All in good condition...



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Conditioning is the process post primary fermentation to achieve the correct appearance, flavour and carbonation profile of the beer. This overview looks at some of the key aspects of conditioning techniques.

by ***Shane McNamara***

Any process applied after the primary fermentation should be considered to fall under the conditioning process (the beer can even be conditioned in 'package'). There are several key areas which fall under the heading of conditioning; these are maturation, stabilisation, clarification and carbonation. Each of these processes has several purposes and is often not linear. Conditioning has no strict step-by-step process and every brewery will carry out conditioning according to its own particular method. This overview is divided into the three primary purposes of conditioning: flavour, appearance and carbonation.

Flavour

Maturation

Post fermentation there is often a maturation period. Why should a brewer want to mature their brew in the first place? In maturation, there are several flavour objectives; these being to remove underside flavours, promote desired flavours and/or introduce new flavours.

Removal of undesirable flavours

Without placing limitations on the vast potential of undesirable flavours that may be found in post primary fermented beer ('Green Beer'), the following three are some of the foremost contributors to be removed or minimised:

- Acetaldehyde (green apples): Coming from the aldehyde group (carbonyl compounds), acetaldehyde is an intermediate product during alcoholic fermentation with a flavour threshold of >10mg/l. In green beer, approximate levels of 20-40mg/l may be found, while finished levels are often 2-10mg/l - levels >35mg/l should be avoided, although the style of beer will impact upon how apparent the flavour becomes. Acetaldehyde is increased in green beer by rapid fermentation, high fermentation temperature, over pitching yeast, fermentation under high pressure, reduced wort aeration or infection. Acetaldehyde may also be a result of oxidation of ethanol and the decarboxylation of pyruvate; therefore poor oxygen control will also contribute to levels. It is often also present in older cask beer (>3 days) on dispense, the dispense system introduces air into the cask as a part of the process causing oxygen pickup. Acetaldehyde can be removed by a vigorous secondary fermentation, warmer maturation stage (it has a boiling temperature of 20.2°C), sufficient wort aeration, increased yeast concentration in maturation stage and limiting oxygen pickup.
- Hydrogen sulphide (rotten eggs): During the fermentation process yeast can generate sulphur containing compounds from both organic (cysteine) and inorganic (sulphate) constituents. One of the most common sulphur compounds is the very volatile hydrogen sulphide, with the smell often disappearing after a few minutes. Much is removed by the stripping effect of CO_2 during late fermentation and early warm

'Green Beer' and the heavy hangover.....

There is an interesting tie-in with a German 'beer fable' on beer maturation. There is a belief by some that if a beer is not matured you will have a heavy hangover the next day after drinking it. Apart from German lager breweries, probably trying to create a marketable difference for their beer, there is potential for this fable to be true. But how?

Acetaldehyde is the answer. Acetaldehyde has been found to be one of the key drivers behind your heavy next-day hangover. When alcohol in the liver is metabolized by alcohol dehydrogenase, it creates acetaldehyde (which is 10-30 times more toxic). The acetaldehyde is then further metabolized by acetaldehyde dehydrogenase and glutathione forming the non-toxic acetate. It is an efficient process, minimising the time of acetaldehyde in the body, however, the body stores only limited amounts of glutathione and it quickly runs out – causing a build-up of acetaldehyde while the liver creates more glutathione.

'Green beer' or beer that has not gone through a maturation period may have indecently high levels of acetaldehyde. Consuming such a beer may place a strain on the capability of your liver to deal with it, as it not only has to deal with the high acetaldehyde levels in the beer – but more will be created as it begins to metabolize the alcohol. Therefore your hangover may be worse the next day. Maturation will most often ensure very low levels of acetaldehyde – thus the German lager makers may be on to something and it may not be just a fable.

maturation (where the levels of carbon dioxide dissolved in the beer will increase, especially if the beer is held under pressure) – particularly in shallow vessels. The other way to control formation is to limit the amount of sulphate found in the brewing water, although this is done prior to the conditioning process.

