point of use. They are usually installed in conjunction with a pressure relief valve so the system is protected in event of a failure. The following is a simplified example of a steam control valve.



When the pressure is too high, the valve closes slightly and when the pressure is at the desired level, the valve takes up a pre-set central position.

Applications

- They are used for liquids and gases, though the exact internal design will differ for each application.

Anti-vacuum valve

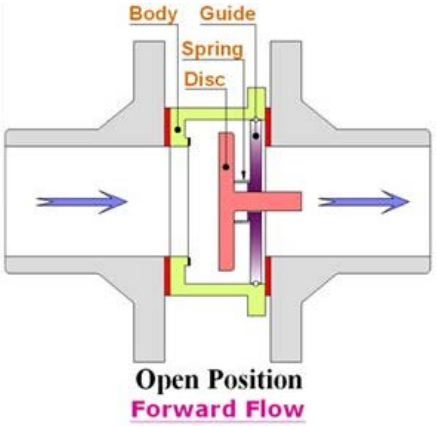
These are designed to minimise the risk of implosion of tanks being exposed to vacuum (e.g. during emptying, cool rinsing after hot-cleaning or caustic cleaning in a CO_2 atmosphere). These valves can be installed on any closed tank. The size and setting of the anti vacuum valve is based on thetank design data, cleaning procedure and process requirements. The following picture is of a dead weight anti vacuum valve. (Photo courtesy of Alfa Laval)

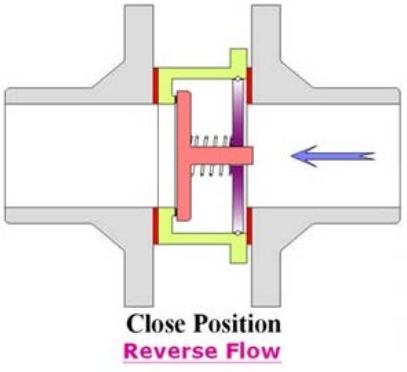
Cleaning
The underside of the anti-vacuum valve is cleaned when closed, by the tank cleaning head, but this will not include the valve seal. To include the valve seal in the cleaning cycle a CIP device can be mounted on the valve.

The CIP device uses the CIP pressure to open the valve slightly and cleaning liquid flushes the valve disc and drains back in to the tank. The CIP device is supplied with a splashguard to catch reflecting sprays. Note: This facility can only take place if the tank is fully depressurised.

Mounting
The valve should be seated horizontally. An inclination of max. 10° is acceptable but the lever arm must then point in to the centre of the tank top.

Non-return valves
Non-return valves in hygienic pipelines (beer, cider, dilution water etc.) should be avoided. The principle of operation of a non-return valve of the type widely installed in breweries is shown in the following diagrams.





JOINTS

The installation should fulfil the following requirements to be considered hygienically designed:

- No metal on metal joints unless welded
- The minimum number couplings
- No sharp corners
- No dead ends, pores, cracks
- No O-rings, unless these provide a smooth seal
- No thread ends
- No shadow areas
- No possibility of stagnant liquid (self draining)
- No risk of air entrapment (no 'goal posts')

It is strongly recommended that joints are avoided wherever possible. Bending of the pipe is highly preferable over the use of prefabricated bends with couplings. If pipe bending is not possible, welding is the preferred method provided that the welding is done correctly to ensure smooth and continuous welds. Where detachable joints are necessary, they should be sealed by suitable elastomer seals.

Over-compression of seals may affect the hygienic characteristics of equipment in two ways.

- Firstly, over-compression may lead to destruction of the elastomer particularly if the over-compressed seal is heated (such as during pasteurization or sterilization). The elastomer may become brittle and fail to provide the required seal, whilst parts of the elastomer may break off and contaminate the product.

- Secondly, over-compression may lead to protrusion of the elastomer into the equipment, thereby hampering cleaning and draining. Under-compression too is highly undesirable as it may lead to crevices and fail to provide a reliable seal. Even when it is not visibly leaking, the seal may permit the ingress of microorganisms.

Not only the dimensions of the metal components, but also those of the gasket must be correct, ensuring adequate compression at the product side, allowing for differences in thermal expansion under all operation conditions (cleaning, pasteurization or sterilisation, and processing).

Improper alignment may also result in inadequate cleaning and reduced drainability. Many designs of joint (e.g. traditional flange connection) do not control compression of the gasket and automatically result in misalignment.

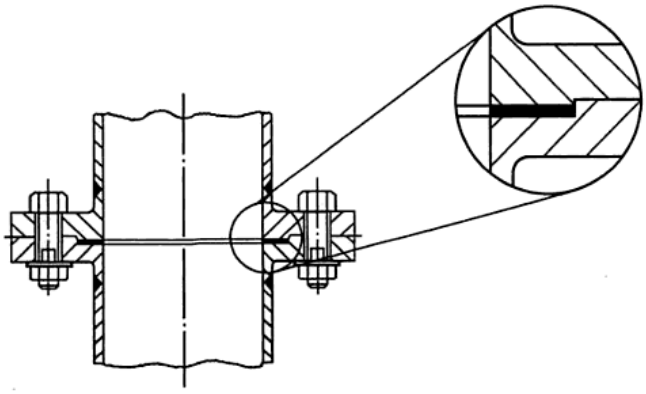
Installations containing conventionally designed O-ring seals invariably create crevices that are impossible to clean in-place. Further, it is difficult to inactivate micro-organisms present in conventional O-ring seals because when heating equipment with O-ring seals, the O-ring expands trapping and protecting micro-organisms between the O-ring and

the steel surface against contact with the hot water, chemical solution or steam used for sterilizing. On cooling down, the O-ring shrinks and surviving micro-organisms will be freed to infect the product at the start of production.

O-rings can be acceptable from a hygienic point of view if mounted in a way that ensures that the area of steel covered by the rubber at the product side does not change with temperature. However repeated changes in temperature may result in accelerated ageing, so that periodic replacement of the elastomer seal is required.

Non welded metal-to-metal joints seal as a result of the deformation of the contacting metal surfaces. The result is permanent damage to these surfaces which makes it more difficult to obtain a tight seal after every disconnection. Even when these joints are not visibly leaking, the ingress of microorganisms is probable. Further, the seal obtained is very unlikely to be at the product side. More likely, the actual seal follows an irregular line between the inside and outside. The resulting annular crevice will trap product. Therefore, metal-to-metal joints must not be used in a hygienic plant.

Seals should be resilient enough to guarantee an adequate seal under all process conditions. The selection of seal type must take into be design to accommodate processes carried out at both the maximum temperature (e.g. during pasteurization or sterilization) and minimum temperature (e.g. during the cooling to cold maturation / filtration temperatures). Generally EPDM or Viton seals will meet the requirements of the production processes.



INSTRUMENTS

Analogue

- Used where a continuous range of values needs to be monitored e.g. dissolved CO_2 levels in beer, turbidity, tank levels (variable volume indicated)

- Where a range of changeover setpoints may be used, e.g. buffer tank top pressure control :–

  High level value - start venting the tank, Set point - stop pressurising or venting the tank, as appropriate, Low value - start pressurising the tank, Low low value – put the associated processes into alarm hold.

- Almost all other analogue instruments (flow meters, temperature sensors, conductivity sensors use 4 - 20 mA signals. If a pump runs at 0 % this corresponds to 4 mA and 100% corresponds to 20 mA. We start at 4 mA so it is easy to detect an open circuit (i.e. 0 mA).
- Thermocouple devices used to measure temperature use a mV signal. The change in temperature changes the resistive properties of the sensor, thus changing the voltage (ohms law)
- All analogue instruments present a 4 - 20 mA or variable mV signal to a PLC input card. This is converted to a integer value e.g. 0 - 32000 which is used in the program.

Digital

- Used where a distinct change of state is being determined. e.g. vessel empty or full level switches.
- Digital Inputs are usually 0 - 24 volts DC where zero is off and 24 volts is on (can also be 0 - 110 V or 0 - 240 V)
- Digital Outputs normally switch 0 volts = off and 24 volts = on (can also be 0 - 240 V)
- Note 0 - 5 volts may be off, 5 - 15 volts not reliable, 15 - 24 volts is on. So if you get interference (noise) between 0 - 5 volts the input is off because it needs more than 15 volts to switch on.

Instruments commonly used in a brewery

- Oxygen
- Carbon dioxide
- Nitrogen
- Alcohol
- PG
- OG
- Level
- Colour
- Conductivity
- Turbidity
- Biomass / Viability
- pH
- Flow
- Pressure
- Temperature

Installation

Protection against the environment

The instrument itself must be protected by suitable enclosure against the conditions anticipated including dust, water, steam.

It should be positioned so that where it is not intended to use the instrument to measure that condition, it is not exposed to abnormal conditions such as strong electric fields, dust, water, water vapour, vibration, aggressive chemicals such as caustic or peracetic acid.

The field wiring associated with the instrument must be suitable for the environment in which it is laid, and should be protected by careful routing and trunking or cable trays.

Protection against workforce
The instruments and associate wiring should be positioned to minimize accidental damage due to knocks, washing down etc., but ensuring good access for maintenance.

Robust
The instrument should be suitable for the environment it is to be used in. For example, a temperature probe in a CIP return line should be designed to cope with the flow rates and temperatures required, with strong fittings to ensure physical stability in the line.

Accessible for maintenance
Technician's own access. Although desirable to site instruments at high levels, or at the back of a valve block, easy access is required by the maintenance technicians. If they are working at a comfortable height in good lighting conditions, then maintenance will be quicker, easier, and with less risk of safety problems.

Plant isolations. It should be possible to isolate the instrument from the plant using local isolation manual valves so that, for example, full drain down is not required. It is essential to be able to isolate the plant electrically and or mechanically to prevent it running whilst maintenance is in progress.

Easy to replace / maintain
The fittings used to insert the instrument should be compatible with others used across site, and require only standard tools to remove & replace. Ideally it should be possible from a time and cost point of view, to repair the instrument in the brewery workshop, rather than replace, or have to return to supplier / manufacturer.

Operating conditions

Good practice operating conditions for in line sensors such as flow meters, conductivity probes, pH meters are as follows –

The pipe should be full whenever the sensor is required to measure. This is particularly important for instruments such as flow meters and haze meters, where entrained gas will cause a false reading. It may be less critical for instruments such as conductivity or pH probes. However, some probes are not designed to cope with drying out, and suitable instruments must be installed if the main dries out as part of normal production procedures.

Ideally the pipe should be rising or at least horizontal, with a rising loop after the instrument to help ensure a full pipe. A falling pipe requires high flow rates to ensure the pipe is fully gas free should it ever entrain gas.

The flow through the pipe should be reasonably "laminar", such that excessive turbulence in the flow does not affect the instruments reading, or even damage the instrument. This is assisted by not positioning the instruments too close to sharp bends (typically less than 1.5 D radius) Tee pieces, or other sudden changes in pipe diameter. In the case of magflow meters, typical distances quoted are 5D prior to, and 2D after the meter of straight pipe of equal internal diameter to that of the meter. More recent meters may not require as much – check the individual instrument installation details.

The instrument itself should not restrict the flow, otherwise it may affect the overall process design, or the increased pressure and turbulence may damage the instrument.

Instrument reliability

Install in a fail-safe condition
The instruments should be installed in a fail-safe condition, i.e. in the event of instrument failure; the plant the instrument is controlling will revert to a safe condition. Examples include high level probes which if they fail normally indicate the vessel is full, thus preventing overfilling, or if a temperature probe controlling a beer chiller should fail, then the coolant supply is shut off fully in the belief that the product is already too cool.

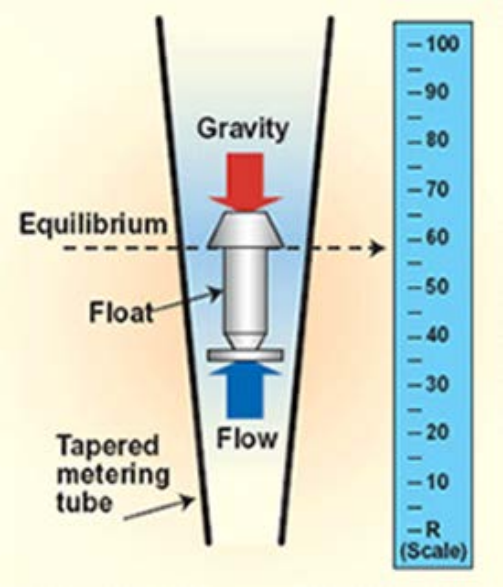
Cross checked
The instrument may be cross checked against another instrument for validity. An example is the use of cross checked low and high level probes set to operate an alarm condition if the indicated values are incompatible. Should the low level probe fail whilst the high level probe is covered, then an "incompatible levels" alarm may be generated and the process held. Another is the use of a tank level transmitter (and hence volume) with a low level probe in the outlet to control the tank empty sequences. The tank may only be deemed empty if the measured tank volume is less than a small, but consistently measurable volume, and the level probe is uncovered.

The instrument may be cross checked against an operator input into a SCADA system for validity. An example is the use of a temperature probe on the filter discharge during sterilisation, which may be used to prompt the operator to confirm once all physical checks have been made, and the sterilisation timer may be started.

The instrument may be cross checked against the stage of the process for validity. An example is the use of interface detection devices only being enabled during the beer push out DAL pre-flush to BBT sequence when the interface is anticipated. Should a change of state be detected during the forward flow sequence, then an alarm condition may be generated, or perhaps the instrument may not be monitored at all.

FLOW METERS

Rotameters
This is a simple and economical means of flow control, with local readout, for a wide variety of gases and liquids of low-to-moderate viscosities.



Rotameter operating principle


Rotameter with built in manual flow control

A rotameter is a variable-area flowmeter inside of which a float rises and falls in a tapered tube to provide a measure of flowrate. The downward force of gravity on the float continuously opposes the upward force of the flowing fluid. With a change in flowrate, the float rises or falls in the tapered tube until the size of the annular area between the float and tube changes sufficiently to create a new equilibrium position (hence variable area). There is one installation requirement - the measuring tube must be vertical, to balance the float against the full force of gravity. The exact specification of a rotameter will vary slightly due to the density and viscosity of the fluid or gas, i.e. a unit purchased for measuring air flow will not read accurately if used for measuring CO_2 flow.

Although shown with a visual indication, the height of the float, and thus measured flow rate may be measured electronically. Rotameters are often combined with a needle valve so the flow can be adjusted at the point of measurement (as shown in the bottom picture).

When measuring gases, the gas must be completely dry to ensure the float does not stick.

Electromagnetic

An electromagnetic flowmeter operate on Faraday's law of electromagnetic induction that states that a voltage will be induced when a conductor moves through a magnetic field. The liquid serves as the conductor and the magnetic field is created by energized coils outside the flow tube. The voltage produced is directly proportional to the flow rate. Two electrodes mounted in the pipe wall detect the voltage which is measured by a secondary element.

Electromagnetic flowmeters can measure difficult and corrosive liquids and slurries, and can measure flow in both directions with equal accuracy.

Electromagnetic flowmeters have relatively high power consumption and can only be used for electrical conductive fluids such as water, beer or cider. This type is perhaps the most common flowmeter in use for drinks production.

Coriolus

Direct mass measurement sets coriolis flowmeters apart from other technologies. Mass measurement is not sensitive to changes in pressure, temperature, viscosity and density.

Coriolis mass flowmeters use the coriolis effect to measure the amount of mass moving through the element. The fluid to be measured runs through a U-shaped tube that is caused to vibrate in an angular harmonic oscillation. Due to the coriolis forces, the tubes will deform and an additional vibration component will be added to the oscillation. This additional component causes a phase shift on some places of the tubes which can be measured with sensors.

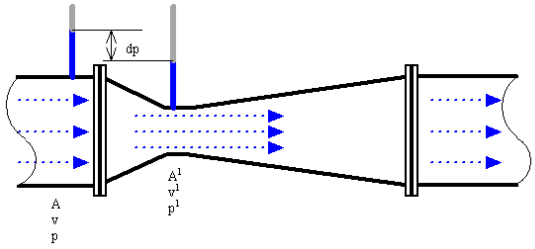
The Coriolis flow meters are in general very accurate, better than +/-0.1% with an turndown rate more than 100:1. The Coriolis meter can also be used to measure the fluids density.

They are commonly used for measuring wort and beer density, both in-line and off-line, in the laboratory.

Venturi Tube

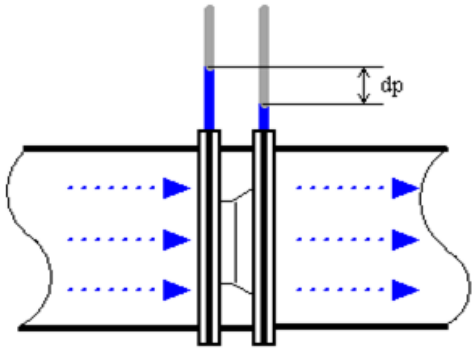
Due to simplicity and dependability, the venturi tube flowmeter is often used in applications where higher turn down rates, or lower pressure drops are required than the orifice plate can provide.

In the venturi tube the fluid flowrate is measured by reducing the cross sectional flow area in the flow path, generating a pressure difference. After the constricted area, the fluid is passes through a pressure recovery exit section, where up to 80% of the differential pressure generated at the constricted area, is recovered.



With proper instrumentation and flow calibrating, the venturi tube flowrate can be reduced to about 10% of its full scale range with proper accuracy. This provides a turn down rate of 10:1.

Orifice plate

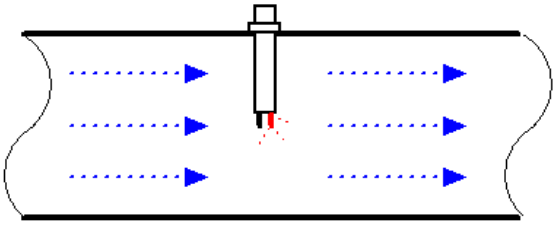


With an orifice plate, the fluid flow is measured through the difference in pressure from the upstream side to the downstream side of a partially obstructed pipe. The plate obstructing the flow offers a precisely measured obstruction that narrows the pipe and forces the flowing fluid to constrict.

The turn-down rate for orifice plates is less than 5:1. The accuracy is poor at low flow rates. A high accuracy depends on an orifice plate in good shape, with a sharp edge to the upstream side. Wear reduces the accuracy.

Calorimetric

The calorimetric principle for fluid flow measurement is based on two temperature sensors in close contact with the fluid but thermal insulated from each other.



One of the two sensors is constantly heated and the cooling effect of the flowing fluid is used to monitor the flowrate. In a stationary (no flow) fluid condition there is a constant temperature difference between the two temperature sensors. When the fluid flow increases, heat energy is drawn from the heated sensor and the temperature difference between the sensors are reduced. The reduction is proportional to the flow rate of the fluid.

The calorimetric flowmeter can achieve relatively high accuracy at low flow rates, and can be used where low flows may be experienced at times, e.g. the beer supply to a lane keg racking machine.

Turbine flowmeter

There are many different manufacturing design of turbine flow meters, but in general they are all based on the same simple principle. If a fluid moves through a pipe and acts on the vanes of a turbine, the turbine will start to spin and rotate. The rate of spin is measured to calculate the flow.

The turndown ratios may be more than 100:1 if the turbine meter is calibrated for a single fluid and used at constant conditions. Accuracy may be better than +/-0.1%.

These are commonly used in keg filling machines.

PRESSURE GAUGES

Pressure gauges and switches are among the most often used instruments. But because of their great numbers, attention to maintenance and reliability is often compromised and it is not uncommon in older plants to see many gauges and switches out of service. This is unfortunate because, if a plant is operated with a failed pressure switch, the safety of the plant may be compromised. Conversely, if a plant can operate safely while a gauge is defective, it shows that the gauge was not needed in the first place. Therefore, one goal of good process design is to install fewer but more useful and more reliable pressure gauges and switches.

TEMPERATURE

A number of different types of thermometer may be used in a brewery or packaging plant.

Thermocouples

Thermocouples consist essentially of two strips or wires made of different metals and joined at one end. Changes in the temperature at that joint induce a change in electromotive force (emf) between the other ends. As temperature goes up, this output emf of the thermocouple rises, though not necessarily linearly.

Resistance (RTD)

Resistive temperature devices use the fact that the electrical resistance of a material changes as its temperature changes. Two key types are the metallic devices (commonly referred to as RTDs), and thermistors. These devices are commonly used in automated breweries. They have rapid response times. An example of a hygienic in-line sensor is shown below.