- Diacetyl (butterscotch): With a flavour threshold around 0.1mg/l diacetyl is often considered undesirable, although minimal levels may contribute positively to palate fullness. Diacetyl is formed by both bacteria (*Pediococcus*) and yeast (*Saccharomyces*). Yeast produces diacetyl by excreting α-acetolactic acid; this acid chemically decarboxylates and oxidises to yield diacetyl. Yeast then removes diacetyl by enzymically reducing it to α-acetoin and 2,3-butanediol (both of which have lower flavour thresholds). The amount of excretion is influenced by high levels of yeast assimilable nitrogen (YAN), rapid fermentation, heavily flocculent strains, premature separation of yeast, premature chilling of the fermentation vessel and poor physiological condition of the yeast. The removal is aided by metabolically active yeast, adequate levels of dissolved oxygen, high yeast concentrations and warm temperatures. Diacetyl removal can be attained post fermentation, although the removal rate is slower (due to the often lower yeast count and cooler temperatures), more expensive and reduces the processing time. Modern techniques in speeding up this process include the use of immobilised yeast, genetic modification of yeast strains in order to reduce their diacetyl formation potential and the addition of the enzyme α-acetolactate decarboxylase to the cold wort prior to fermentation. Ideally, minimal diacetyl levels are left after the primary fermentation. Brewers should promote the maximum α-acetolactate levels as early as possible; the resultant diacetyl may then be rapidly reduced due to the presence of a high suspended yeast count. A warm temperature step often forms part of a fermentation, whereby the initial fermentation is warm followed by a cold maturation, or towards the end of a cold fermentation the beer is allowed to free-rise in temperature for 48 hours then brought back down to a cold temperature ('Diacetyl Rest').

Promote desired flavours

During the process of removing undesirable flavours, desirable ones are also going through biochemical changes. One of the key factors as highlighted above is the presence of yeast. Maturation in the presence of yeast will often cause the breakdown of cell constituents and the excretion of compounds (amino acids, peptides, nucleotides, proteinases and phosphates) into beer and potentially improve the palate and mouth feel. Other changes include those mentioned before such as reductions in diacetyl and acetaldehydes, changes in sulphur compounds and volatile fatty acids levels. Fatty acids are often needed in certain amounts to give a fuller mouth feel.

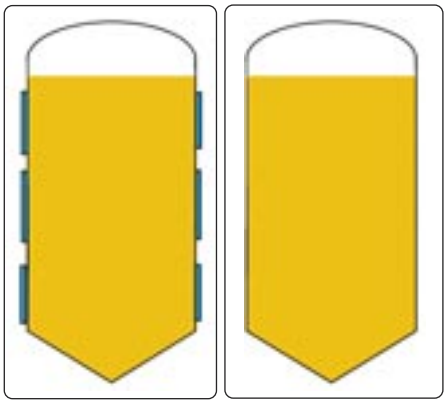


Oak maturation tanks at the Rodenbach Brewery.

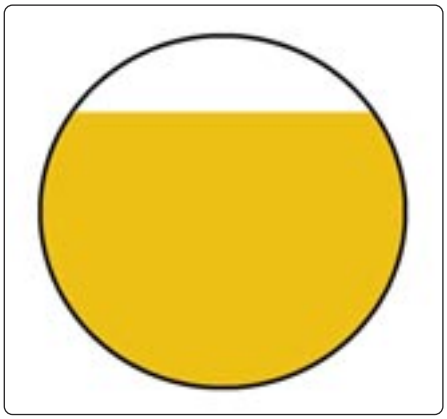
Introduce new flavours

The introduction of new flavours, not already developed by those currently in the beer, are potentially limitless. New flavours can be influenced by the introduction of new botanicals and/or the choice of materials of construction for the maturation vessel. Below are some of the common flavours that may be introduced during maturation:

- Dry-hopping: the act of adding hops post wort production process. Hops are added during fermentation, maturation or in package (and now even at the point of dispense). It has been shown that the most effective utilisation of dry hopping for aroma intensity is post fermentation during maturation (high levels of yeast and $C0_2$ stripping have been shown to remove aroma compounds). Dry hopping rates can range from 5g/hl to 375g/hl. Temperature and times for dry hopping vary – warmer temperatures and increased length of time promote increased extraction of hop oils. Pellets are used due to their improved efficiency in imparting flavour; while whole hop cones may be used they cause higher beer losses due to their material and beer absorption. Post fermentation aroma hop products (hop oil extracts) may also be added to enhance the aroma of the beer – these products are not considered dry hopping; although they are often used in conjunction with dry hopping to ensure consistency.
- Bitterness: the use of bittering agents (isomerized hop extract) to correct the IBU or create a brand difference is a common technique to create consistency.
- Blending: By mixing two beers of the same kind a brewer may be able to create consistency in the beer without having to adjust the beer. Blending may also be a part of the production process by mixing different ages of beer together, such as in the production of Gueuze.
- Dilution; high-gravity brewing is an effective way to increase yield from the brewhouse. Post fermentation during the conditioning process the level of alcohol is often adjusted with deaerated treated water.



Left: Vertical maturation tanks with side wall and cone cooling. Each tank is individually cooled. Right: Vertical maturation tanks in a cold room. The temperature is controlled by the room; often used when oak maturation is in use.



Horizontal maturation tanks in a cold room.



Horizontal maturation tanks within a cold room

This will lighten the flavour and colour.

- Candy and fruit; Belgian candy and fruits such as raspberries and cherries are well established in brewing, being added during maturation to create certain styles of beer including framboise and lambics. The fruit may introduce wild yeast and bacteria if not treated by freezing or boiling; it may also introduce a pectin haze in the beer.
- Yeast and bacteria: Yeast (*Saccharomyces*) in fermenting wort is often added during maturation as a krausening technique for the purposes of carbonation and flavour consistency. Other such yeasts (*Brettanomyces*) and bacteria (*Lactobacillus*) may be added during maturation to introduce new flavours to the beer – most notably sourness.
- Barrel flavour: Maturation in wooden vessels does not necessarily mean the introduction of oak/wooden flavour. However, they may be used in such a way to introduce the flavours of the previous beverage aged in it (bourbon, whiskey or rum) sherry or the wooden material itself (most commonly oak); it can be added as woodchips.

Maturation vessel – type and orientation

Depending on the brewery and/or beer style, a brewer may mature beer in the order of minutes (continuous), days, weeks, months or even years.

There are several different types of maturation systems. A single-tank system which ferments and matures in the same tank (commonly called a 'unitank' system), dual tank in which beer is transferred from the primary fermenter to a maturation tank, or a third vessel could be used if using warm and cold maturation. Construction materials are commonly either stainless-steel or oak. Maturation tanks can be cooled by external jackets or they can be sited in a cold room as illustrated.

The horizontal system takes advantage by reducing the time in which it would take a particle to reach the bottom of a vessel by minimising the distance.

Maturation temperature techniques

Over the years a wide diversity in the temperature regimes for the maturation process has developed. With most breweries implementing a mixture of warm and cold maturation techniques, it is not done according to whether they are making an ale or a lager - but what is the intended profile of the beer. At the completion of primary fermentation, beer contains:

- Unpleasant flavour compounds.
- Haze particles in suspension.
- Haze formation precursors.
- Low carbonation levels.

To ensure an active maturation period with yeast, the beer is sometimes 'primed' (with the addition of sugar) or 'krausened' (adding fermenting wort) to provide a good secondary fermentation. The rate of removal is temperature dependent, being much higher at higher temperatures and higher yeast concentrations. Because the rate is dependent on the temperature and viable yeast cell concentration, maturation often takes place before chilling of the beer and sedimentation of the yeast. Improvements in beer flavour are achieved in two stages, warm maturation and cold maturation. Cold maturation takes place at 0°C or below and beer flavour continues to improve as the unpleasant compounds are often reduced, though the rate of reduction is very much slower than at warm maturation temperatures. 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.
- Process aid reaction time – to allow sufficient time for reactions and settlement to take place.

Beers such as ales are held typically at -1°C for one to seven days. Shorter residence times are most easily obtainable when using beer stabilisers such as silica gels or PVPP. Beers such as lagers are held at -1°C for four days up to a number of 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.

Appearance

Clarification and Stabilisation

Colour

Beer that is out of the desired colour specification of the brewer is often adjusted by blending it with another beer or with the use of malt-based extracts (dilution with water will also impact the colour).