Infrared

Infrared sensors are non-contacting devices. They infer temperature by measuring the thermal radiation emitted by a material. They are sensitive to the roughness and colour of the surface, and normally have a range of different settings available for selection. Due to the variation in the surface, these cannot be considered

accurate, but are suitable for quick checks where for instance thermal strips of the correct range are not available.

Bimetallic strip

Bimetallic devices take advantage of the difference in rate of thermal expansion between different metals. These devices are portable and they do not require a power supply, but they are usually not as accurate as thermocouples or RTDs and they do not readily lend themselves to temperature recording. They are best used inserted into a pocket, not directly into the product.

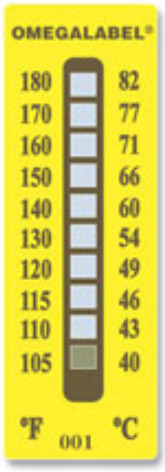
Fluid-Expansion

Perhaps better known as conventional liquid (mercury or alcohol) in glass thermometers. Ideally, these should not be used in production plant due to the risk of breakage and contamination of the product by mercury or alcohol. However, if necessary, only alcohol in glass thermometers should be used. Again ideally, the thermometer should sit in a pocket to ensure isolation from the product.

Fluid-expansion sensors do not require electric power, do not pose explosion hazards, and are stable even after repeated cycling. On the other hand, they do not generate data that is easily recorded or transmitted, and they cannot make spot or point measurements.

Change-of-state

These are commonly used for validation of temperatures achieved when sterilising plant, e.g. plate and frame filters, as part of the routine quality checks, or during commissioning.



They are self adhesive, but are removable, particularly whilst still hot and so can be transferred to paper for long term record.

They are available in a number of different temperature ranges, changing colour once the surface to which the label is attached reaches the indicated temperature.

Note that they are not very accurate so can only be used as a guide to the maximum temperature reached.

CONDUCTIVITY

Electrical Conductivity is the ability of a solution to transfer (conduct) electric current. Conductivity is used to measure the concentration of dissolved solids which have been ionized in a polar solution such as water. The unit of measurement commonly used is one millionth of a Siemen per centimetre (micro-Siemens per centimeter or µS/cm). When measuring more concentrated solutions, the units are expressed as milli-Siemens/cm (mS/cm - thousandths of a Siemen). 1000 µS/cm are equal to 1 mS/cm. Conductivity is usually simply expressed as either micro or milli Siemens.

Temperature plays a role in conductivity. Ionic activity, and therefore conductivity, is directly proportional to temperature. The effect is predictable and repeatable for most chemicals, but unique to each chemical. The effect is instantaneous and quite large (typically 1%- 3% / ºC) compared to the reference value of 25ºC. Advanced meters allow for custom reference temperatures, and / or measure the temperature of the liquid and automatically compensate for the temperature.

They are widely used for beer / water interface detection and for control of detergent strengths.

pH

Because pH plays such a critical role in enzyme activity, and hence mash conversion, fermentation etc., accurate measurement is critical.

The methods for measuring pH fall roughly into a number of categories. However for practical use in breweries, only

the following are currently used:-

- Indicator methods.
- Glass-electrode methods.

Indicator methods

One method involves comparing the standard color corresponding to a known pH with the colour of an indicator immersed in the test liquid using buffer solution.

The other method involves preparing pH test paper which is soaked in the indicator, then immersing the paper in the test liquid and comparing its color with the standard color. This method is simple, but prone to error. A high degree of accuracy cannot be expected.

Glass-Electrode Method

The glass electrode method uses two electrodes, a glass electrode and reference electrode, to determine the pH of a solution by measuring the voltage (potential) between them.

This method is the one most commonly used for pH measurement, since the potential quickly reaches equilibrium and shows good reproducibility, and can be used on various types of solution.

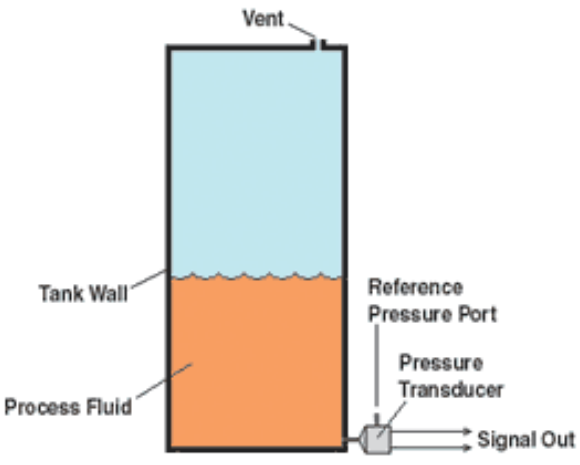
LEVEL SENSORS

Floats

Floats work on the simple principle of placing a buoyant object with a specific gravity intermediate between those of the process fluid and the headspace vapor into the tank, then attaching a mechanical device to read out its position. The float simply floats on top of the process fluid. While the float itself is a basic solution to the problem of locating a liquid's surface, reading a float's position (i.e., making an actual level measurement) is still problematic. Early float systems used mechanical components such as cables, tapes, pulleys, and gears to communicate level. Magnet-equipped floats are popular today.

They are not suitable for product, and due to complexity are now rarely installed for other purposes.

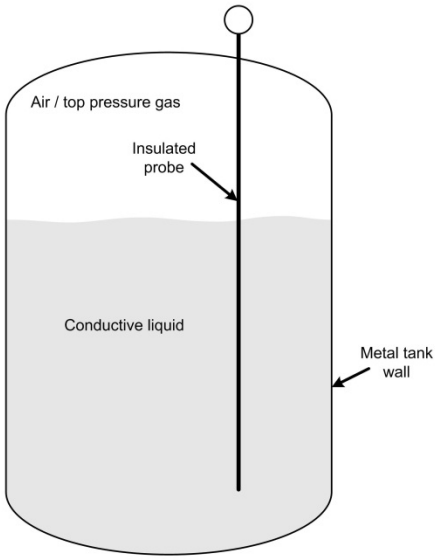
Differential pressure



The essential measurement is the difference between total pressure at the bottom of the tank (hydrostatic head pressure of the fluid plus static pressure in the vessel) and the static or head pressure in the vessel. The hydrostatic pressure difference equals the process fluid density multiplied by the height of fluid in the vessel. The example above uses atmospheric pressure as a reference. A vent at the top keeps the headspace pressure equal to atmospheric pressure. Where a tank is pressurised, a second sensor is used to measure the pressure of the gas and this value deducted from the bottom sensor readout to give the fluid height.

Capacitance Transmitters

These devices operate on the fact that process fluids generally have dielectric constants significantly different from that of air or other gases used such as CO_2. They are commonly used for CIP fluids but may still be found in product tanks. They are not ideal here as they are difficult to clean effectively, or may cause “CIP shadows” on the vessel walls. They are also not normally able to detect when a tank is completely empty due to the length of probe required and the potential for it to bend sue top turbulence during filling.



Load Cells

A load cell or strain gauge device is essentially a mechanical support member or bracket equipped with one or more sensors that detect small distortions in the support member. As the force on the load cell changes, the bracket flexes slightly, causing output signal changes.

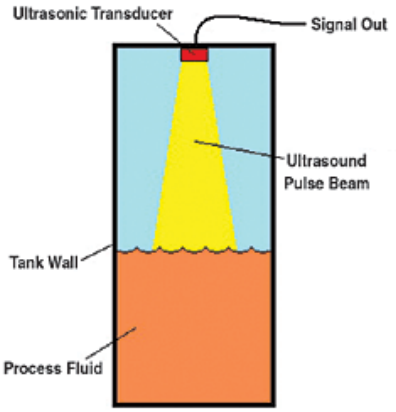
To measure level, the load cell must be incorporated into the vessel's support structure. As process fluid fills the vessel, the force on the load cell increases. Knowing the vessel's geometry (specifically, its cross-sectional area) and the fluid's specific gravity, it is a simple matter to convert the load cell's known output into the fluid level.

Load cells do not come into contact with the product and so are hygienic. The vessel support structure and connecting piping must be designed so the vessel movement due to increase weight is not restricted by the pipework.

The supporting structure's expansion or contraction, caused by uneven heating (e.g., morning to evening sunshine) may be reflected as level. Load cell weighing system requirements must be a paramount consideration throughout initial vessel support and piping design, or performance is quickly degraded.

Ultrasonic Level Transmitters

Ultrasonic level sensors measure the distance between the transducer and the surface by measuring the time required for an ultrasound pulse to travel from a transducer to the fluid surface and back. The speed of sound depends on the mixture of gases in the headspace and their temperature. The sensor temperature is compensated for (assuming that the sensor is at the same temperature as the air in the headspace).

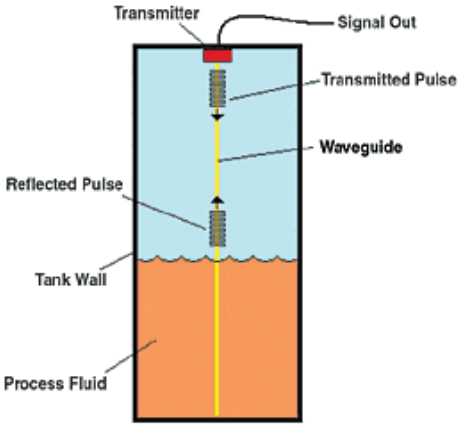


They have also been used in beer, the sensor being located in the base of the tank, but have only proven reliable in filtered beer due to the attenuation due to the solids in fermenting or unfiltered beer.

Radar Level Transmitters

Through-air radar systems beam microwaves downward from either a horn or a rod antenna at the top of a vessel. The signal reflects off the fluid surface back to the antenna, and a timing circuit calculates the distance to the fluid level by measuring the round-trip time.

In through-air radar systems, the radar waves suffer from the same beam divergence that afflicts ultrasonic transmitters. Internal piping, deposits on the antenna, and multiple reflections from tank buildup and obstructions can cause erroneous readings.



LEVEL SWITCHES

Capacitance, conductance and vibrating level switches may be used in addition to or instead of variable level sensors.

Vibrating sensors

Vibrating level switches detect the dampening that occurs when a vibrating probe is submerged in a process medium. They may be used to detect liquids or solid materials such as powders and grain. They provide excellent performance as high or low level switches and can be mounted from the tops or sides of tanks. Vibrating and tuning fork probes can tolerate a fair amount of material build-up without affecting their performance, unlike conductivity switches.

They are extremely useful where there is foam formation as they can distinguish between foam and liquid, unlike conductivity probes, and are unaffected by films of highly conducting liquid such as caustic remaining at the end of a tank CIP scavenge cycle, and so can be used to accurately determine when a tank is empty during burst delivery cycles.

Capacitance sensors

To measure the liquid level, the level switch emits a signal from the sensor tip into the tank. If the medium is conductive (e.g. beer) then an insulated probe is used and the capacitor is formed by the outer surface of the insulation ("shorted" to the wall) and the electrode. This capacity depends upon the dielectric value of the liquid, which is well defined for most media. The capacitance is directly proportional to the height of the medium.

There are a number of issues associated with these sensors:

- Coating or build-up of salts or other process chemicals
- Wicking and uneven coating of the electrode
- Corrosion
- Non-conductive tanks
- Splashing or bubbles/foam

Conductivity sensors

The signal generator in the circuit generates a signal on its reference probe. If a current is detected by the sensor terminal, then conductive liquid must be present.

A number of different length probes can be used to determine different levels.

17.2 Brewing Plant Maintenance - Approaches and Tasks

Maintenance is the management of activities that contribute to optimum levels of availability and performance of plant.

The **AIMS** of maintenance are:

- To sustain the functionality of plant
- To minimise downtime
- To provide a safe environment for personnel operating/cleaning/maintaining the plant
- To protect product quality
- To prove due diligence, for example for consumer safety
- To ensure legal requirements are met, for example environmental compliance
- To protect the value of plant

There are four approaches to maintenance.

1. No maintenance.
This is when no checking and no maintenance take place at all.

This applies to certain items like electrical components that as and when they fail are discarded and replaced. This approach will only be appropriate in some circumstances.

2. Breakdown maintenance.
This is when equipment is only attended to if it breaks down.

With this system, there is a big risk of lost production because breakdowns often occur at the worst time.

It may be applicable if duplicate plant is installed; otherwise a big stock holding of spares is needed. Breakdown maintenance can also be known as **Corrective** maintenance.

3. Preventative maintenance.
This is where plant is maintained to a plan whether or not it shows signs of wear.

Usually components are replaced at the same time, for example pump glands or wear strips on conveyors.

Planned maintenance can vary from a weekly inspection and oil top, through two or three day mini-overhauls, up to a complete line or major item annual overhaul.

The concept is that unforeseen breakdowns are much less likely to occur.

Preventative maintenance can also be known as **Planned** maintenance or **Planned Preventative** maintenance.

4. Predictive maintenance.
This is where plant condition is monitored and a prediction is made about when it is likely to break down. A maintenance programme is developed based on the information gathered.

This is called 'Condition Monitoring' and specifically it is a maintenance process where the condition of equipment is monitored for early signs of impending failure. Equipment can be monitored using sophisticated instrumentation such as vibration analysis, oil analysis, laser alignment of shafts in rotating equipment and thermal imaging. More traditionally, temperature, over voltage or current and liquid level has been monitored to warn of problems. Equally monitoring can be manual often using the human senses. Where instrumentation is used (automatic monitoring) actual limits can be imposed to trigger maintenance activity, generally through a computerised maintenance management system.

Predictive maintenance can also be known as **Condition Based** maintenance. A further variation can be **Risk Based** maintenance where maintenance tasks are arranged to reflect the risk of failure based on predicted plant life and plant history.

Comments

a) Whatever maintenance system is employed all activities must be carried out safely and meet all legal requirements. To meet these requirements a system of 'safe working practices' should be employed to ensure that Health and Safety is treated as a priority at all times. A system of safe working practices would include items such as:

- Some form of permit to work.
- Use of the correct personal protective equipment.
- Interlocked guarding systems.
- Training
- System reviews

b) Most maintenance systems now employ computers for recording information, issuing work and storing plant history. This also enables automatic electronic spares ordering and easily obtainable financial information about maintenance.

c) The cost of engineering maintenance needs to be controlled so annual budgets and regular reviews (normally monthly) of expenditure are a pre-requisite for control purposes. The normal costs for day-to-day maintenance activities are usually referred to as revenue items whereas the purchases of new plant like a hammer mill or filling machine are capital items.

The advantages and disadvantages of the various maintenance systems are detailed in the table below:

System	Advantages.	Disadvantages.
No maintenance.	Easy to set up. Appropriate in some circumstances	Risk of plant unavailability at key times. High cost of replacement parts.

Breakdown maintenance.	No unnecessary work on the plant.	Risk of plant unavailability at key times. High cost of spares.
Preventative Maintenance.	Work done on the plant at a convenient time. Less likelihood of breakdowns.	Expensive. Plant may be worked on unnecessarily.
Predictive maintenance.	Most effective use of engineering resources. Work done on the plant at a convenient time. Less likelihood of breakdowns.	Complex information system needs to be maintained.

Types of tasks associated with engineering maintenance.

Whether the conditions are breakdown, planned, preventative or associated with an overhaul the majority of engineering maintenance tasks can be linked to the following headings:

Mechanical
Lubrication
Electrical
Software/hardware
Calibration
Inspection
Condition monitoring
Cleaning of plant
Health and Safety
Recording and updating information

Notes:
Specify important pieces of mechanical and electrical plant that you are familiar with.

What method of maintenance is employed to ensure that these pieces of plant or equipment perform as required?

Describe in detail a variety of maintenance tasks that are performed under the headings shown above.

How much does engineering maintenance cost on an annual basis. How is the budget controlled?

Find out the costs of major capital plant items.

Describe how health and safety and other legal requirements are met under the engineering maintenance banner

17.3 Performance Improvements

Poor plant performance and plant failure in one form or another has a major impact on business performance; consequently systems that improve plant reliability are becoming widely implemented.

Three process improvement initiatives are:-

- **Reliability Centred Maintenance (RCM)** where teams of key personnel for example maintenance engineers and plant operators decide on how the plant can fail, the consequences of failure and finally the most appropriate maintenance procedures that will reduce the incidence of failure.

- **Total Productive Maintenance (TPM)** where the plant technicians/operators are trained to pay strict attention to detail, to take great pride in their equipment and to tolerate zero plant defects.

- **Workplace Organisation (5S)** where technicians or operators focus on achieving and maintaining visual order and cleanliness. 5S aims to remove unneeded items and organise the workplace so that it is easy for the operatives to carry out their tasks and maintain a clean and orderly environment.

In more detail:

Reliability Centred Maintenance (RCM)

The principles which define and characterise RCM are:

- a focus on the preservation of system function;

- the identification of specific failure modes to define loss of function or functional failure;

- the prioritisation of the importance of the failure modes, because not all functions or functional failures are equal;

- the identification of effective and applicable maintenance tasks for the appropriate failure modes. (Applicable means that the task will prevent, mitigate, detect the onset of, or discover, the failure mode. Effective means that among competing candidates the selected maintenance task is the most cost effective option).

These principles, in turn, are implemented in a seven-step process:

1. The objectives of maintenance with respect to any particular item/asset are defined by the functions of the asset and its associated desired performance standards.
2. Functional failure (the inability of an item/asset to meet a desired standard of performance) is identified. This can only be identified after the functions and performance standards of the asset have been defined.

3. Failure modes (which are reasonably likely to cause loss of each function) are identified.
4. Failure effects (describing what will happen if any of the failure modes occur) are documented.
5. Failure consequences are quantified to identify the criticality of failure. (RCM not only recognizes the importance of the failure consequences but also classifies these into four groups: Hidden failure; Safety and environmental; Operational and Non-operational.)
6. Functions, functional failures, failure modes and criticality analysed to identify opportunities for improving performance and/or safety.
7. Preventive tasks are established. These may be one of three main types: scheduled on-condition tasks (which employ condition-based or predictive maintenance); scheduled restoration; and scheduled discard tasks.

Although one of the prime objectives of RCM is to reduce the total costs associated with system failure and downtime, evaluating the returns from an RCM program solely by measuring its impact on costs hides many other less tangible benefits. Typically these additional benefits fall into the following areas:

(1) improving system availability;
(2) optimising spare parts inventory;
(3) identifying component failure significance;
(4) identifying hidden failure modes;
(5) discovering significant, and previously unknown, failure scenarios;
(6) providing training opportunities for system engineers and operations personnel;
(7) identifying areas for potential design enhancement;
(8) providing a detailed review, and improvement where necessary, of plant documentation.

Total Productive Maintenance (TPM)

TPM aims to establish good maintenance practice through the pursuit of "the five goals of TPM":

(1) Improve equipment effectiveness: examine the effectiveness of facilities by identifying and examining all losses which occur - downtime losses, speed losses and defect losses.

(2) Achieve autonomous maintenance: allow the people who operate equipment to take responsibility for, at least some, of the maintenance tasks. This can be at:

- The repair level (where staff carry out instructions as a response to a problem).
- The prevention level (where staff take pro-active action to prevent foreseen problems).
- Improvement level (where staff not only takes corrective action but also propose improvements to prevent recurrence).

(3) Plan maintenance: have a systematic approach to all maintenance activities. This involves the identification of the nature and level of preventive maintenance required for each piece of equipment, the creation of standards for condition-based maintenance, and the setting of respective responsibilities for operating and maintenance staff. The respective roles of "operating" and "maintenance" staff are seen as being distinct. Maintenance staff is seen as developing preventive actions and general breakdown services, whereas operating staff take on the "ownership" of the facilities and their general care. Maintenance staff typically moves to a more facilitating and supporting role where they are responsible for the training of operators, problem diagnosis, and devising and assessing maintenance practice.

(4) Train all staff in relevant maintenance skills: the defined responsibilities of operating and maintenance staff require that each has all the necessary skills to carry out these roles. TPM places a heavy emphasis on appropriate and continuous training.

(5) Achieve early equipment management: the aim is to move towards zero maintenance through "maintenance prevention" (MP). MP involves considering failure causes and the maintainability of equipment during its design stage, its manufacture, its installation, and its commissioning. As part of the overall process, TPM attempts to track all potential maintenance problems back to their root cause so that they can be eliminated at the earliest point in the overall design, manufacture and deployment process.

TPM works to eliminate losses:

- Downtime from breakdown and changeover times
- Speed losses (when equipment fails to operate at its optimum speed)
- Idling and minor stoppages due to the abnormal operation of sensors, blockage of work on chutes, etc.
- Process defects due to scrap and quality defects to be repaired
- Reduced yield in the period from machine start-up to stable production.

Workplace Organistion (5S)

5S can be broken down into 4 activities and one conviction to continue with the 4 activities. 5S originated in Japan and there are many translations of the Japanese words for 5S – a common set is listed below:

- “Sein” - Sort
- “Seiton” - Set in order
- “Seiso” - Shine
- “Seiketsu” - Standardise
- “Shitsuke” - Sustain

Sort

The aim of Sort is to remove from the workplace items that are not needed, such as tools, materials and parts, and to identify what items are needed to perform the operations at each of the workstations.

Set in order

Set in order is the part of the 5S technique that arranges materials, components and tools in such a way that the operatives can easily access them. An example of this is a shadow board, where each tool has its own place and can be easily located. Additionally, if an empty place exists on the board the missing tool can easily be identified.

Shine

For Shine, the workplace needs to be kept clean so that it is safe for the operators to carry out their tasks and move around their workstation. This also benefits productivity as the easier it is for the operatives to move around the quicker it is for them to carry out their tasks.

Standardise

Formalise the Sort, Set in order and Shine activities to standardise their practice so that all involved can achieve the same results. Application of this will ensure that the workplace is clean and organised.

Sustain

The sustain activity will ensure that 5S is ingrained in the organisation culture. Sustain aims to keep the workforce focussed on carrying out 5S activities on a regular basis, usually daily. Performance is measured to maintain consistency and ensure that all involved are informed of their progress.

The direct changes resulting from carrying out 5S are workplace tidiness and orderliness; these have a beneficial effect on a large number of other factors which improve efficiency. These range from reduced time searching for tools, reduced changeover time, reduced inventory to reduced cycle time.

All three methods rely on detailed records and analysis and 'problem solving' in a teamworking environment. These methods also depend on the teams being supported by senior management.
High initial set-up costs ultimately enable the achievement significantly improved and sustainable plant reliability.

Comments:
There are a number of performance improvement initiatives that are similar to RCM, TPM and 5S. The majority of them focus on improving plant performances by combining a number of simultaneous initiatives and typically include the following:

- 'Organisational Changes'.
- Computerised systems for maintenance, measuring plant breakdowns and performance.
- Predictive maintenance techniques.
- Cleaning-inspection-lubricate.
- Teamworking.
- Improvement analysis (various techniques).
- Defining roles, responsibilities and accountabilities.
- Training and education.

Notes:
Describe the typical features of a performance improvement initiative you are familiar with.

Describe your role and responsibilities, who you consult and who you inform.

Qualifications

The General Certificate in Brewing (GCB)

Learning Material © Institute of Brewing and Distilling 2016

Section 18 Utilities – Water & Effluent

18.1 Water sources and treatments

Introduction

Water is the principal ingredient in beer, accounting for around 94% of the content of a normal 5% alcohol beer. As well as being the principal ingredient in beer, water has a number of important functions in the brewing process. It is therefore important that each brewery has a reliable supply of good quality water.

Generally it takes between 3 and 20 hectolitres of water to produce 1 hectolitre of beer depending on the efficiency of the brewery and the range of packaging tasks. The adjudged minimum ratio of consumption, allowing for unavoidable losses, is approximately 1.4:1. In practice the minimum consumption is generally in the range 2.5:1 to 5:1 depending on the operations carried out by the particular brewery, with best practice sites down to 2 to 2.2:1. The ratio is normally measured in hectolitres water per hectolitre beer produced (hl/hl).

Characteristics and quality of brewery water supply

A brewery water supply should have the following characteristics:

Characteristic	Standard
Appearance.	Clear and colourless.
Wholesomeness/ potability.	Freedom from undesirable flavours or odours which may be derived from organic or inorganic sources, or from poisonous material, metals or (usually) organic compounds.
Mineral salt and metallic content.	Contents that meet the brewing and process requirements. The quantity and type will affect the pH, which should ideally be neutral or slightly acidic. Heavy metal ions, most commonly ferrous or ferric ions must be absent.
Microbiological standard.	Freedom from any micro-organisms that would spoil the beer or affect the people who drink it. The presence / absence of coliform bacteria are a commonly used indication of microbiological purity. They should be absent from a 100 ml sample.
Organic compounds.	The water should be free of dissolved organic compounds. These indicate contamination with, for example sewage, industrial (e.g. oils, detergents, phenolic compounds) or agricultural runoffs (biocides, fertilisers) and may require extensive (and expensive) treatment to make fit for brewing purposes.
Reliability of supply.	There must be water available at all times, ideally having consistent specifications as outlined above.

Product water (brewing liquor and water used in the production of beer, i.e. it will eventually be consumed by the customer) makes a major contribution to the quality of the beer that is produced. Salts dissolved in the water affect the beer's flavour, influence the pH (acidity/alkalinity) of the process and the final product and they provide essential trace elements for yeast growth.

In general:-

- Chlorides give beer a fuller flavour.
- Sulphates give the beer a dry sulphury character.
- Calcium helps to reduce the mash pH and is needed by the yeast and for beer stability.
- Carbonates raise pH and form scale on heating surfaces.
- Iron gives beer a metallic flavour and will form hazes.
- Nitrates indicate surface water or sewage contamination.
- Magnesium and zinc are trace elements required by the yeast.

The following are overviews of water ionic compositions used for different beers.

Pilsener type lagers

- Soft water, low mineral content.
- Low levels of carbonates, helping to bring out delicate flavours.
- Low calcium ion level.

Ales (bitters, pale ales)

- Sulphates > chlorides to bring out bitter flavours.
- Low carbonates (< 30 ppm) to help achieve low pH.
- Higher calcium (> 135 ppm) for flavour and pH.

Milds, stouts, porters

- Chlorides > sulphates for enhanced fullness & sweetness.
- Carbonates medium (< 70 ppm).
- Calcium levels lower around 75 ppm for mild and 30 ppm for Stouts.

Specific mineral ion contents will of course vary from brewery to brewery, and beer types brewed within the same brewery may have different mineral salts added to change the ionic composition. The following table shows examples of ionic composition of water from a number of brewing centres.

Ions in ppm	Burton on Trent	Munich	Dublin	Pilsen
Type of Beer	Pale Ale	Dark Lager	Irish Stout	Light Lager
Total dissolved solids	1300	280	340	50
Ca - calcium	352	106	132	10
Mg – magnesium	24	30	18	1
Na – sodium	54	6	12	2
Cl – chloride	16	2	15	5
SO_4 – sulphate	820	8	15	6
NO_3 – nitrate	18	3	5	Na
*HCO_3 – bicarbonate	320	120	175	15
Main salts	$CaSO_4$	$CaCO_3$ & $MgCO_3$	$CaSO_4$ & CaCl	

* Before being suitable for brewing, the "temporary hardness" or bicarbonates (HCO3) have to be removed. Hardness is usually expressed in terms of calcium carbonate (CaCO3).

Further details of the quality aspects of water are discussed in the following section.

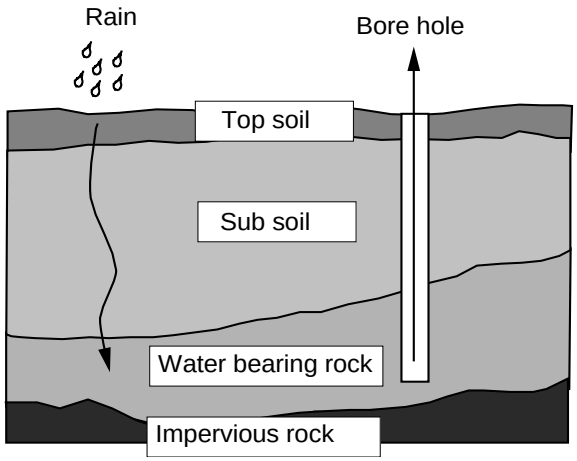
Sources of water for a brewery

A plentiful supply of water is essential to the brewery; this is why, in the past, breweries were built in areas that had their own sources, usually in the form of wells or boreholes. These original sources are still used in some plants while others have to rely on the local water authority for their supply.

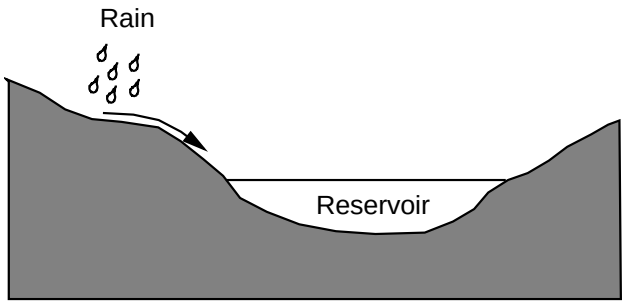
The nature of the water source will affect the quality of the beer and this has resulted in some areas being famous for their beers. Examples are Burton-on-Trent for strong bitters and Pilsen for fine lagers. The quality of the water will also affect the efficiency of the processes where it is used, for example in boiler feed water or in plant cleaning systems.

As water falls to the ground as rain or snow, it is free of minerals, but may contain particles of soot and grits, and will contain some dissolved gases such as SO2 and CO2, the latter being particularly important. Whilst some is absorbed by plants or evaporates directly, much will run off into rivers and lakes, either natural or artificial, from where it may be recovered for use. Some will also percolate through the ground and porous subsurface rock layers to form aquifers where it meets a layer of impermeable rock. Boreholes may be sunk into the aquifers for recovery of the water.

Borehole Water:



Surface Water:



Water can be sourced directly from underground wells (boreholes) or from a surface supply such as a reservoir. Normally, surface water will have been treated at a municipal treatment works before distribution to the brewery and other domestic and commercial users.

Some of the key differences in untreated water quality from boreholes and surface water, along with treated municipal supply water are shown in the following table.

Comment	Borehole	Surface water	Municipal supply
Temperature			
May need to be cooled to allow use in production processes – additional costs	Consistent	Varies with season. Cooling may be required particularly during summer.	Rather variable, depending on source and method and distance of transport to brewery.
Turbidity			
Turbid water will need to be filtered before use – additional cost.	Generally low (borehole not generally considered suitable supply if the water is not clear).	Varies, can be high, especially after heavy rain following dry periods.	Normally very consistent assuming municipal supply treated to WHO guidelines for potable water.

Colour			
Indicates high dissolved mineral or organic matter content. This needs to be removed to ensure it does not affect the brewing process / final product.	Generally low (borehole not generally considered suitable supply if the water is not colourless).	Varies, can be high, especially after heavy rain following dry periods.	Normally very consistent assuming municipal supply treated to WHO guidelines for potable water. However, in spite of complying with WHO guidelines, can still vary, and can be high, especially after heavy rain following dry periods.
Mineral content			
Can affect brewing process and flavour of beer. May also adversely affect utilities, particularly if mineral content high.	Will contain some of the soluble material present in the rock strata where the water is held. Depending on the type of rock, it could be high or low in minerals.	Varies, but likely to be low unless agricultural chemicals are being washed off the land.	Depends on whether the source is borehole or surface. Any anomalies should be known if the supplies alternate.
Hardness			
Can affect brewing process and flavour of beer. May also adversely affect process water and utilities, particularly if high.	Depends on the type of rock, may be high or low, but is generally consistent.	Varies – usually low, but may vary with season / rainfall.	Depends on whether the source is borehole or surface.
Nitrate			
Must be removed to reduce risk of nitrosamine formation.	Usually low.	May be high due to agricultural runoff	Depends on whether the source is borehole or surface, but generally low due to treatment process. (+ legal requirements)

Taints			
Flavour or aroma may carry through to final product and both actual taints and precursors must be removed prior to use. Many compounds have low sensory thresholds.	Usually very low (borehole not generally considered suitable supply if the water is contaminated) .	May be present, particularly because of agricultural or industrial runoff.	Likely to be low because of treatment by the water authority. However, chlorine content (for sterilisation) is often unacceptably high.
Microbiological			
Must be removed / killed to prevent contamination / slime build ups.	Usually very low (borehole not generally considered suitable supply if the water is contaminated.	Likely to be high because of agricultural runoff.	Likely to be low because of treatment by the water authority.
Consistency of supply			
Required to allow consistent treatment for brewing & utilities without excessive costs.	Very good over long periods of time.	Can be variable especially in periods of drought, or rain immediately following drought.	Microbiologically, clarity and aroma - very good because of the water authority's legal obligations. However mineral content may vary with water source, especially if a number are used.

The composition of brewing water has now been determined scientifically, it so can be adjusted to brew a range of different beer types, even though the source water may not be particularly suitable. Water which would in the past have been considered totally unsuitable for brewing can now be treated to allow its use, allowing breweries to be built close to centres of population for ease of transport, rather than according to the water type available.

The following sections describe the different methods available to treat water from virtually any source and ensure it is usable in breweries, both for the brewing water itself, and all other activities associated with the brewing and packaging processes.

The basic principles of water treatment plant

Treatment depends on the source and quality of the water, and whether it is to be used of brewing, or for cleaning and heat transfer, boiler feed water etc.

Brewing water treatment depends on the kind of source and the quality of the water, and the type of beer to be brewed. Treatment must ensure removal of any suspended solids and organic matter, on sterilisation and adjustment of the ionic content if necessary. Where water is to be used post fermentation then the oxygen must also be removed.

Water filtration
Water from deep boreholes is usually clear and colourless, but surface water may need treatment. This is usually achieved by -

Sand filtration
Pressure type (tank) filters are normally used. The suspended solids are removed periodically by backwashing the filter. To improve filtration efficiency, a layer of anthracite is normally placed on top of the sand.

If iron and / or manganese are present, the sand media is mixed with a catalyst to speed up the oxidation of the soluble ferrous iron, converting it to insoluble ferric iron, which is then filtered out.

Supplies which contain colour due to the presence of organic matter are clarified by coagulating the organic matter with alum or aluminium sulphate and polyelectrolyte. The floc formed by the chemicals attracts the colloidal particles responsible for forming the colour which are then filtered out. Where the water contains high levels of solids, the coagulation may also be carried out in separate settling upflow tanks.

If the incoming supply only periodically suffers from suspended solids, cartridge type filters may be used instead as these can be considerably smaller and thus cheaper.

Carbon filtration
In addition to solids removal, the water may be carbon filtered to remove flavour taints like chlorine and organics such as trihalomethanes. These use granular activated charcoal, which are periodically back-flushed with water to remove any fines and suspended matter.

Typical surface area for activated carbon is between 500 and 1000 square metres per gram, depending largely on the raw material it was produced from. Organic materials are removed by adsorption. Disinfectants such as chlorine are removed by catalytic reduction. The chlorine capacity of new activated charcoal is approximately 1 kg chlorine per kg charcoal.

When exhausted, the carbon has to be replaced with a fresh batch. It cannot be regenerated.

Water sterilization
Most of the water used for brewing will be heated prior to mashing and sparging, and then boiled in the kettle thus ensuring it is free from non-sporulating micro-organisms. However additional water used for diluting wort or beer or rinsing equipment may not be microbiologically sterile and it may be necessary for the brewery to carry out some sterilisation treatment of this water.

The method of water sterilisation depends on the level of infection and on the subsequent use of the water. If the water is heavily infected it may require filtration followed by a secondary sterilization treatment using one of the following methods.

- Chlorination
- Chlorine dioxide
- Ozone
- Ultraviolet light
- Ultraviolet light + silver addition
- Sterile filtration (0.2 - 0.45 micron) (note this is not pharmaceutically sterile, but commercially acceptable for brewing operations)

Chlorine
If the water will become part of the beer, or come into contact with the wort or beer, chlorine, added either as gas, or as hypochlorite, must not remain in the water at point of usage, because of the risk of off flavours. If used, it must be removed before the point of final use, normally by passing through an activated charcoal filter.

Chlorine dioxide
Chlorine dioxide works as an effective oxidising agent. It is typically used for sterilising water by addition at up to 0.2 ppm. Higher rates are sometimes used, up to 0.5 ppm for example for pasteuriser and CIP water, but if used to sterilise dilution water, or as flush water which may come into contact with product, a maximum of 0.2 is advised due to potential flavour / aroma off flavours.

Chlorine dioxide may also be used at up to 5 ppm as a terminal sterilant, though in this case, it must be flushed off with suitable sterile water (e.g. max 0.2 ppm ClO_2 or UV treated water).

Ozone
This is a strong oxidising agent which kills off micro-organisms. It is an unstable oxygen molecule comprised of three atoms of oxygen, formed by passing clean air through a high voltage discharge tube. It decomposes rapidly, reverting to normal oxygen, normally in minutes. It leaves no residue, and oxidizes organics leaving little or no off flavour. Dosage rates are 0.1 to 4 mg / litre, with exposure times of 4 to 10 minutes.

It is not currently widely used for sterilising brewing or dilution water, but is more commonly used for sterilizing washdown water and filler external rinse water. It is highly

aggressive to many gaskets and “rubber” membranes. Some brewers have been using this for final sterilising rinses in CIP systems.

Ultra-violet light

UV light in the wavelength of 200 to 280 nm destroys the DNA in micro-organisms provided a sufficient level of light to ensure adequate dose rate is applied. Because there is no residual action, the effect is limited to the point of application, and it must be possible to clean and sterilize the distribution system after the point of treatment. Because there is no residual action, it is also essential to ensure no ingress of contaminants between the point of treatment and the point of use. Water should be treated immediately before use. To be effective the water must be colourless and free from suspended material or the sterilisation will be ineffective. In order to ensure the consistent clarity of the water some form of water pre-treatment is invariably required.

Some other industries add silver to the water to ensure a residual secondary sterilising effect. However, this is not used within the brewing industry as with care, adequate sterility can be achieved by application of UV alone.

Sterile filtration

Water may be filtered to produce sterile water at point of use. For the purposes of breweries, it is considered necessary to filter through a 0.45micron absolute (or finer) filter. Although this will not produce water to pharmaceutical standards of sterility, it is generally considered adequate for breweries as any micro-organisms that pass through are not pathogenic and will not grow in beer, to create off flavours, hazes, or illness of the consumer.

Note that prior to “sterile” filtration, it is necessary to ensure the water is filtered, typically with a 5 and or 1 micron filter first to ensure the fine filter does not get blocked too rapidly.

As with UV treated water, because there is no residual chemical sterilant effect, it is essential to ensure the distribution system can be adequately cleaned and sterilised. For this reason sterile filtration is generally only used for low volumes, and immediately before the point of use.

Reverse osmosis systems produce sterile water, but this is not its primary function, and will be discussed in the following sections under mineral ion adjustment.

Water softening / de-ionization

Water may be unsuitable for brewing or other production processes because of the mineral ions present in the source water. The type and quantity of mineral ions dissolved in the water will determine the type of treatment required to remove or adjust the mineral content. One of the key factors is the degree of, and type of hardness.

Hardness is defined as a property of water which enables it to "collapse" soap lather by forming insoluble salts of fatty acids.

- Hardness can lead to scale developing on brewing vessel surfaces, which can lead to microbiological contamination build up / retention in the scale.
- Hardness causes scaling in wort kettles, boilers and hot water installations reducing the thermal efficiency.
- Hardness increases the consumption of detergents, an in particular the chelating agents of the detergents which dissolve or keep dissolved, the mineral salts responsible for the above problems.
- Temporary hardness makes the water alkaline and therefore is liable to increase the pH throughout the brewing process.
- Hardness depends almost entirely on the calcium and magnesium ionic content of the water.
- The fraction of hardness remaining after boiling is called “permanent hardness” and consists mainly of salts of sulphate, chloride, calcium and magnesium. Permanent harness may also be termed non-alkaline hardness. This type of harness has little effect on the pH of the water.
- Temporary hardness is due to the carbonate and (principally) the bicarbonate salts of calcium and magnesium. These are precipitated during boiling, hence the term. Water with high temporary hardness tends to be more alkaline.
- Total hardness is the total hardness attributable to both the temporary harness and the permanent hardness

As noted above, not only may it be necessary to treat brewing water, but it is often necessary to treat boiler feed water, since hard water leads to a build-up of scale with a loss in boiler efficiency.

The methods used in a brewery to treat the source water will be determined by a number of factors, including

- The number and type of different beers to be brewed.
- The amount of temporary hardness
- The amount of permanent hardness
- Other mineral salts dissolved in the water, and their effects on
  - The beer being brewed
  - The brewing process itself
  - Utilities such as steam raising

Removal of hardness by boiling

Boiling the water breaks down the soluble calcium bicarbonate and magnesium bicarbonate into the insoluble carbonates, thus

$$Ca(HCO_3)_2 \xrightarrow{\text{Heat}} CaCO_3 \downarrow + H_2O + CO_2 \uparrow$$

The treatment also removes the chlorine and sterilises the water. However, this is an expensive process as it is necessary to boil all the water used for brewing (mashing, sparging and dilution) for around 30 minutes, and tends to be used in microbreweries only for this reason. It can create large quantities of scale, particularly on the heating surfaces which must be regularly removed to ensure good thermal efficiency.

Note that this only removes the temporary hardness, and cannot be considered a suitable treatment on its own if the water contains considerable permanent hardness, or other undesirable mineral salts.

Lime addition

Lime reacts with soluble calcium bicarbonate to form insoluble carbonate, as follows

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$$

The water must be allowed to stand for a considerable time to allow the precipitated carbonate to settle, or be passed through settling systems. Again, this only removes the temporary hardness, and cannot be considered a suitable treatment on its own if the water contains considerable permanent hardness, or other undesirable mineral salts.

Acid treatment

Sulphuric acid (H_2SO_4), hydrochloric acid (HCl) or phosphoric acid (H_3PO_4) may be used to remove carbonate. Where the calcium acid salt is insoluble, part of the calcium content will be removed as well (as shown below). The type of acid used will influence the ionic composition of the water. Typically sulphuric acid is used as it is cheaper than phosphoric acid, and not as corrosive to stainless steel as hydrochloric acid.

$$Ca(HCO_3)_2 + H_2SO_4 \rightarrow CaSO_4 \downarrow + 2H_2O + 2CO_2 \uparrow$$

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 \downarrow + H_2O + CO_2 \uparrow$$

It is normally necessary to pass the treated water through a degassing column to strip out the CO_2, and to allow settling time to allow the insoluble calcium sulphate to settle out.

Again, this only removes the hardness attributable to the carbonates and bicarbonates, and cannot be considered a suitable treatment on its own if the water contains considerable permanent hardness due to for example calcium sulphate, or other undesirable mineral salts.

Distillation

This process involves boiling the raw water to create pure water vapour and then condensing back to the liquid in a separate collection system. The dissolved mineral salts remain in the boiler. Freshly distilled water is sterile, but volatile impurities such as ammonia and a variety of organic compounds can carry over into the distillate. Because distillation requires such high energy (heat) input, it is generally only used for producing distilled water for the laboratories. Where high purity water is required in larger volumes, reverse osmosis is generally used.

De-ionisation

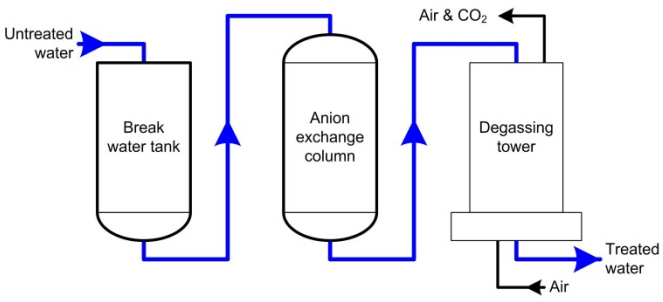
It is not common for brewing water to be treated using ion exchange. However boiler feed water treatment varies with the type of boiler, but usually the choice is between chemical treatment with lime and more commonly, by ion exchange.

De-ionisation (removal of the salts) in ion exchange columns is common in breweries. The columns contain special resins that are capable of exchanging the unwanted ions for harmless ones. The resins can be regenerated when exhausted, usually by washing through with mineral acids. In the plant illustrated below, carbonates are removed in ion exchange columns and CO_2 is formed. This is removed in the degassing towers.

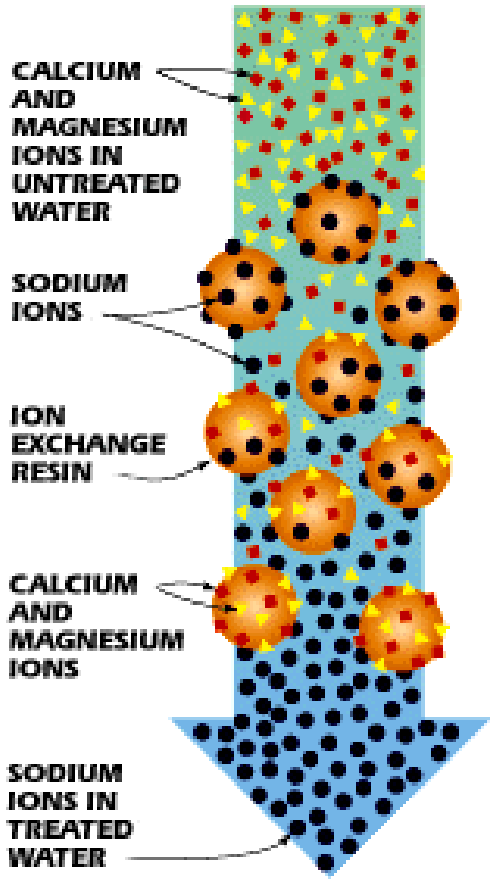
A typical water softener has a pressure tank partially filled with ion exchange resin. The resin consists of highly porous, plastic beads loaded with "exchange sites" that preferentially remove hardness (typically calcium and magnesium) ions and replace them with sodium, a "soft" ion.

At the beginning of the softening cycle, sodium ions occupy the resin's exchange sites. As water passes through it, the resin's stronger attraction for the hardness ions causes it to take on the hardness ions and give up its sodium ions. Iron and manganese are considered hardness and they are removed also, provided they are in solution. Ion exchange cannot remove suspended matter.

As water flows downward through the resin bed, the resin at the top of the bed gives up its sodium first. The exchange process is not instantaneous, so exchange occurs in a band called a "reaction zone". When the reaction zone's leading edge reaches the bottom of the resin bed and hardness passed into the service line, the resin has become "exhausted" and it must be regenerated before it can remove hardness again.



The regeneration cycle starts with backwash, an upward flow that loosens the resin bed and flushes out suspended particles. Regeneration is carried out by passing a solution of sodium chloride (salt) solution through the resin. A large excess of sodium ions causes the resin to release its hold on hardness ions picked up during the preceding service cycle and returns the resin to its sodium state. This is followed by a rinse to displace spent brine from the resin. It also carries the hardness removed from the resin to drain.



Ion Exchange

The disadvantages of water softening become apparent when high-quality water is required. Softening simply exchanges the hardness ions in the water supply for normally less-troublesome sodium ions. Since the treated water contains sodium instead of calcium or magnesium, and the sodium salts are not scale forming it is often used for softening water for boiler treatment or CIP. On its own it is not suitable for treating brewing water e.g. mashing / sparging / dilution water, but it may be used as a pre-treatment for further ion exchange.

Demineralisation

Demineralisation replaces the sodium ion exchange resin with a hydrogen ion exchange resin making it possible to swap the calcium and magnesium (and any sodium) ions for hydrogen.

The dissolved salts are converted into their corresponding acids instead of sodium salts. The water cannot be used until the acids have been removed or neutralised. It is possible to add alkali such as lime or dilute sodium hydroxide to neutralise the acid, but as this would add more (undesirable) ions, the water is passed through an anion exchange resin which exchanges the sulphate, carbonate and chlorides for the hydroxyl ion (OH-). The salt represented by MAn (metal anion) is absorbed on to the resins:

ACID RESIN (Ra)

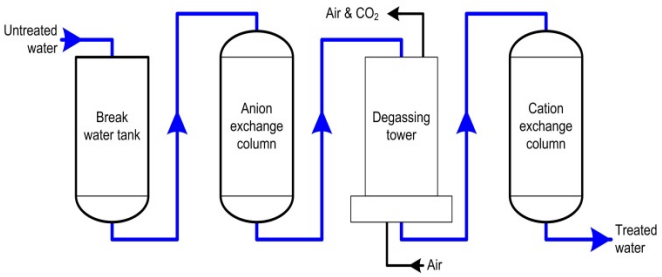
$$RaH + MAn \rightarrow RaM + Han$$

BASIC RESIN (Rb)

$$RbOH + HAn \rightarrow RbAn + H_2O$$

The hydroxyl ion (OH^-) reacts with the hydrogen ion (H^+) to produce a very pure water similar to distilled water in mineral ion composition, but it may still contain an organic residues, and silicates from the source water.

When all the sites on the exchange resins are saturated they are regenerated with dilute acid or alkali as appropriate.



Reverse Osmosis

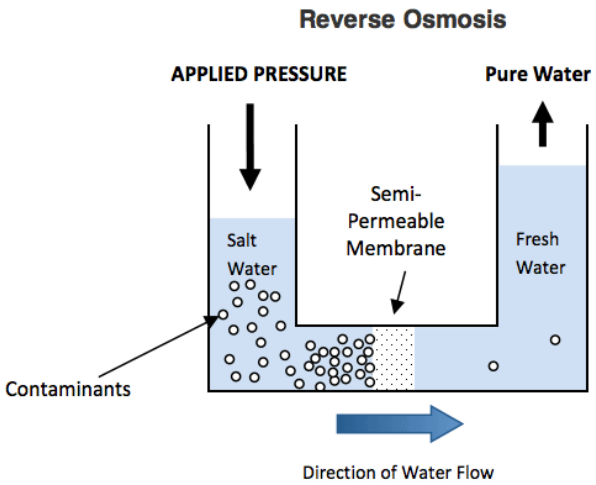
Full demineralisation can also be achieved by the use of membrane filters for Reverse Osmosis. Reverse osmosis, commonly referred to as RO, is a process where water is demineralized or deionized by pushing it under pressure through a semi-permeable membrane.

With the appropriate selection of membrane, water can be totally de-mineralised and have bacteria, trihalomethanes (THMs), some pesticides, solvents and other volatile organic compounds (VOCs) removed.

To help understand what RO is, it is useful to have a basic understanding of Osmosis. This is a naturally occurring phenomenon where water from a weaker saline solution will tend to migrate to a strong saline solution. Examples of osmosis are when plant roots absorb water from the soil and our kidneys absorb water from our blood.

A semi-permeable membrane is a membrane that will allow some atoms or molecules to pass but not others. An example is Gore-tex clothing fabric that contains an extremely thin plastic film into which billions of small pores have been cut. The pores are big enough to let water vapour through, but small enough to prevent liquid water from passing.

Reverse osmosis is the process of osmosis in reverse. Whereas osmosis occurs naturally without energy required, to reverse the process of osmosis you need to apply energy to the more saline solution. A reverse osmosis membrane allows the passage of water molecules but not the majority of dissolved salts, organics, or bacteria. However, you need to 'push' the water through the reverse osmosis membrane by applying pressure that is greater than the naturally occurring osmotic pressure allowing pure water through while holding back a majority of contaminants.



When pressure is applied to the source water, using a high pressure pump, the water molecules are forced through the semi-permeable membrane leaving almost all the dissolved salts and all bacteria behind in the reject stream. The amount of pressure required depends on the salt concentration of the feed water. The more concentrated the feed water, the more pressure is required to overcome the osmotic pressure.

The desalinated water that is demineralized or deionized, is called permeate (or product) water. The water stream that carries the concentrated contaminants that did not pass through the RO membrane is called the reject (or concentrate) stream.

An RO system employs cross flow filtration rather than standard filtration where the contaminants are collected within the filter media. To avoid build-up of contaminants, cross flow filtration allows water to sweep away contaminant (mainly mineral salts) build up so keep the membrane surface clean. The pore sizes in the membrane determine the mineral salts that are allowed to pass through the membrane.

Water deaeration

It is common to brew beer at 'high gravity' and to dilute the beer to its specified alcohol content at a later stage, for example post filtration. The water used for dilution has specific quality requirements.

- It must be sterile.
- The ionic composition should be similar to the brewing liquor, or be demineralized, but certainly with a lower calcium level than brewing liquor to reduce the risk of oxalate haze formation.
- The pH should be neutral or very slightly acidic.
- It should be carbon filtered to ensure it is halide free.
- It must have a very low dissolved oxygen level – typically less than 50 ppb.
- It must be at a suitable temperature for blending and flushing, typically 2 – 4 deg C, which also has the benefit of restricting growth of any contaminating micro-organisms.

There are a number of methods of producing deaerated liquor.

- Stripping at high temperature and atmospheric pressure
- Vacuum stripping at low temperature
- Gas stripping with nitrogen or CO_2 (or a mixture)
- Membrane gaseous exchange
- Chemical methods (for boiler water)

High temperature stripping

Water is heated to 105°C. It is then sprayed through nozzles into a tank at atmospheric pressure. This gives a fine mist of water, subject to flash evaporation which releases the dissolved gases. This method of deaeration is not as common as a few years ago due to the energy costs. Due to the high temperature, it is often not considered necessary to install additional water sterilizers after the plant.

Vacuum stripping

The principle is just the same as at high temperature. Water boils at low temperatures the lower the atmospheric pressure. By applying a vacuum to the tank into which the water is being sprayed, the boiling point is substantially reduced, and thus far less thermal energy is required. The process is carried out at 1 or 2°C above the boiling point at the selected low pressure.

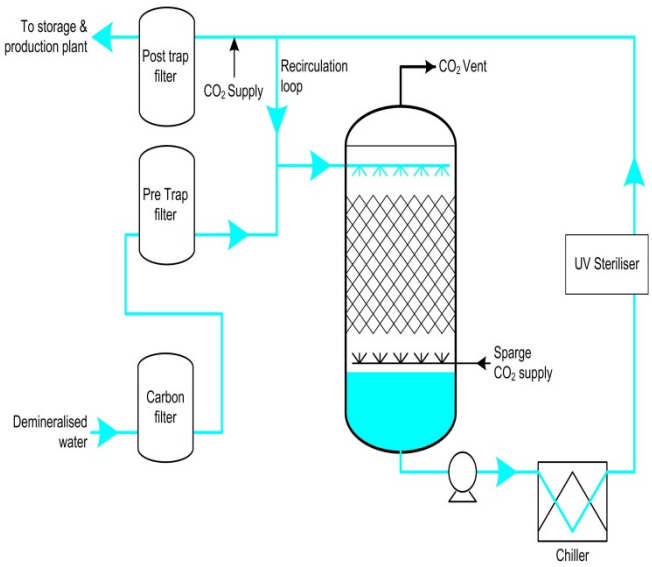
Gas stripping

In one method, this is achieved by saturating the water with nitrogen (or CO_2) and then allowing the nitrogen to flash off, carrying the dissolved oxygen with it. This gives a ten-fold reduction in a single pass, so that a number, typically two or three, are used in practice.

An alternative is to stream water downwards through a packed stripping column against a counter-current of inert gas (CO_2 or nitrogen). The water is sprayed into the top of the de-aerating column and it slowly trickles down the packed columns. The upward flowing CO_2 (N_2) ensures the release of the oxygen. At the outlet of the system the water is saturated with CO_2 (N_2).

Water for high gravity beer dilution is normally carbonated immediately after deaeration if CO_2 has not been used as the stripping gas. The use of nitrogen is often considered preferable as it is often cheaper than CO_2, certainly if bought in CO_2, and the small quantity of N_2 dissolved (circa 10 ppm) helps to improve foam stability on beer dispense.

The following diagram shows the general layout of a gas stripping deaeration system, using a packed column, carbon filter and trap filter prior to the column, UV steriliser, post column trap filter and CO_2 injection point, with a recirculation loop to ensure the product running forward to storage is always below the maximum permitted oxygen (instrument not shown).



Membrane gaseous exchange
Very low residual oxygen values can be achieved with low energy and purge gas consumption (CO_2 or N_2).

The water flows along the outside of the pack of hollow fibres made of hydrophobic polypropylene. Purge gas (CO_2 or N_2) flows at low pressure through the inside of the hollow fibre and is sucked out by a vacuum pump. Due to this, the partial pressure of the oxygen inside the hollow fibre is reduced almost to zero. The partial pressure difference between both sides forces the oxygen to flow through the membrane from the water into the gas.

The membrane material can allow only gases to pass through. Thousands of hollow fibres are bound together to form a bundle in a tube. The high surface area compared to the small volume is the main reason for the high efficiency and low running costs. The number of bundles of hollow fibres (and thus the surface area) is determined by the required residual oxygen values and the throughput required.

Chemical methods
Chemical can be added to boiler water to reduce the oxygen level and thus the corrosion during steam generation and distribution.

Corrosive components, especially oxygen and CO_2 have to be removed, usually by use of a deaeration chemical such as hydrazine. Remnants can be removed chemically, by use of an oxygen scavenger such as hydrazine. Feed water also has to be treated to attain a pH of 9 or higher, to reduce oxidation and to support the forming of a stable layer of magnetite on the water-side surface of the boiler, protecting the material underneath from further corrosion.

18.2 Water types and uses

Differentiation and uses of different waters
Brewing requires a plentiful supply of good clean water.

The main categories of use are:-

Product water
Water used for brewing & processing, including dilution, normally treated to some degree. All water which is added to the wort or beer must be product water.

- Deaerated water –used for diluting high gravity brewed beer, or where it will come into contact with beer, or other materials such as filter aids which will come into contact with beer.
  Most cask beers are not brewed at high gravity. However, where they are, the beer is normally diluted on transfer to cask racking tank.
  Bright packaged beer is normally diluted after filtration on transfer to BBT, though less commonly may be added prior to filtration or after the bright beer tank on transfer to the packaging line.
- Mixing water – used for mixing up, for example filter aids, caramel, enzymes, hop extracts which are then dosed into beer post fermentation, thus requiring very low oxygen levels. Additional deaeration is normally required in mixing tanks, achieved by bubbling carbon dioxide or nitrogen through the mixture.
- Flush water – used to purge lines or process plant such as centrifuges, filters or yeast presses clear of highly oxygenated CIP final rinse water, or to flush out the beer on completion of a transfer, prior to a quality change or CIP.

Process water
Process water is that water used for:

- Cleaning brewery plant.
- Washing beer packages before filling.
- Heating, for example in tunnel pasteurisers.

Service water
Service water is generally softened water (typically with reduced temporary hardness to prevent scale formation, but may also be completely demineralized). It is used for:-

- Boilers for raising steam and hot water for general use (i.e. not brewing water). The water may be softened or completely demineralized for boiler feed water. Even if fully demineralized, boiler feed water will be chemically treated to prevent corrosion, sludge build up etc.
- Cooling towers as part of the refrigeration plant.

Hot water systems
Hot water systems also present a potential source of legionella especially where aerosols are formed (e.g. by showerheads). Cold water systems also present a risk, though lower. To minimise the risk, sites ensure:

- Suitable sized storage tanks are used.
- Water is stored at the appropriate temperatures.
- Ensure regular use.
- Regular flushing of low use outlets.

General cleaning water
This is water that is used for hosing down, e.g. floors, and general hygiene and the normal standard supply can be used. This is normally mains or water that remains

untreated other than being sterilised, normally with chlorine.

Cooling tower water

Water used in cooling towers is prone to the growth of bacteria of which the most important is Legionella. Cooling tower water is an ideal environment for growth as it is at a suitable temperature for growth, and usually contains suitable nutrients, oxygen and of course water. The very action of the cooling tower generates an aerosol during the process, which allows a single cooling tower to affect a wide and diverse population.

In many countries there are regulations for managing the risks from legionella. These regulations generally include:

- The identification and assessment of sources of risk;
- The preparation and management of a scheme to prevent or control the risk;
- The keeping of records to check that what has been done is effective.

Cooling towers and similar systems are often treated using biocides but other treatments are available such as UV irradiation, copper / silver ionisation and ozone.

In hot and cold water systems legionella has traditionally been controlled by storing water above 60^{o}C and distributing it above 50^{o}C - and cold water below 20^{o}C if possible. Other methods which are used include copper / silver ionisation and chlorine dioxide treatment.

Legionella

Legionnaire's disease is a potentially fatal pneumonia caused by legionella bacteria. The infection is caused by breathing in small droplets of water contaminated by the bacteria. Only droplets of 5 microns or less will pass deeply into the lungs. This is 1/1000th the size of a raindrop. The disease cannot be passed directly from one person to another.

Legionella bacteria are common in natural water courses such as rivers and ponds. Since legionella are widespread in the environment, they may contaminate and grow in other water systems such as cooling towers, evaporative condensers and hot and cold water services. They survive low temperatures and thrive at the optimum temperatures between 30^{o}C – 40^{o}C when the conditions are right, e.g. if a supply of nutrients is present such as rust, sludge, scale, algae and other bacteria. Over 40 °C, the multiplication will cease, but bacteria are not killed. Legionella is not viable at temperatures higher than 65 °C, and will be killed.

Areas of risk of encouraging growth and risk of spreading legionella include

- Water systems incorporating cooling towers, evaporative condensers and pasteurisers.
- Hot and cold water systems.
- Other plant and systems containing water which is likely to exceed 20^{o}C, and may release aerosols during operation or maintenance.

Points of use, and quality of water at usage points

The following tables show further details of the water quality requirements for the different types of water at points of use.

Product water

Task	Type of water	Treatment
Mashing - water is mixed with the grist (ground malt and dry adjuncts) at mashing.	Product water with the correct salts needed to ensure the optimum conditions for effective enzyme activity particularly pH control.	Addition of calcium salts, particularly calcium sulphate. Calcium chloride or sodium chloride can be added to the water tanks or into the mash. Lactic acid preparations are also widely used to correct pH
Sparging - water used to wash the extract from the malt husk.	Product water – should be neutral or slightly acidic with low dissolved mineral salts.	Adjusted for pH and mineral composition, often by addition of calcium salts if required.
Breakdown or dilution water used to dilute the wort to collection gravity (strength.)	Product water – free of taints and micro-organisms.	Often use same water as used for sparging. Hot water is cooled through the wort chillers, or cold sterile product water may be used instead.
Additions or makeup water used in fermentation, maturation and filtration for mixing process aids like finings.	Product water – free of taints and micro-organisms. Post fermentation additions must be free of any dissolved oxygen.	Often use demineralized and deaerated water. See water sterilisation & de-aeration.
Dilution of high gravity beer - water used to adjust alcohol content in high gravity beers – normally after filtration.	Product water – free of taints and micro-organisms and any dissolved oxygen.	Often use demineralized water for preparation of deaerated water. See water sterilisation & de-aeration.
Water jetting in bottling - water is used to jet into bottles to promote a CO_2 purge.	Product water – free of taints and micro-organisms and any dissolved oxygen Often hot water (circa 80^{o}C +) is used	See water sterilisation & de-aeration.

Process water

Task	Type of water	Treatment
CIP and manual cleaning of plant.	Softened or fully demineralized process water is used to reduce the formation of scale in CIP delivery systems and spray heads which is caused by the presence of carbonates in the water. Carbonates & bicarbonates affect the efficiency of caustic based detergents.	Removal of carbonates & bicarbonates during softening process, or full demineralization.
Returnable bottle, cask & keg washing.	Softened or fully demineralized process water is used to reduce the formation of scale in CIP delivery systems and spray heads. Temporary hardness can cause 'bloom' in washed returnable bottles. Carbonates & bicarbonates affect the efficiency of caustic based detergents.	Removal of carbonates & bicarbonates during softening process, or full demineralization.
Final rinses of plant and packages after cleaning. Non returnable bottle and can rinsing	Softened or fully demineralized process water is used to reduce the formation of scale.	Removal of carbonates & bicarbonates during softening process, or full demineralization. The water must be sterile to reduce the risk of re-infection by micro-organisms contained in unsterile rinse water.
Tunnel Pasteurisers.	Softened or fully demineralized process water is used to reduce the formation of scale.	Removal of carbonates & bicarbonates during softening process, or full demineralization. Anti fungicides used to prevent mould formation. Rust inhibitors used to help prevent rust on bottle crowns.

Services water

Task	Type of water	Treatment
Boiler Water.	Uses softened or fully demineralized water to reduce the formation of scale and form deposits which can corrode heating surfaces.	Removal of carbonates & bicarbonates during softening process, or full demineralization. To prevent corrosion, additives are used to scavenge dissolved oxygen the water pH is adjusted.
Cooling tower water	Risk of bacterial contamination by Legionella bacteria which cause Legionnaires disease, a potentially fatal pneumonia type disease following breathing in small droplets of contaminated water.	To reduce risk: generally • Risk assessment • Management of risk • Records of treatment • Regular operation to prevent build up • Water temperature control • Filtration of water and / or • Treat water with biocide E.g. UV, bromine or chlorine, chlorine dioxide, silver ionisation, ozone.
General cleaning water	This is water that is used for hosing down.	Normal hygiene standards apply.

18.3 Sources of effluent and its measurement

The nature and characteristics of brewery effluents

Effluent is any liquid containing dissolved solids, suspended solids, brewing materials, beer, yeast, lubricants, detergents, refrigerant or other chemicals that does not leave the brewery as product and which will, with or without treatment, eventually enter a water course. Clean water or even good quality beer accidentally discharged to a foul drain becomes effluent.

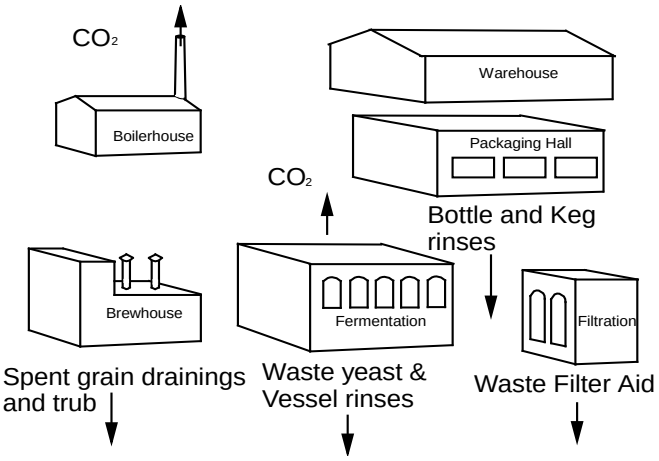
It is expensive to process and the brewery is charged for this processing. The local water authority will normally also impose limits to the volume of and content (including temperature, suspended solids, pH, COD, BOD) of the effluent that the brewery is allowed to discharge.

Note that there are a number of materials that it is prohibited to discharge to an effluent system. Special arrangements must be made for disposal of these materials. However, these materials are not common in brewery operations.

This section will not discuss a number of brewery and packaging waste products such as packaging materials or oils from engineering, but will be limited to product that is discharged to the drains, as indicated above.

Sources in brewing and packaging operations

Examples of effluent from different parts of a brewery.



Most of the waste water from a brewery is biodegradable, although there may be a problem with some CIP wastes.

Brewhouse

Spent grain is the husk that remains from the malted barley used to produce beer. This grain (grist) has been sparged with hot water to extract the maximum amount of sugar from the malt. After sparging, the grain is still very wet. The grain is sold as cattle food as a co-product but the final drainings from the spent grain are high in solids and Chemical Oxygen Demand (COD), and are normally run to drain. Modern mash filters and lauter tuns minimise the amount of liquid not recovered for use in the next brew.

Trub is formed when the wort is boiled and subsequently cooled. Effluent can be produced if this is washed away to drain. Trub contains a large proportion of solids and has very high levels of COD. For this reason, trub is often returned to and disposed of with the spent grains. Trub also contains considerable amounts of retained wort, and for this reason, it is often added back to the lauter tun / mash filter prior to recovery of the final drain down, so reducing the amount of COD / BOD sent to effluent. For an explanation of COD, see later in this section.

Large volumes of water are used to cool the hot wort, usually in plate heat exchangers. The water is normally recovered as hot water but an excess can be sent to the effluent system.

Brewhouse plant becomes heavily soiled and must be cleaned regularly. A lot of water is used and the effluent from this cleaning operation can be high in solids and normally has a very high pH because of the use of caustic detergents.

Fermentation, yeast room and maturation (cold storage)

During fermentation, the amount of yeast in the beer can multiply four fold or more resulting in a surplus. Without effective processing, there is the potential for this surplus, including entrained beer, to be washed down the drain. Yeast has a very high COD and suspended solids (SS). The beer portion has a very high COD & BOD.

Purges from maturation or cold storage tanks contain yeast and protein, both of which have high solids and COD levels. In older breweries, water is used to cool fermentations via attemperating coils / jackets, rather than recirculating refrigerant such as glycol. This water is often run directly to drain.

Fermentation, yeast room and maturation plant becomes soiled and must be cleaned regularly. Large quantities of water are used and the effluent from this cleaning operation can be high in solids and have a high or low pH depending on the detergents and sterilants used.

Filter room

In kieselguhr filtration, beer is dosed with filter aid on its way to the filter, the filter aid being added to trap yeast and other small particles so that they do not pass through into the final package beer. When the filter needs cleaning this filter aid is washed off. Effluent from the filter room will have very high solids content and COD from the entrained yeast and protein particles, and if not flushed out effectively, will also have a very high COD due to the entrained beer.

Filter runs are started and completed by pre and post filter flushes with water. Often, large quantities of interface, with high COD levels are run to drain.

Packaging Effluent

Effluent from the packaging plant comes from returnable bottle, cask and keg washing machines, from filling machines and from pasteurisers.

Returnable package washing is main source of effluent. Detergents are used and the packages have to be rinsed with fresh water before being filled. Returnable bottle washing machines are required to remove paper labels which could be washed to drain. The packages themselves usually contain small quantities of beer residues.

Bottles and cans are rinsed prior to pasteurisation and must be rinsed off before their transfer to the pasteuriser to prevent corrosion of the pasteuriser by the acid beer, or as a result of bacterial growth. This rinse water often contains comparatively large proportions of beer.

Tunnel pasteurisers invariably use large volumes of water, and in spite of recycling within the pasteuriser considerable quantities may be run to drain. This may be greatly reduced by water recovery systems which use refrigerant to remove the excess heat, along with use of biocides to prevent microbial growth.

The components of effluent quality

Effluent Costs

The authorities operating the effluent plants often have particular problems to resolve and their charging policies reflect these. Effluent is typically measured in five ways - Volume, Suspended Solids, COD, pH and temperature. The charge for discharging effluent generally takes these values and uses them in a formula e.g. the UK's Mogden formula to calculate the cost per unit of effluent. Individual authorities may adjust the formula itself to reflect their own problems.

An example of the as used Mogden Formula is as follows

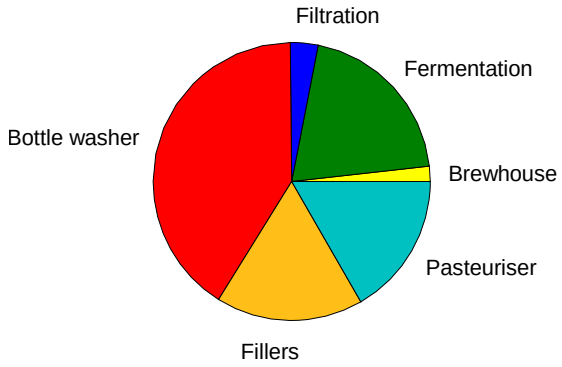
$P = C + V + (St / Ss)S + (Ot / Os)O$

where

- P = cost (pence) per m3
- C = conveyance charge, p per m3
- V = volumetric charge, p per m3
- S = suspended solids charge, p per m3
- O = COD charge, p per m3
- St = suspended solids content of trade waste, mg/l
- Ss = suspended solids content of sewage, mg/l
- Ot = COD of trade waste, mg/l
- Os = COD of sewage, mg/l

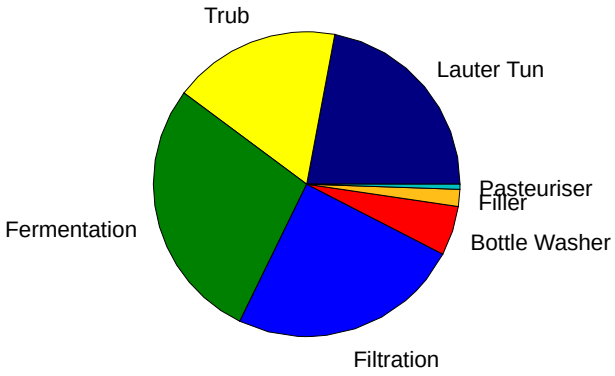
Volume

Value	Explanation	Source
Volume	The volume of effluent discharged, usually measured in cubic metres.	Wastage of water described above.



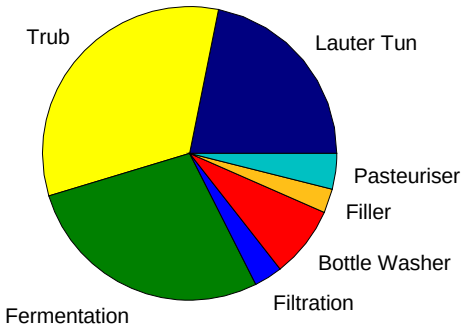
Suspended solids

Value	Explanation	Source
Suspended Solids	This represents that material not settling in 30 minutes of standing. The solids are recovered by filtration through paper, which is then dried and weighed. The suspended solids can smother aquatic organisms and, of course, increases the sludge quotient in the treatment works. It is expressed in ppm (parts per million) or mg/litre.	Spent grain, trub, yeast, filter aid and bottle labels.



Chemical oxygen demand

Value	Explanation	Source
C.O.D.	COD was developed as a rapid test for the extent of organic assimilable material in industrial or trade wastewaters. It does not depend on the growth of microorganisms and there are not the same concerns that there may be toxic material present that would inhibit microbe growth and therefore lead to a depression of BOD values. A sample of the waste stream is oxidized with a mixture of sulphuric acid and potassium permanganate and the extent of reduction in the permanganate assessed. The test takes about two hours.	Organic material like spent grain, trub and yeast.



Biological oxygen demand

Value	Explanation	Source
B.O.D.	BOD is a measure of the impact of a waste stream on a river based on its content of nutrients that will support the growth of micro-organisms, thereby removing oxygen from the water and contributing to its stagnancy. The test measures how much oxygen is consumed over a five day period. The test has been around since 1908, it having been established through the work of the Royal Commission on Sewage Disposal.	Organic material like spent grain, trub and yeast.

pH

Value	Explanation	Source
pH	A measure of the acidity/alkalinity of the effluent. Water is neutral at 7.	Detergents, sterilants and beer.

Temperature

Value	Explanation	Source
Temperature.	A measure of the heat in the effluent.	Hot effluent from the brewhouse, boilerhouse, hot CIP units or pasteurisers.

In addition to the above measurements, the following may be measured and used in a modified version of the formula.

Total organic carbon

Value	Explanation	Source
TOC	TOC has been recognized for more than thirty years as an analytical technique to measure water quality. It is determined as the carbon dioxide released by chemical oxidation of the organic carbon in a sample. After the sample has been acidified and purged of inorganic carbon, the strong oxidiser sodium persulphate is added and, at 100ºC, the carbon is converted to CO_2 which is measured in an infra-red analyser.	All organic material such as spent grains, trub, yeast, beer.

Statutory Controls

Water Authorities generally impose limits to the amount of and condition of effluent being discharged from a brewery into their systems. They can levy penalties and fines to companies who persistently exceed the limits.

A typical set of limits is detailed in the table below:

Parameter	Limit
Maximum volume	100,000 litres per 24 hours
Maximum suspended solids	500 mg/litre
Maximum COD	10,000 kg per 24 hours
pH range	6 – 10
Maximum temperature	40° C

Notes:

Write down the sources of your own brewery's water supply.
Write down the principal characteristics of your own brewery's water supply and how it meets the standards required.
Investigate the uses for product water in your brewery and the reasons for the chosen treatments.
Write down the primary treatment procedures of your own brewery's water supply. Illustrate with flow diagrams.
Describe the problems experienced with your brewery's process water and how these are overcome.
Describe the treatment used for your brewery's boiler water and cooling tower water.
Describe how the de-aerated water plant operates in your brewery. Use flow diagrams to illustrate your description.
Write down the sterilisation procedures of your own brewery's water supply. Illustrate with flow diagrams.
Describe an area in your brewery where effluent is a problem.
Identify the charges for your own brewery and how they are calculated.
Identify below the limits set for your brewery.

Qualifications

The General Certificate in Brewing (GCB)

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Section 19 Utilities - Process Gases

19.1 Properties, applications and safety of gases

The essential properties & quality of air and oxygen

Compressed air and oxygen are used for a number of different purposes. The specific requirements for each purpose vary slightly, and are thus listed separately below
Air or oxygen used for aerating wort or yeast cultures, and for CO_2 degassing towers for water must be:-

- Clean, i.e. free of particulate matter.
- Sterile, to prevent infection by non-culture yeasts or bacteria present in the gas.
- Free of other contaminating gases which would have an adverse effect on the product.
- Oil / grease free, to prevent loss of head retention.
- Normally dry to prevent bacterial / yeast / mould growth on filters, or blockages of filter by moisture (though of course this is not a requirement for water degassing towers).

Air used for pneumatic operation of plant, such as valves, and use in instruments such as pressure sensors must be:-

- Clean and dry, to minimise the risk of corrosion.
- Oil free, to minimise risk of contamination of product in the event of a passing seal, though sometimes, the air will be deliberately "oiled" for lubrication purposes (e.g. cylinders for pneumatic hoists).

Compressed air used for

- spent grains transfer for feedstuffs should be clean and oil free.
- air knives on small pack tunnel pasteurisers to remove excess water and foaming units for environmental cleaning need simply be clean enough not to cause blockages. As it does not come into contact with product, it does not need to be dry, oil free or sterile.

Where gases are to be sterilised, the normal method is filtration through very fine filters. The filters and the pipework from the filter through to the injection point must also be sterilisable. The filter must be capable of being sterilised using clean "wet" steam. The connecting pipework is normally sterilised by the steam or the CIP run through the production plant. See GCB section 4 (wort cooling and oxygenation) for an example of a gas injection system with associated sterilisation / CIP capability.

The essential properties & quality of CO_2 and nitrogen

CO_2 and nitrogen are both used in situations where they will either be in contact with product (e.g. tank top pressure gas) or are injected directly into the product.

They must both therefore be:-

- Clean, i.e. free of particulate matter.
- Sterile, to prevent infection by non-culture yeasts or bacteria present in the gas.
- Free of other contaminating gases which would have an adverse effect on the product.
- Oil / grease free, to prevent loss of head retention.
- Normally dry to prevent bacterial / yeast / mould growth on filters, or blockages of filter by moisture (though of course this is not a requirement for water degassing towers).
- Oxygen free to minimise flavour and haze changes in the beer.

Again, the gas is normally sterile filtered just before the point of use, using a similar design system as used for air or oxygen as shown in the notes GCB section 4.

Note that CO_2 reacts with sodium hydroxide to form sodium carbonate and bicarbonate. Therefore vessels containing CO_2 should ideally only be cleaned using acid detergents and sterilants to prevent severe degradation of the caustic and possible creation of a vacuum. Tanks containing nitrogen may be safely cleaned with caustic or acid as the gas does not react with either.

The practice and benefits of CO_2 collection

There are two sources of CO_2 suitable for recovery in breweries:

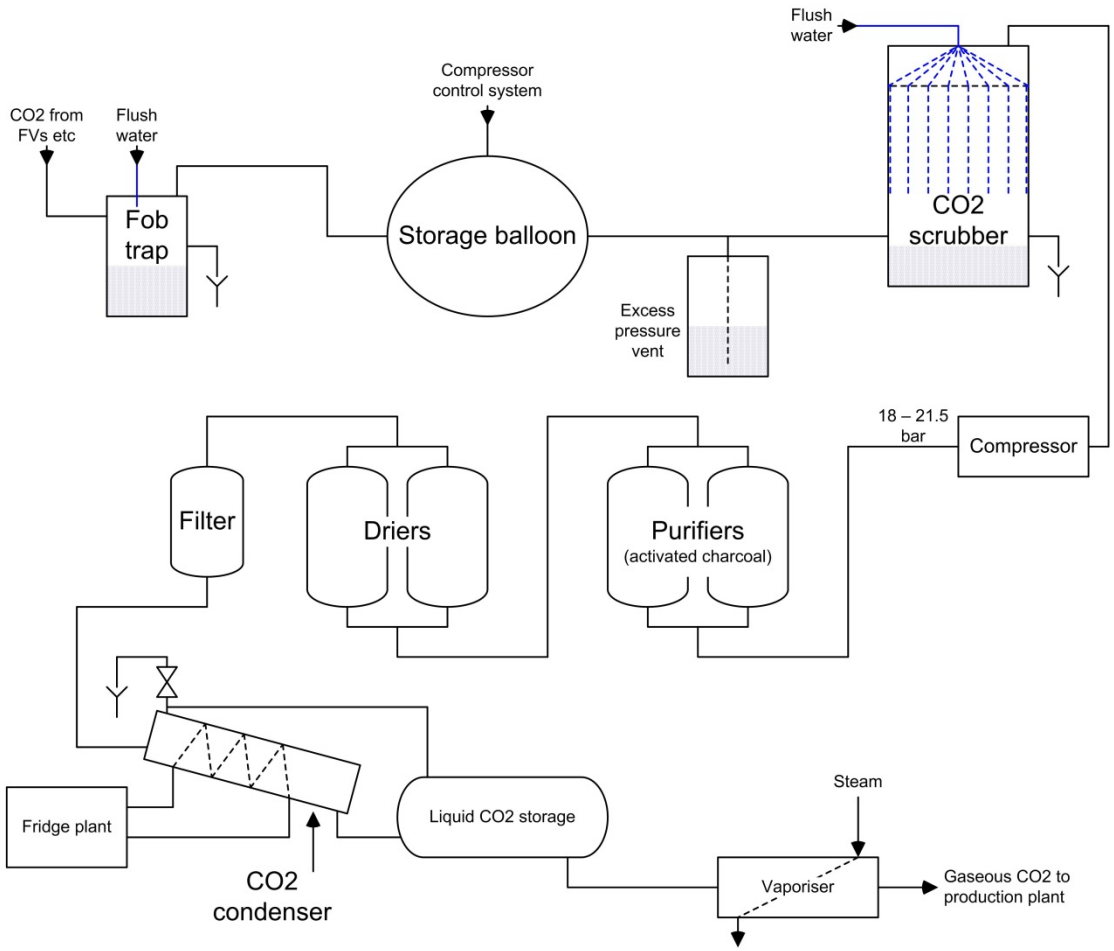
- The CO_2 evolved during fermentation
- The CO_2 being displaced from vessels or beer containers during filling

One hectolitre of 44 SG (12 ^{o}P) wort will produce about 4.2 kg of CO_2. Allowing for initial losses, mainly due to air contamination in the initial stages of fermentation, other losses in the collection system and residual dissolved CO_2, the likely amount collected assuming > 99.5% pure, will be 50 – 60% of this figure – 2.2 to 2.5 kg / hl.

Thus large volumes of high gravity wort are going to make recovery more economically viable than small volumes of wort and/or low gravity wort. The economics of recovery also depends to a large extent on the local cost of purchased gas. In some instances, the brewery may collect gas surplus to its needs, and the sale of CO_2 to a third party can help offset the capital and revenue costs. The design of the brewery can also play a large part in the cost - considerable expenditure may be required to install a suitable large scale hygienic collection network.

Carbon dioxide, especially that collected from FVs, must be checked for purity, cleaned and dried as necessary. Only pure CO_2 must be re-used. A typical collection plant consists of:

- Collection mains from the source (vessels) leading to
- A fob trap, to eliminate any foam or excess moisture vented into the system by a vigorous fermentation, then to
- Balloon storage to provide a low pressure buffer, to collect any surges in load, and provide a constant pressure supply to the compressors. Note this can be a major bug trap.
- Water scrubber, to remove residual foam and more particularly, the water soluble volatiles which would otherwise taint the product when re-used.
- Compressor – to compress the gas, typically to 18 bar.
- Cooler – to remove the heat generated during the compression of the gas.
- Dryer – to remove moisture, typically to achieve a dewpoint of - 40°C.
- Deodoriser – to remove residual volatiles.
- Liquefier – typically a shell and tube heat exchanger. The carbon dioxide liquefies at circa - 20°C.
- Storage tank – insulated, and fitted with a refrigeration coil to maintain the temperature at circa - 20°C and 20 bar.
- Vaporiser. The gas is then normally stored in liquid form and subsequently evaporated, using a steam or sometimes electric vaporiser to produce gas at a suitable pressure for distribution. It is essential no liquid gas passes into the distribution system.



The significance of inertness

CO_2 and nitrogen are both used in situations where they will either be in contact with product or are injected directly into the product. They need to be oxygen free because the oxygen will react with haze forming materials in the beer, leading to flavour changes and decreases in solubility of haze forming materials. These flavour changes, hazes, and in extreme cases, sediment will cause a reduction in the shelf life of the product.

Where CO_2 and nitrogen are injected into the beer, to be fully dissolved, this is particularly critical. However, experience shows that even small amounts of residual gas in a vertical bright beer tank counter pressure gas for example can increase the dissolved oxygen from an in specification 75 ppb to an out of specification 200 ppb.

Thorough gas purging of tanks after they have been opened for inspection is critical for this reason, some breweries making a point of flood filling the tank with water, then emptying with CO_2 or N_2 top pressure, before cleaning and refilling with beer.

The complete lack of oxygen also makes CO_2 and nitrogen extremely dangerous to use in confined spaces.

The typical uses of process gases

Pure oxygen is used for:-

- Wort oxygenation to allow healthy yeast growth and subsequently, fermentations and excess yeast suitable for re-pitching.
- Yeast culture oxygenation – for reasons as above.

The oxygen requirement of some yeasts can be met by dissolving air, which can provide up to about 10 ppm dissolved oxygen. However, others require more than this, which can only be met by pure oxygen, which can provide up to approximately 30 ppm. Excessive foaming due to the presence of approximately 4/5 nitrogen by volume in air may also drive the use of oxygen instead.

Air may be used for:-

- Wort and yeast culture oxygenation – as above.
- Spent grains discharge from mash / lauter tun or mash filter dump tanks to silos.
- CO_2 stripping in water degassing tower (for CO2 removal).
- Operation of pneumatic actuators such as valves.
- Operation of pneumatic cylinders such as pallet hoists.
- Instruments such as pressure sensors.
- Air knives on small pack tunnel pasteurisers to remove excess water.
- Air curtains on small pack pasteurisers or building entrances
- Cleaning, either simply as air lines, or incorporation into chemical foaming units.

CO_2 and nitrogen are both used in situations where they will either be in contact with product or are injected directly into the product including:-

- Tank top pressure gas to eliminate contact with oxygen from air.
- Filler counter pressuring to minimise oxygen pickup during filling.
- Package flushing to minimise oxygen pickup during filling.
- Undercover gassing of canned beer immediately prior to seaming.
- Deaeration of water for use prior to and after beer transfers such as through mains and filters.
- Deaeration of filter aid slurries of other additions to beer after fermentation.
- Outside the brewery itself, it may be used to flood fill hop storage bags to reduce the oxidation of the hop oils and resins.

CO_2 is also used for:-

- Direct injection in order to give beer its fizzy character.
- Purging water in a deaeration column to produce de-oxygenated water for flushing and dilution, with the added benefit (compared to other means of deaeration) when used for dilution that the carbonation plant does not have to add as much CO_2.
- Degassing beer by bubbling CO_2 through beer with reduced top pressure, to wash out excess CO_2, or to remove dissolved oxygen. This process is not widely used as it is not easily controlled; it adversely affects head retention by using up the supply of head forming proteins, and may cause haze or even gushing due to the collapsed foam.
- Some breweries have used it to correct high pH effluent, the CO_2 reacting with alkaline materials, especially NaOH to form the carbonate or bicarbonate form, which both have considerably lower pH. This helps bring the pH of the effluent into the permissible range. CO_2 used for this purpose does not have to be particularly pure (unless it had to be liquefied for storage).
- It is used for beer dispense, either on its own, or mixed with nitrogen for improved head formation and retention.

Nitrogen is also used for:-

- Direct injection in order to enhance the foam retention of the beer to achieve for example, 10 ppm for conventional keg lagers and ales, up to approximately 50 ppm for stouts or nitro-keg beers.
- Liquid nitrogen may also be used in canned products instead of widgets to help create a dense long lasting head.
- Degassing beer by bubbling N_2 through beer with reduced top pressure, to wash out excess CO_2 or dissolved oxygen. This process is not widely used as it is not easily controllable; it adversely affects head retention by using up the supply of head forming proteins, and may cause haze or even gushing due to the collapsed foam.

The economic importance of leak prevention

The purchase of, collection and storage of, or the production on site of these gases is expensive. Considerable energy is required to compress and cool the gases for storage, normally as a liquid, and subsequently to consistently evaporate the liquid to usable gas. Other materials and operations required to ensure efficient operation may include maintenance, water, CIP.

Gas leaks result not only in loss of the gas, generally at high pressure, and thus all the electrical, thermal energy etc. required to produce the gas at that point. High losses may result in failure of other plant to operate less efficiently. Where an inert gas such as CO_2 or nitrogen is lost, there may be safety risks associated with increased levels in the atmosphere due to reduced oxygen levels. Where pure oxygen is lost, there may be an increase fire risk in that area.

Gas leaks may also damage plant if not maintained promptly, either from failure to operate correctly, or from simple wear of, for example the flange surfaces from where the gas is leaking.

Safe handling & storage of gas cylinders

Dispense gas cylinders are heavy and are filled with gas held under high pressure. If a cylinder discharges or ruptures (perhaps through mishandling), the damage is likely to be considerable because a cylinder can become a missile-like projectile or fracture catastrophically.

Cylinders must be handled and stored in accordance with the UK Manual Handling Regulations 1992 (or similar in other countries) and other health and safety guidelines.

There are well recognised procedures to minimise risks covering:

- Labelling
- Handling
- Storage
- Transporting
- Use of personal protective equipment

Some key aspects include the following:-

- Keep cylinder stocks to the minimum necessary.
- Only use cylinders filled by a reputable gas supplier who fills and regularly tests cylinders in accordance with current safety regulations.
- Return gas cylinders to the supplier you purchased them from – and to no-one else.
- Cylinders should be handled with care and not knocked violently or allowed to fall. They should be stored and secured in an upright position.
- Always store full cylinders in an area away from cylinders in use.
- When in use cylinders should be firmly secured to a suitable cylinder support.
- Never drop, throw or mishandle cylinders.
- Never use cylinders for anything other than storing and delivering the gas for which the cylinder is specified.
- Never store cylinders where they may come into contact with water.
- Never store next to a direct heat source; e.g. radiators, coolers etc.
- **Medical gases must only be used for medicinal purposes.**

Safety hazards of gases and high pressure distribution

Carbon dioxide

Carbon dioxide is present in the atmosphere at concentration of 0.04% and is a normal body constituent arising from respiration. It is toxic in high concentrations acting directly on the respiratory centres in the brain.
In liquid form, there is a risk of frost burns due to the extreme low temperature.

A major gas leak may be reportable to the HSE as a dangerous occurrence under RIDDOR regulations. (UK – equivalent regulations may apply elsewhere).

Carbon dioxide is a special safety hazard in fermenting rooms. There are several features of this gas to be considered:

- It is a toxic gas at high concentrations in the atmosphere – see table later.
- It is heavier than air and it will accumulate in low-lying areas.
- It is generated in very large quantities during fermentation.

The risks associated with CO_2 can be reduced by:

- Effective removal of the gas from FV rooms using extraction systems.
- CO_2 collection from fermentations.
- The installation of gas detectors with associated alarm handling.
- Safe systems of work, including permits to work, permits to enter confined spaces and evacuation procedures.
- Clearly defined evacuation procedures.

The effects of increasing CO_2 concentrations are noted in the following table:

CO_2 conc. by volume of air	**Effects and Symptoms**
1 %	Slight and unnoticeable increase in breathing rate – this is the level commonly used to evacuate an area.
2 %	Breathing rate increases (increase to 1.5 times normal rate), and prolonged exposure over several hours may cause headache and feeling of exhaustion
3 %	Breathing becomes deeper (increase to twice normal rate). Hearing ability reduced, headache experienced with increase in blood pressure and pulse rate
4 – 5 %	Breathing becomes deeper and more rapid (increase to four times normal rate). Signs of intoxication after exposure for half an hour, with slight choking feeling.
5 – 10 %	Characteristic pungent odour noticeable. Breathing very laboured leading to physical exhaustion. Headache, visual disturbance, ringing in the ears and confusion, probably leading to loss of consciousness within minutes.
10 – 100 %	Loss of consciousness more rapid, with risk of death from respiratory failure. Hazard to life increases with the percentage concentration, even if there is no oxygen depletion.

CO_2 reacts with sodium hydroxide to form sodium carbonate and bicarbonate. Therefore vessels containing CO2 should ideally only be cleaned using acid detergents and sterilants to prevent severe degradation of the caustic and possible creation of a vacuum. Tanks containing nitrogen may be safely cleaned with caustic or acid as the gas does not react with either.

Occupational exposure limits

The exposure limits for carbon dioxide published by the UK Health & Safety Executive are:

- **0.5% as a time weighted average over an 8 hour working day**.
- **1.5% as a time weighted average over a 10 minute period.**

Most UK companies apply their own restrictions based on these values which appear, at first glance to be considerably stricter, but are designed to ensure the "weighted average" is never exceeded.

Typical alarms are set up with 2 level settings as follows:

- CO_2 first level alarm (limited access time) = > 0.5%in air
- CO_2 second level (immediate evacuation) alarm = > 1.0% in air

Nitrogen

Air contains approximately 80 % N_2. Nitrogen levels above this are potentially dangerous because it will suffocate and it is difficult to detect. In liquid form, there is a risk of frost burns due to the extreme low temperature. People required to enter tanks where N_2 is used for back pressure are especially at risk. Dangers can be reduced by the installation of gas detectors (Oxygen deficiency meters).

Atmospheric sampling of an area where there is a significant risk that nitrogen could be released / present in dangerous quantities must be carried out prior to entry. When testing for the presence of nitrogen it is usual to achieve this by measuring oxygen levels as nitrogen diffuses into the atmosphere and will displace oxygen.

Oxygen levels should be between 19.5% and 21.5% prior to entry into confined working spaces.

In liquid form, there is a risk of frost burns due to the extreme low temperature. One tonne of liquid N_2 will generate approximately 840 m^3 of CO2 at atmospheric pressure.

Typical alarms are set up with range settings as follows

- O_2 depletion = < 19 % vol in air
- Excess oxygen = > 23 % vol in air

Oxygen

Oxygen supports combustion and in high concentrations can therefore lead to very intense fires. Therefore high levels of oxygen can be considered as dangerous as low levels of oxygen, though in the brewing industry, high levels are not generally considered a common risk. In liquid form, there is a risk of frost burns due to the extreme low temperature.

It is stored in high pressure containers, sometimes as a liquid, when it must be vaporised before distribution and use.

The effects of decreasing O_2 concentrations due to increased CO2 or nitrogen concentration are noted in the following table:

O_2 conc. by volume of air	**Effects and Symptoms (Normal air contains 20.9% oxygen by volume)**
21 - 14 %	Increasing pulse rate. Tiredness.
14 - 11 %	Physical movement and intellectual performance becomes difficult.
11 - 8 %	Possible headaches, dizziness and fainting after short period of time.
8 – 6 %	Fainting within a few minutes, resuscitation possible if carried out immediately.
6 – 0 %	Fainting almost immediately, death or severe brain damage.

Pressurized gas systems

All pressurized process gas systems (including compressed air) present safety hazards. If pressure systems fail, they can seriously kill or injure people. Most countries have regulations dealing with the risks created by a release of stored energy should the system fail and detailing the measures that should be taken to prevent failures and reduce risks. The regulations generally cover:

- Safe operating limits.
- Written schemes of examination.
- Specific requirements relating to most pressure vessels, all safety devices and any pipework which is potentially dangerous.

Notes:

Candidates should familiarise themselves with their own brewery's procedures for:

- *the safe entry into tanks, cold rooms and other confined spaces where carbon dioxide or excessive nitrogen may be present*
- *the use of portable and fixed alarms together with other personal protective equipment.*

Candidates should also investigate their own national (and any local) safety regulations and procedures relating to:

- *the storage of liquid gases and their distribution in high-pressure mains.*
- *compressed air systems and equipment.*
- *the safe handling and storage of compressed gas cylinders.*

Qualifications

The General Certificate in Brewing (GCB)

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Section 20 Brewing and the Environment

20.1 Sustainability and climate change

The concept of a sustainable industry

The brewing industry, in common with other industries, impacts on the environment in many different ways. For example:

- As a user of energy.
- As a 'consumer' of water and other natural resources.
- As a source, both directly and indirectly, of atmospheric emissions, trade effluent and packaging waste.

Some of the materials consumed can be considered "renewable", such as the barley grown for malting, although its production actually consumes considerable fossil fuel energy. Others resources such as fossil fuels are consumed by the process. The malting, brewing, packaging, distribution, and consumers generate "waste" contributing to land fill material and gas emissions which impacts on the environment.

Sustainable development has been described as:

- Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (ref: Brundtland Commission, 1987)
- Sustainable development is about ensuring a better quality of life for everyone, now and for generations to come. To achieve this, sustainable development is concerned with achieving economic growth, in the form of living standards, while protecting and where possible enhancing the environment – not just for its own sake but because a damaged environment will sooner or later hold back economic growth and lower the quality of life – and making sure that those economic and environmental benefits are available to everyone, not just the privileged few. (ref: UK Department of the Environment, Transport and Regions. 1998)

The challenge of sustainable development is to achieve economic, social and environmental objectives at the same time. In the past, economic activity and growth have often resulted in pollution and wasted resources. A damaged environment impairs quality of life and at worst may threaten long term existence, for example as a result of global climate change.

Climate change

Climate change is being caused / accelerated by an increase in greenhouse gases in the atmosphere. These gases come from both natural and man-made sources, but the increase is the result of human activity, mainly the release of carbon dioxide from the use of fossil fuels such as coal, gas, oil, petrol and diesel.

All businesses and societies, to a greater or lesser extent, are feeling the impact of climate change and the policies of governments around the world to address it. These may include:

- restrictions on emission levels
- restrictions on water use
- changes in agricultural growth patterns
- increases in energy prices
- changes in consumer habits

Sustainability guiding principles

Our industry consumes significant resources. Can true sustainability be achieved? Probably not, but there is much we can do to improve our use of diminishing resources.

Companies committing to minimising the total impact of their activities on the environment, to using natural resources wisely, to pursuing social progress and to playing leading roles in their economies adhere to certain guiding principles typified by the following:

- To comply with all relevant national and local legislation and regulations.
- To design, operate and maintain processes and plants to:
  - optimise the use of all resources (materials, water, energy etc.) whilst ensuring that unavoidable wastes are recovered, reused or disposed of in an economically sustainable and environmentally responsible manner.
  - minimise the potential impact on the environment from site emissions to air, water and land.
  - regularly assess the environmental impacts of processes and plants and, based on the assessments, set annual objectives and targets for the continual improvement of environmental performance.

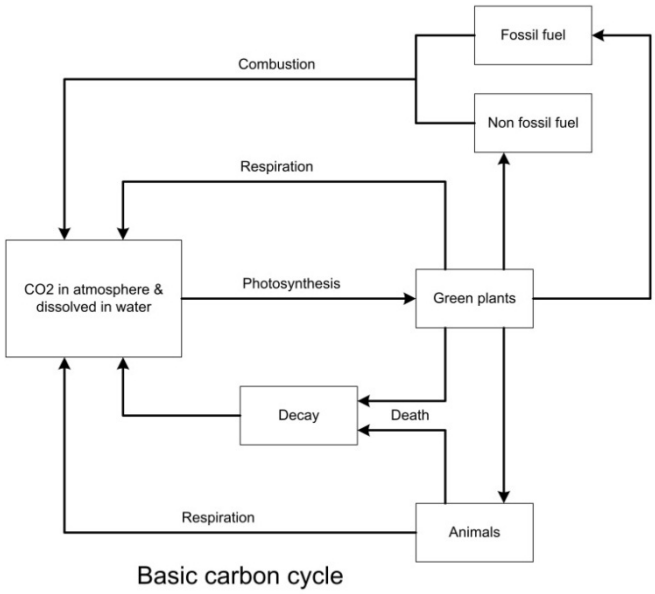
- use and develop packaging distribution systems for which packaging/product combination will make fewer demands on non-renewable and renewable natural resources.
- minimise the use of substances which may cause potential harm to the environment and ensure they are used and disposed of safely.
- encourage a culture of awareness on sustainability issues amongst employees through management commitment, appropriate communications, training and other initiatives.
- establish and maintain appropriate procedures and management systems to implement these principles through policy commitment.
- work with suppliers and other business partners in the supply chain to maintain high environmental standards.

The role of carbon dioxide – the carbon cycle

Carbon dioxide emission is seen as a key measure of environmental damage. During fermentation the yeast metabolises the sugars in the wort to produce a combination of alcohol and carbon dioxide. The impression may erroneously be given that the brewing industry is a net generator of carbon dioxide as a result. In reality, carbon dioxide evolution through that route is simply part of the natural carbon cycle:

- The amount of carbon dioxide released during fermentation is roughly a quarter of the amount absorbed from the atmosphere through photosynthesis by the growing grain.

- Photosynthesis by the growing grain releases oxygen back into the atmosphere.

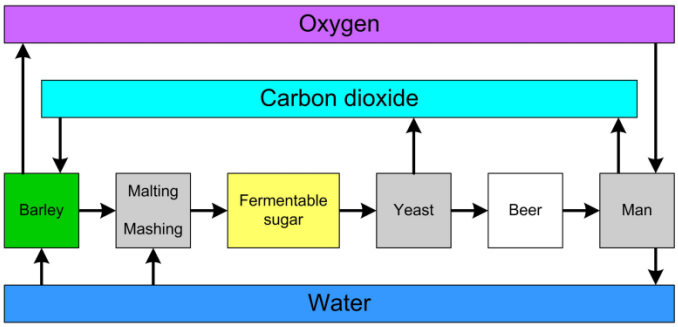


Basic carbon cycle

However, note that carbon dioxide is also released back into the atmosphere through human metabolism, including the alcohol and residual sugars in beer.

Other organic residues such as spent grains, trub and yeast also release CO_2 when they are microbiologically degraded. These activities are of course out of the direct control of the brewer, though he may be able to influence the quantities of waste, and the way in which they are treated.

Carbon dioxide cycle relating to the brewing process



Carbon dioxide derived from the fermentation process is increasingly recovered in the brewery for use in the process and product. The carbon dioxide emitted at the start of fermentation is mixed with air, is uneconomic to recover, and is therefore vented to atmosphere. Carbon dioxide recovery becomes viable when the gas reaches a predetermined purity level (e.g. 99.5%). Generally, the recovery process involves the following stages:

- Collection
- Washing / scrubbing
- Compression
- Deodorising and drying
- Liquefaction and storage

In addition to reducing emissions to the environment, this saves the brewery having to purchase all the gas it requires from outside manufacturers thereby reducing demand on resources and indirect energy use.

Sources of carbon dioxide emissions

The real source of carbon dioxide emissions in the brewing industry is the combustion of fossil fuels – either at the brewery itself for steam raising, or for the generation of the electricity used by the brewery. There is therefore a need for continuing improvement in the efficiency with which fossil fuels are used, whether through the use of purchased electricity or through the combustion of fuel at the brewery:

- Electricity, as compared with natural gas, gives rise to three times the quantity of carbon dioxide for the same amount of delivered energy.
- Whereas electricity provides only perhaps 25% of the energy requirements of the brewing industry, the generation of electricity creates almost 50% of carbon dioxide emissions.
- Where available, natural gas generally provides perhaps 66% of the total energy requirement but creates only 40% of carbon dioxide emissions.

Fossil fuels are of course used for all vehicular movements of materials to and from the brewery, adding to the total CO_2 produced during beer production.

Agricultural operations such as planting, harvesting and use of fertilisers, the transport and drying of barley, and the malting process also have an impact on the carbon emissions of the total brewing process.

Other gases
Other gases including sulphur dioxide, hydrogen sulphide, oxides of nitrogen, possibly partially burned fuel and particulates may also be emitted to the atmosphere if the control of the burners is inadequate. These emissions are also subject to controls and may require use of scrubbers etc. to clean up flue gas prior to discharge.

20.2 Conservation

Principal energy consuming activities in a brewery

Within the brewing industry the main energy usage will vary between breweries (large, small, old, modern), with product (beer, lager), with the mix of package type (cask, keg, returnable bottle, non-returnable bottle, can) and with location (ambient air temperature and water temperature).

The following are some illustrative examples:

Thermal Energy	%
Brewhouse	20 to 50
Packaging	25 to 30
Utilities	15 to 20
Admin, space heating	Up to 10

Electricity consumption	%
Refrigeration	30 to 40
Packaging	15 to 35
Compressed air	10
Brewhouse	5 to 10
Boilerhouse	5
Other	15 to 35

Typical energy reduction strategies
The energy used in brewing where it interfaces with the processes takes the form of heat (steam and hot water) and power (electricity). The heat energy is normally generated on site in boilers using primary fuels such as gas, oil or coal. Electricity on the other hand is usually purchased from national grids, even though some breweries generate a proportion in-house.

The approach to achieving savings in the use of energy can be categorised under the following headings:

- Process technologies
- Horizontal technologies
- Overall energy management

Process technologies
Process technologies relate to the use and treatment of the materials themselves, principally malt, water and hops in a way specific to brewing. Energy savings can be achieved by the adoption of Best Available Techniques (BAT) which are widely disseminated within the brewing industry. Examples of processes which require high energy inputs where much work has been carried out might include:

- Mashing
- Wort boiling
- Wort cooling
- Hot water management
- Fermentation
- Pasteurisation

Horizontal technologies
Horizontal technologies (with demonstrable Best Available Techniques) can invariably be applied across many industries. Examples include:

- Steam raising
- Refrigeration
- Compressed air
- Utility pipework distribution systems and insulation
- Combined heat and power
- Electric motors and drives
- Biomass solutions as alternative energy sources

Overall energy management
A number of well proven techniques can be employed in the effort to reduce energy use:

(1) Analysis of energy use and implementation of a monitoring and targeting (M & T) system

This is the fundamental energy management technique that must always be implemented first. It ensures that all energy usage is monitored on a regular basis.

The key is the installation of strategically positioned effective metering to provide reliable data. Best practice is to develop the energy metering to allow the transfer of measured energy costs into the user cost centres with a comparison of usages against calculated standards, any variance being reported.

The energy data provided by the monitoring and targeting system must be disseminated inside the brewery. This is of prime importance, in conjunction with awareness training, to motivate the staff to save energy and allow them to participate and improve the efficiency of the equipment.

(2) Targeted investigation and action plan

Here an investigation is initiated to look at an area (or areas) of high energy usage or known inefficiency. For a generalised approach the highest users of energy would be targeted first (adopting the Pareto principle).

Examples for high levels of thermal energy usage are mashing and lautering, wort boiling, CIP and pasteurisation / sterilisation.

Examples for electricity are refrigeration, compressed air, pumps and conveyor systems.

Examples for effluent are trub, tank bottoms, returnable packaging container cleaning, detergents & sterilants used in CIP.

The key stages in the investigation process are:

- Audit the process
- Produce findings
- Evaluate findings
- Produce action plan
- Make modification / investment
- Re-evaluate process performance
- Assess energy saving and financial implications

This technique can be developed into one of continuous improvement:

- Evaluate against standard / benchmark
- Assess options
- Make change
- Re-evaluate
- Monitor improvement
- Etc.

(3) Pinch analysis and pinch technology

Introduced in the mid-1980s, pinch analysis is a methodology for minimizing energy consumption of industrial processes by calculating thermodynamically feasible *energy targets* (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and process operating conditions.

Pinch technology proceeds in two steps:

- In the first step, the process data is represented graphically as a set of energy flows in the process, as a function of heat load against temperature to determine the minimum energy consumption a process should use to meet its specific production requirements. Composite curves are created considering all the streams within the process that require cooling as "hot" lines and all the streams that require heating as "cold" lines. The point of closest approach between the hot and cold composite curves is the pinch point (or just pinch) with a hot stream pinch temperature and a cold stream pinch temperature. This is where the design is most constrained.

- In the second step of the pinch technology analysis, aspects that can be improved are studied from the perspective of energy conservation, operational costs and new plant capital cost. Finally the heat exchange network is improved and optimised.

By finding the pinch point and starting the design there, energy targets can be achieved using heat exchangers to recover heat from the hot to the cold streams in two separate systems, one for temperatures above pinch temperatures and one for temperatures below pinch temperatures.

The concept is designed applicable for both new breweries or for retrofit situations. In its widest application it can take account of all the energy flows on a site and identify projects that look attractive on their own or inappropriate when considered in a wider context.

(4) Feasibility studies into alternative technologies

In addition to the energy saving techniques described above, it may be appropriate from time to time to carry out feasibility studies into alternative technologies which may lead to strategic capital investment. Examples of such technologies might be:

- Combined heat and power
- Wind power
- Photovoltaic cells for electrical generation
- Solar panels for thermal energy
- Generation of methane from biomass (anaerobic digesters)
- Burning of biomass, including spent grains to produce heat and power (steam and / or electricity).

Specific examples

Specific examples of methods of reducing energy consumption include:-

- Movement sensors to control lighting
- High efficiency motors
- Variable speed drives to optimise pump outputs and reduce starting loads
- Good design of process pipework and pumps to minimise pressures and excess flow rates
- Automatic shutdown / restart for computer systems
- Building insulation
- Maximising refrigerant temperatures
- Wort kettle vapour heat recovery
- Condensate recovery
- Light weight bottles and cans.

Principal water consuming activities

See section 18.2 for more detail. There are three distinct purposes:

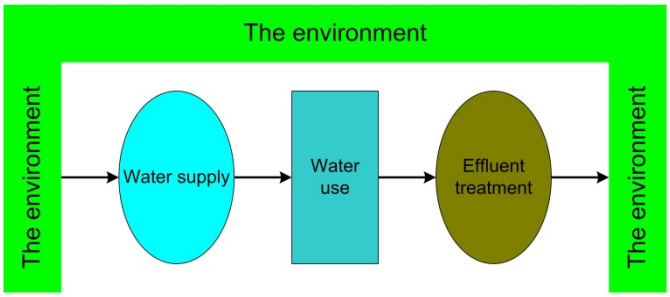
- Product (brewing) water (liquor) - for the production of the beer itself
- Process water - for cleaning brewery plant, washing beer packages before filling, cooling and heating
- Service water - for boilers, utility cooling towers, general cleaning water

Typical water conservation strategies

Access to a sustainable water supply is critical to the brewery as one of the key raw materials. Quality and availability are of major significance. It could, perhaps a little cynically, be said that breweries "borrow" water from the environment:

- treat it as needed
- use it once (mostly)
- treat it again
- throw it away

This can be represented as the "Water Supply Chain"



Surveys of breweries have shown that the ratio of volumes of water consumption to production varies from 3:1 to 20:1. The adjudged minimum ratio of consumption, allowing for unavoidable losses, is approximately 1.4:1. In practice, however, the minimum consumption is regarded as being in the range 2.5:1 to 5:1 depending on the operations carried out by the particular brewery.

Strategies to conserve water are, not surprisingly, very similar to those to conserve energy (see Section 20.2). The adoption of Process and Horizontal Technologies incorporating Best Available Techniques (BAT) is essential in seeking step-wise reductions in water use.

As described in the section on energy reduction, similar approaches can be adopted:

- Analysis of water use and implementation of a monitoring and targeting (M & T) system
- Targeted investigation and action plan
- Feasibility studies into alternative technologies

An example of a well proven staged approach to improve water management is detailed below:

- Produce mass balance
  - Start with survey of water use across brewery
  - Include all water use – product, process, and services
  - Aim to account for > 80% of water use
- Construct simple model
  - Build simple network model based on information known (flows, concentrations) to identify areas of inaccuracy
  - Resample critical nodes to improve accountability to 90 to 95%
- Reduce Waste

  Focus on poor housekeeping to reduce wastage
  - routine inspection for leaks
  - prevention of losses from taps, triggers by fitting flow restrictors
  - or shut-off valves
- Improve Management
  - Examine CIP programmes to ensure the water is being used effectively
  - Examine operations of keg washers, bottle washers and all small pack pasteurisers to prevent unnecessary wastage of water
  - Examine utilities (cooling systems, water purification, boiler operation) to check for inefficient water usage
- Identify Reuse or Recycling Options
  - Using network model, identify opportunities for water reuse and water recycling
  - Identify minimum economic water consumption for site
- Generate Strategic Vision
  - Incorporate new plant, expansions, discharge consent levels (new plant will be designed for minimum economic water use)
  - Identify new minimum economic water consumption for site
- Improvement Plan
  - Identify steps to implement water management strategy and
  - Prepare economic cases
  - Implement water reuse and recycle improvements

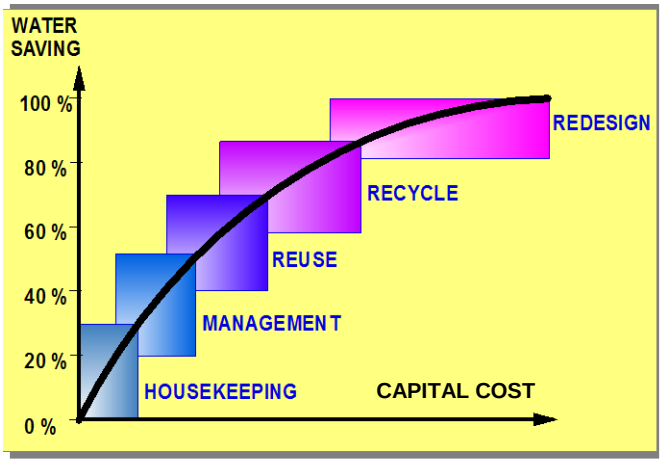
It is generally accepted that full savings cannot be achieved in one step. There is often merit in starting with the cheapest and most cost effective.

Typical savings may then build up in the following way:

- Reduction in uncontrolled use (housekeeping) **20 to 30%**

- Improved control (management) **20 to 30%**
- Water reuse **10 to 20%**
- Water recycling **10 to 20%**
- Design improvements **10 to 20%**

Diagrammatically this staged approach might be represented as shown:



Specific Water Conservation Measures

Management of water usage can be improved by adopting good practices, a number of which are detailed below:

Water Use	Wastage	Conservation
Product water	Excessive drainings from the mash/lauter tun.	Measure and control the volumes of water used. Change from lauter tun to mash filter. Recover 'last runnings' and reuse
	Excessive evaporation from wort boiling.	Optimise mash and sparge water volumes.
	Hot water recovery system (primarily from wort cooling) out of balance leading to an excess of hot water going to drain.	Ensure processes are well designed and tightly controlled.
	Excessive flushing or chasing following product transfer.	Ensure processes are well designed and tightly controlled.
Process water	Excessive flushes/rinses during plant cleaning.	Automate and optimise CIP systems to reduce rinse times / cycles / improve interface accuracy. Recover and re-use water and chemicals (where possible). Use several short rinses rather than one long rinse.
	Unnecessary dumping of detergent.	Optimise pre-rinses. Remove CO_2 from FVs if using caustic detergent. Use sacrificial detergent cycles for heavy soil removal. Use acid detergents where possible to avoid CO_2 degradation.
	Tunnel pasteuriser water.	Recover, cool and treat with biocides prior to re-use.
Service water	Loss of steam condensate. Leaks.	Plant maintenance.
	Over use of hoses for hygiene cleaning.	Training and supervision to ensure careful use. Use of triggers and restrictors on hoses. Use of high pressure, low volume cleaning systems where appropriate.
	Water used for cooling.	All cooling water recovered and re-used in the most energy efficient way.

20.3 Waste

Principal waste generating activities in a brewery

Brewing operations achieve good conversion rates of raw materials into product. As well as beer products, reasonable quantities of surplus yeast and spent brewer's grain are produced during the process. These are considered "co-products" rather than waste streams since in the main they are sold on for animal feeds or, in the case of yeast, often for human consumption.

Most of the solid waste produced by a brewery site is generated from packaging materials whilst most of the non-solid waste primarily arises from the production and processing of beer.

Note: Brewery effluent is covered separately in Section 18 and packaging waste is covered in the GCP syllabus in Section 19.

In general, waste streams comprise:

- process wastes specific to brewing and packaging.
- residues of raw materials and product removed from wastewaters by drainage catch pots and screens.
- dust and particulate caught in abatement equipment, for example, bag filters.
- product wastage.
- boiler plant ash (for coal).

Most of the waste produced by breweries can potentially be recycled into the process, reworked for animal feed, used in land spreading or is suitable for waste treatment methods such as composting.

The following table gives a list of the main waste streams arising at a brewery, where they originate from and how they are disposed of and the usual storage containers used within a brewery for temporary storage.

Description of waste	Disposal route	Storage container
Malt screenings	Landfill / animal feed	Bag
Spent grains	Animal feed / burning directly or after digestion for methane production for burning	Bulk silos (appropriate to brewery size)
Trub	With spent grains	
Yeast	Foodstuffs e.g. animal feed, Marmite, medical, e.g. yeast supplements	Bulk slurry / pressed cake
Yeast	Effluent	Direct to sewer
Waste beer or fob	Recycle as soil improver specialist effluent treatment	Bunded tank
Processing aid bags and fines (e.g. kieselguhr)	Landfill	Bag / skip
Spent processing aid slurry (e.g. kieselguhr)	Recycle as soil improver / landfill	Bunded tank
Cans	Recycle	Skip
Glass	Recycle	Skip
Cardboard	Recycle	Cage / skip / compacted bundle
Polythene	Recycle	Cage / skip / compacted bundle
Effluent screenings (biodegradable)	Landfill	Skip
Building waste (from minor civil works)	Landfill	Skip
Wood (non-returnable or damaged pallets)	Recycle	Skip
Stainless steel (processing pipework modifications etc.)	Recycle	Skip
Metal waste (e.g. aluminium, steel from plant modifications)	Recycle	Skip
Office paper waste	Recycle	Bin
Spent oil	Recycle	Bunded tank
Ink	Specialist disposal	Bin
Fluorescent tubes	Specialist disposal	Specialist storage containers
Special cleaning chemicals	Specialist disposal	Bunded drum / IBC
Fibreglass (insulation)	Specialist disposal	Covered skip

Issues for waste disposal

Waste disposal and duty of care

Where waste disposal is controlled by taxation, levy or simply cost, systems to monitor waste are required. Information recorded would normally include:

- quantity
- nature
- origin (where relevant)
- destination
- mode of transport
- treatment method

Increasingly breweries have service agreements with specialist, licensed waste disposal contractors for the provision of comprehensive waste disposal and management services, covering but not limited to:

- Reducing the amount of waste produced.
- Making the most efficient use of waste.
- Selecting waste disposal options which minimise the risk of environmental pollution and harm to human health.
- Employing the hierarchy of waste reduction, reuse, recycle, recover and dispose.

The duty of care responsibility ensures that waste management is audited throughout the process including confirmation of the final location of the waste disposal or recycling.

The pressure on landfill
Land fill is increasingly discouraged for a number of key reasons:

- Climate change caused by landfill gas from biodegradable waste.
- Loss of resources.
- Constraints on areas suitable for landfill sites.
- Loss of recyclable components of waste landfilled.

Many countries have introduced a landfill tax which is a form of tax that is applied to increase the cost of landfill. The tax is typically levied in units of currency per unit of weight or volume. The reasons for landfill taxes can vary from country to country.

They may include:

- a means of raising general revenues.
- to generate funds for solid waste planning and inspection programmes.
- for long-term mitigation of environmental impacts related to disposal.
- a means of inhibiting disposal by raising the cost in comparison to preferable alternatives (in the same manner as an excise or “sin tax”).

Waste storage and segregation
Best practice dictates that, where possible:

- wastes are stored as close as possible to the point of generation
- waste storage areas are clearly marked
- skips are specified appropriate for the duty
- skips are stored on hard standing areas
- wastes are segregated wherever possible to maximise the opportunity to reuse or recycle.

From time to time “special” wastes may arise which have particular storage requirements. Typical examples may include:

- Surplus cleaning chemicals (typically strong alkaline or acid products).
- Residual chemicals left in portable storage containers (thus prohibiting return of the containers to the supplier).
- Chemicals that have been identified as waste due to quality aspects (e.g. contaminated, out of specification or simply substances no longer used)
- Flammable wastes
- Wastes sensitive to heat or light.

In such cases, some or all of the techniques listed below may be applied to minimise potential environmental impacts:

- The storage area is covered.
- The storage area is fully enclosed (to contain spillage).
- There is protection against flood or fire-water ingress.
- There is an air extraction system.
- Drainage liquids are contained, treated and tested prior to release.
- There is fire protection.

When considering temporary waste storage areas, factors considered when assessing a storage risk assessment would normally include:

- Compatible containers are used for the substances being stored and that these containers are of robust construction to ensure that spills and leaks do not occur
- Adequate warning notices, barrier tape and signage are in place forbidding access to the storage area
- Storage areas are not located adjacent to surface water drains and, where possible, these areas are located within bonded or kerbed areas
- Individual containers are labelled to identify their contents and volume
- The period of storage is minimised so that all waste containers are removed from the area as soon as possible
- No other wastes are stored in the temporary area other than those that have been agreed.

Strategies to minimize waste and encourage recycling

Waste recovery or disposal
In terms of environmental impact there is increasing pressure to improve the utilisation of materials, water, energy and minimise waste. The hierarchy of waste reduction applies:

- Reuse
- Recycle
- Recover
- Dispose

Increasingly governments and other regulating authorities are “encouraging” the recovery of waste unless it is technically or economically impossible to do so.

In considering options for waste management, many countries now encourage a process known as “Best Practical Environmental Option (BPEO) Assessment”. As the term suggests the assessment is designed to demonstrate that the chosen routes for recovery or disposal represent the best environmental option considering, but not limited to, the following:

- All avenues for recycling back into the process or reworked for another process.
- composting
- animal feed
- land spreading where the brewery:
  - Can demonstrate that it represents a genuine agricultural benefit or ecological improvement.
  - Has identified the pollutants likely to present from a knowledge of the process, materials of construction, corrosive / erosion mechanisms, materials related to maintenance, for both normal and abnormal operation, validated as necessary by appropriate analytical techniques.
  - Has identified the ultimate fate of the substances in the soil.

Qualifications

The General Certificate in Brewing (GCB)

Examination Syllabus 2016

IBD	**Syllabus Section 1: Beer types; their raw materials; sweet wort production.**

Ref.	Topics (No. of questions to be answered = **5**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
1.1	Definition of beer and types of beer	1. A generic, non-legalistic definition of beer in terms of its typical ingredients and methods of production. 2. Characteristics which differentiate lagers, ales and stouts.
1.2	Barley and malt	1. The role of barley as a principal source of starch. 2. The special attributes of barley for malting. 3. The significant changes that occur when the barley grain is malted. 4. The principal constituents of malt. 5. The key malt parameters of degree of modification, extract content, moisture content, extract, and colour. 6. The selection of malt for beer type and mash conversion method. 7. Pre-acceptance checks at malt intake.
1.3	Adjuncts and coloured malts	1. Reasons for the use of adjuncts. 2. Types of adjunct and their method of use. 3. Typical usage rate as proportion of the grist. 4. Types of coloured malt and their characteristics. 5. Typical uses of coloured malts.
1.4	Mash conversion	1. The respective roles of the amylases and protease, the effect of temperature, pH and time on their activity. 2. Temperature and wort viscosity. 3. The influence of the ionic composition (hardness salts) of mashing water in the mash and on beer flavour. 4. The starch test. 5. Key sweet wort parameters of fermentability. [See also section 10.2]
1.5	Grist composition and extract performance	1. The extract yield of raw materials. 2. Malt and adjunct quantities required for a grist from theoretical material extract values. 3. Calculation of brewhouse extract performance.

IBD	**Syllabus section 2: Sweet wort production (methods and plant).**

Ref.	Topics (No. of questions to be answered =**4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
2.1	Brewing process overview	1. The sequence of events from raw material intake to the preparation of beer for packaging and the typical points of use for raw materials and process aids. 2. A representation of the brewing process as a flow diagram.
2.2	Brewhouse plant operation – grain handling and milling	1. The purposes of milling with respect to the type of mashing / mash separation systems available. 2. The significance of grist fraction analysis (expressed in quantitative terms) and its assessment. 3. The operating principles and diagrammatic representation of malt mills and their associated malt preparation equipment.[i] 4. Grain handling and safety.
2.3	Brewhouse plant operation – mashing and conversion	1. The operating principles and diagrammatic representation of mashing/mash conversion systems, including the cereal-cooking vessel, if appropriate.[ii] 2. An awareness of the operational differences between isothermal (mash-tun) conversion and temperature programmed conversion vessels. 3. A quantitative knowledge of typical times, temperatures and grist ratios used in the conversion vessel. 4. The qualitative assessment of starch conversion.
2.4	Brewhouse plant operation – wort separation	1. The operating principles and diagrammatic representation of wort separation devices. 2. The significance of cycle times for brewhouse capacity. 3. Methods for the assessment of wort clarity / solids content. 4. Use of spent grains as a co-product.

IBD	**Syllabus section 3: Wort boiling.**

Ref.	Topics (No. of questions to be answered = **4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
3.1	Wort boiling	1. The purposes of boiling: sterilization, stabilization of enzyme action, evaporation, coagulation and precipitation of protein (trub formation) and beer haze precursors, flavour development other than hop bitterness [see 3.2 below], and colour formation. 2. Factors affecting the effectiveness of wort boiling. 3. The purposes of liquid adjunct additions to the wort kettle.
3.2	Wort boiling systems	1. The operating principles and diagrammatic representation of wort boiling systems.[iii] 2. Typical boiling times and hop addition practices.
3.3	The nature of hop bitterness	1. The nature and origins of hops and hop products. 2. Isomerization and how hops or hop products yield bitterness during wort boiling. 3. How alternative or supplementary additions of hop bitterness are made at later stages in brewing.
3.4	Hop calculations	1. How bitterness value of beer is expressed and typical values. 2. The bitterness potential of hops. 3. Calculation of required hop addition rates to achieve a given beer bitterness. 4. Calculation of hop utilization.

IBD	**Syllabus section 4: Wort clarification, cooling and oxygenation (aeration).**

Ref.	Topics (No. of questions to be answered = **3**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
4.1	Wort clarification	1. The potential of trub constituents, spent hops, etc in boiled wort to detract from beer quality. 2. Methods available for kettle fining. 3. Methods available for the removal of trub and / or spent hops. 4. The basic operating principles and diagrammatic representation of wort clarification devices.[iv]
4.2	Wort cooling	1. The purposes of wort cooling. 2. The effect of cooling on wort constituents. 3. Methods available for cooling wort. 4. The basic operating principles and diagrammatic representation of a type of wort cooler.
4.3	Wort oxygenation / aeration	1. The purpose of wort oxygenation. [See also section 5.2] 2. Methods of wort oxygenation / aeration and values achievable. 3. The basic operating principles and diagrammatic representation of wort oxygenation systems, including the air or oxygen sterilization equipment.

IBD	**Syllabus section 5: The basic principles of yeast fermentation.**

Ref.	Topics (No. of questions to be answered = **3**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
5.1	Brewing yeast	1. Basic understanding of the relationship of brewing yeast to other living organisms. 2. The differences between the bottom-fermenting/cropping (lager) and top-fermenting/cropping (ale) yeasts in terms of their practical brewing applications. 3. The microscopic appearance of a yeast cell. 4. The nutritional requirements of yeast derived from wort including trace elements.
5.2	Fermentation theory	1. The production of alcohol and carbon dioxide from wort sugars by yeast.[v] 2. Key flavour compounds produced by yeast. 3. The main phases and events of brewery fermentations. 4. The significance of the presence and absence of dissolved oxygen. 5. Other factors affecting the phases of fermentations. 6. Other factors affecting the speed of fermentations.

IBD	**Syllabus section 6: Fermentation practice.**

Ref.	Topics (No. of questions to be answered = **2**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
6.1	Fermentation vessels and their control	1. General knowledge of the basic requirements of brewery fermentation vessels**.** 2. The operating principles and diagrammatic representation of fermentation vessels, the reasons for their choice, their advantages and disadvantages.[vi] 3. Reasons for temperature control. 4. Procedures for the temperature control of fermentations**.**
6.2	Health and Safety	1. The evolution of carbon dioxide from fermentations. 2. The hazards associated with carbon dioxide. 3. The monitoring / checking of atmospheres for safe working including a quantitative knowledge of exposure limits. 4. Safe working practices for fermenting room operations.

	Syllabus section 7: Yeast management.

Ref.	Topics (No. of questions to be answered = **2**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
7.1	Yeast propagation, storage and cropping	1. The reasons for yeast propagation. 2. Basic procedures for producing a pure culture yeast. 3. The operating principles and diagrammatic representation of a yeast culture plant. 4. The purposes and timing of yeast cropping. 5. The operating principles and diagrammatic representation of systems for the removal of yeast from a completed fermentation.[vii] 6. The monitoring of yeast growth. 7. The conditions necessary for the storage of either pressed or liquid yeast.
7.2	Yeast selection, treatment and pitching	1. The selection of yeast for pitching. 2. Characteristics of healthy pitching yeast and the assessment of yeast condition and purity. 3. Acid washing procedures including a quantitative knowledge of time, temperature and pH ranges. 4. Yeast pitching methods. 5. The calculation of yeast pitching rate for a fermentation.

IBD	**Syllabus section 8: Beer maturation and cold storage.**

Ref.	Topics (No. of questions to be answered = **2**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
8.1	Warm maturation	1. The purposes of warm maturation. 2. Typical times and temperatures appropriate to different beer types. 3. Typical changes affecting beer flavour. [See also section 11.1]
8.2	Cold storage and stabilization	1. The purposes of cold storage. 2. Typical times and temperatures appropriate to different beer types. 3. The general principles of stabilization. 4. Haze precursors and their removal. 5. The nature and action of the principal types of stabilizing agents.

	Syllabus section 9A: Bright beer preparation (for Mainstream Brewery option A).

Ref.	Topics (No. of questions to be answered = **4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
9.1	Chilling and carbonation	1. The operating principles and diagrammatic representation of a beer chiller (plate or shell and tube). 2. The purposes of carbonation. 3. Typical dissolved CO_2 levels for different beer types. 4. Location in process of carbonation points. 5. The operating principles and diagrammatic representation of a carbonator.
9.2	Filtration	1. The purposes of filtration. 2. The principles of filtration – sieving, depth and absorption. 3. The origin, nature and preparation of filter aid – diatomaceous earth (kieselguhr) and perlite. 4. The operating principles of a rough beer filter. 5. The types of beer sterilizing (polishing) filters available. 6. Representation of the sequence of events in a typical filtration system as a flow diagram. 7. Awareness of alternative rough beer filter types – cross flow filtration. 8. The health and safety hazards associated with filter aids. Personal protection equipment (PPE) and the plant safety features necessary.
9.3	High gravity dilution	1. Reasons for brewing at high gravity. 2. Typical quality specifications for water to be used for dilution (quantitative data required). 3. Deaerated water production. 4. The calculation of blending quantities.
9.4	Considerations for other package types	1. Cask conditioned beer.

IBD	**Syllabus section 9B: Cask and craft beer preparation and packaging (for Craft option B)**

Ref.	Topics (No. of questions to be answered = **4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
9.1	Cask beer preparation for racking	1. The purposes of cask conditioning. 2. The importance of controlling yeast concentration / count, and typical values. 3. Conditioning and the necessity for residual fermentable sugars, with typical values.
9.2	Clarification of cask beer	1. Clarification of cask conditioned beer. 2. The origin, nature and action of auxiliary and isinglass finings. 3. Storage of prepared finings prior to use. 4. Typical addition rates and procedures for finings. 5. The operating principles and diagrammatic representation of finings addition equipment. 6. Reasons for the addition of priming sugar. 7. Types of hops and hop products used for cask beer. 8. Reasons for addition of hops or hop products.
9.3	Cask washing and racking	1. Preparation and inspection of casks for racking. 2. Cask filling practice, typical temperature specifications, filling volume control. 3. Conditioning in cask including storage temperature, the use of soft/hard pegs and shelf life.
9.4	Craft beer preparation for packaging	1. The operating principles and diagrammatic representation of a beer chiller (plate or shell and tube). 2. The purposes of filtration. 3. The principles of filtration – sieving, depth and absorption. 4. The operating principles of a small scale rough beer filter. 5. The types of small scale beer sterilizing (polishing) filters available. 6. The health and safety hazards associated with filter aids. Personal protection equipment (PPE) and the plant safety features necessary.
9.5	Considerations for other package types	1. Bottled conditioned beer.

	Syllabus section 10: Beer quality and process control.

Ref.	Topics (No. of questions to be answered = **2**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
		Key parameters examined in this section are: *Original gravity (OG), present gravity (PG), alcohol content (ABV %), pH, colour, haze, bitterness, head retention or foam stability, dissolved oxygen, dissolved carbon dioxide.*
10.1	Process specifications	1. The variable nature of the natural ingredients of beer. 2. The purpose of process specifications. 3. Effects of the brewing process on the final product value of these key parameters.
10.2	Process control	1. The principles of monitoring and adjustment to achieve product consistency. 2. Simple statistical quality control procedures. 3. The concepts of tolerance and range for specification parameter values. 4. Typical specifications which differentiate beer types. 5. Typical process specification ranges, especially those requiring periodic adjustment to achieve product consistency [see Ref 10.1.above]. 6. Typical applications for in-line and on-line instruments for process control.

	Syllabus section 11: Beer quality – Flavour.

Ref.	Topics (No. of questions to be answered = **2**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
11.1	Terminology, evaluation and tasting during brewing operations	1. The reasons for adopting industry standard descriptors for flavour. 2. The flavour wheel. 3. The more commonly used components. 4. Taste training procedures. 5. The three-glass test – statistical significance rating. 6. Flavour profiling. 7. Trueness to type panel tasting. 8. Common faults / contamination by contact materials that may be detected by tasting during brewing operations.

IBD	**Syllabus section 12: Beer quality – Dissolved oxygen.**

Ref.	Topics (No. of questions to be answered = **2**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
12.1	The spoilage of beer by oxygen	1. Sensitivity of beer to small amounts of oxygen – typical levels causing spoilage. 2. Basic mechanism for haze formation. 3. Oxidation reactions to form flavour compounds. 4. Typical flavour descriptors for oxidation effects. 5. Oxygen as a constituent of air. 6. Typical points of exposure of beer to air.
12.2	Monitoring and control of dissolved oxygen levels	1. Key control points. 2. The significance of sampling time. 3. Operating a dissolved oxygen meter. 4. Typical specified maximum levels. 5. Good practices to avoid oxygen pick-up. 6. The use of sulphur dioxide, ascorbic acid and potassium meta-bisulphite (KMS).

	Syllabus section 13: Beer quality – Microbiological contamination.

Ref.	Topics (No. of questions to be answered = **4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
13.1	Beer spoilage	1. Anaerobic growth. 2. Typical spoilage products formed. 3. Effects on beer quality of microbiological spoilage, appropriate use of flavour descriptors to describe spoilage. [See also section 12.1]
13.2	Spoilage organisms	1. The principal categories of spoilage organisms: *Pediococcus, Lactobacillus, Acetobacter, Obesumbacterium*, *Megasphaera,* wild yeasts: - their common points of contamination in the brewery.
13.3	Detection and monitoring	1. Methods of sampling for microbiological testing. 2. Sampling points.
13.4	Control	1. Practices to protect against infection. 2. Measures to combat known sources of contamination.

	Syllabus section 14: Quality management.

Ref.	Topics (No. of questions to be answered = **3**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
14.1	Features of a quality system	1. The key features of a quality system*:* - written specifications - written procedures - monitoring of performance - corrective actions - auditing - regular reviews for improvement
14.2	Roles responsibilities and benefits	1. The impact of individual actions on product and service quality. 2. The control of documentation. 3. The maintenance of conformity. 4. The business benefits of an effective quality management system.
14.3	Product safety	1. The control of product safety - Hazard Analysis Critical Control Point (HCCP). 2. The importance of traceability for product recall.

	Syllabus topic 15: Plant Cleaning - Detergents and sterilizing agents.

Ref.	Topics (No. of questions to be answered = **4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
15.1	Detergents	1. Types of detergent (alkali, acid and neutral). 2. The constituents of detergents. 3. The individual functions of the constituents. 4. Criteria for choice of detergent for an application. 5. Considerations for the use of hot detergent cleaning.
15.2	Sterilants	1. Types of sterilant as defined by the active agent. 2. Criteria for choice of sterilant for an application. 3. The effect of sterilant residues on beer quality.
15.3	Heat sterilization	1. Uses of steam and hot water as a sterilant. 2. Time and temperature.
15.4	Safety	1. The hazards associated with chemical cleaning and sterilizing agents. 2. Good practices for the storage of chemicals. 3. Use of personal protective equipment (PPE). 4. Procedures in case of accidental spillage or discharge of chemicals.

	Syllabus section 16: Plant cleaning - Cleaning in-place (CIP) and general cleaning.

Ref.	Topics (No. of questions to be answered = **4**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
16.1	Types of CIP systems	1. The general differences between single use and recovery systems – advantages and disadvantages. 2. The types of cleaning head used and reasons for their choice. 3. The operating principles and diagrammatic representation of CIP systems.
16.2	CIP cleaning cycles	1. Typical cleaning programs and cycle times. 2. The function of each of the cleaning cycle stages. 3. Quality assurance of cleaning operations.
16.3	CIP plant design hygiene considerations	1. Design features that minimize soil accumulation in brewery vessels and pipelines. 2. Design features that facilitate vessel and pipeline cleaning using a CIP system. 3. Design features which promote a hygienic working environment.
16.4	General plant cleaning	1. Cleaning plant surfaces, walls and floors. 2. The constituents of foam cleaning agents. 3. The use of foaming systems.

IBD	**Syllabus section 17: Engineering basics and maintenance.**

Ref.	Topics (No. of questions to be answered = **3**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
17.1	Engineering basics	This subsection is not examined.
17.2	Brewing Plan Maintenance – Approaches and Tasks	1. The key business reasons for an effective maintenance system. 2. The features, advantages, disadvantages and applications of: - no maintenance - breakdown maintenance - preventive maintenance - predictive maintenance 3. The contribution of maintenance tasks to plant safety, reliability, quality, economics and environmental impact. 4. Familiarity with key maintenance tasks: - mechanical - electrical - calibration - inspection - condition monitoring - cleaning of plant - health and safety 5. Maintenance planning and record keeping. 6. Autonomous maintenance.
17.3	Performance improvements	1. The key features of the following performance improvement systems: - Reliability Centred Maintenance (RCM) - Total Productive Maintenance (TPM) - Workplace Organisation (5S)

IBD	**Syllabus section 18: Utilities – Water and effluent in brewing.**

Ref.	Topics (No. of questions to be answered = **3**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
18.1	Water sources and treatments	1. Characteristics and quality of an ideal brewery water supply. 2. Sources of water for a brewery. 3. The basic principles and diagrammatic representation treatment plants for: - water filtration - water sterilization - water softening / deionization - water de-aeration
18.2	Water types and uses	1. Differentiation and typical uses of: - de-aerated water - process water - service water 2. *Legionella* in cooling water and service water and the health risks associated with the micro-organism. 3. Points at which water is introduced into the process and the special water quality needed at these points.
18.3	Sources of effluent and its measurement	1. The nature and characteristics of effluent from principal brewery operations. 2. The components of effluent quality: - volume - suspended solids (SS) - chemical oxygen demand (COD) - biological oxygen demand (BOD) - pH - temperature

IBD	**Syllabus Section 19: Utilities – Process gases.**

Ref.	Topics (No. of questions to be answered = **1**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
19.1	Properties, applications and safety	1. The essential properties and quality of compressed air and oxygen for use as process gases. 2. The essential properties of carbon dioxide and nitrogen for use as process gases. 3. The practice and benefits of carbon dioxide collection. [viii] 4. The significance of inertness. 5. Typical uses for process gases. 6. The economic importance of leak prevention. 7. Safe handling and storage of compressed gas cylinders. 8. Safety hazards associated with storage of liquid gases and their distribution in high-pressure mains.

IBD	**Syllabus section 20: Brewing and the environment.**

Ref.	Topics (No. of questions to be answered = **3**)	Candidates should understand and be able to explain and describe in simple terms, or demonstrate familiarity with:
20.1	Sustainability and climate change	1. The concept of a sustainable industry. 2. The role of carbon dioxide – the carbon cycle. 3. Sources of carbon dioxide emissions.
20.2	Conservation	1. Principal energy consuming activities in a brewery. 2. Typical energy reduction strategies. 3. Principal water consuming activities. 4. Typical water conservation strategies.
20.3	Waste	1. Principal waste generating activities in a brewery. 2. Issues for waste disposal. 3. Strategies to minimize waste and encourage recycling.

Notes for examiners and tutors.

[i] Options include 4, 5, and 6 –roll dry mills, wet mill, and hammer mill. The malt preparation equipment, appropriate to the type of mill, includes screens, destoners, weighers and malt conditioning devices. Candidates should be aware of the different operating principles of a dry roll mill, a wet mill and a hammer mill, and their association with the type of mash separation device used.

[ii] For decoction systems incorporating a cereal cooker, familiarity with the plant configuration is expected but the quantitative data required is restricted to the temperatures achieved in the main conversion vessel. Details of volumes and cereal temperatures are not required.

[iii] Candidates may be aware of other systems, but questions will only be asked on 'traditional' wort boiling systems.

[iv] Wort filtration systems using filter aids are not required.

[v] Knowledge of metabolic pathways and yeast enzymes is not required.

[vi] No knowledge of continuous fermentation systems is required.

[vii] Includes green beer centrifuging, though questions will not be asked about the centrifuges themselves.

[viii] No knowledge of the collection and compression plant is required. Candidates should be aware of the economic and environmental arguments for collection [see section 20] and the operational procedures for the timing of collection.