Clarification and Stabilisation

If a beer is intended to have a haze, then this process is often passed. However, where the desired profile is clarity, those factors creating the haze must be removed. There are several key factors that will influence the current visible haze in the beer:

- Yeast and bacteria.
- Hops.
- Proteins.
- Polyphenols.

Chilling beer

The raw materials of beer contain protein material and tannins, which can combine together to form particles large enough to create hazes. This haze is termed non-biological 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 stabilised beer is stored in a cold place because the remaining haze particles are less soluble at low temperature. Beer haze is formed during cold storage due to the combination of proteins and polyphenols and often 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 will sediment out as long as they are heavier than 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 most common hazes are derived from protein fractions (polypeptides). The polypeptide material may be polymerised to form visible haze particles by polyphenols or tannins. 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 (iron and copper) link oxidised polyphenols and polypeptides. Thus the build-up of visible haze particles is particularly rapid in the presence of dissolved oxygen and/or heavy metals. The beer may be subject to a succession of alternating periods of chilling and warming, with the beer becoming hazy and then clearing again. Gradually, however, the haze formation ceases to be reversible – 'permanent haze' (visibly stable at 20°C). Not all hazes are associated with protein and tannins. Other hazes include those from calcium oxalate, carbohydrates, filter powders and collapsed foam particles.

The simplest but lengthiest way of clarifying beer is to allow suspended matter to settle. Stoke's Law:

$$\frac{Vg = d^2 (p - l) g}{18 \mu}$$

Stoke's Law describes the rate at which a sphere falls through a liquid and indicates the parameters that influence the rate of beer clarification. The factors the brewer can influence that will have the greatest effect on time to clarify are the particle diameter, the gravitational force and the distance in which the particle needs to travel.

Centrifuge

Centrifugation represents an effective rapid sedimentation option (using Stoke's Law by increasing the gravitational pull). 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 average path length under the applied gravitational force. Disc Bowl Centrifuges are the most commonly used for beer treatment, as they promote maximum beer yield, minimum oxygen pick-up, temperature increase and damage to yeast cells. This machine contains several disc plates on which the deposited particles collect and then slide into the solids holding area. There are three potential drawbacks to the use of centrifuges:

- Beer may be subject to shearing.
- Beer temperature rises.
- Often insufficient to completely clarify the beer.

Auxiliary and isinglass finings

Finings act via an electrostatic effect resulting in the increasing size of haze particles – thus using Stoke's law to sediment more rapidly. Brewers often use two different kinds of finings – auxiliary and isinglass finings. Their use will rapidly clarify a beer containing:

- 0.5 to 2.0 million viable yeast cells per ml; and
- 1 to 3 million non-biological particles (mainly protein) per ml.



GSI 75 separator for medium-sized operations to 250hL per hour. Courtesy GEA Westfalia

Fining is intended for sedimentation and will not remove colloidal hazes caused by metallic contamination, bacterial infections or dead yeast cells.

Auxiliary finings usually comprise of alginates (carrageenan) or silicates and are negatively charged. They therefore flocculate certain protein and other materials which are positively charged. They are usually used in combination (but added separately from) Isinglass finings – if they were added together the charges would cancel each other. Auxiliary finings bind to positively-charged protein and act by effectively increasing the mass of flocs binding to Isinglass.

Isinglass composes of pure collagen, sourced from swim bladders of fish. Collagen has mainly a positive electrostatic charge and binds to yeast cell walls (negatively charged) and some protein molecules (due to negatively charged amino acid side chains). The protein molecules are long, triple helix, containing a high percentage of the amino acid (glycine), but more importantly, the amino acids (proline and hydroxyproline) which are positively charged. Beers vary greatly in their reactions; the flocculence of the yeast strain involved, the protein/polyphenol concentration, pH, calcium and magnesium content can all have an influence. Finings may be added to hasten sedimentation in the tank or it may be used in packaging such as casks to ensure a clear bright beer is served at dispense (primarily because casks undergo a secondary fermentation in package leaving residual yeast).

Silica gels

An absorbent (acidified sodium silicate) to 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 as they are removed during filtration or tank sedimentation.

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. Hydrogels can also be used as filter body feed. Dosing rates are typically 40-60g/hl on transfer from FV to MV, and 40-100g/hl when added at filtration.

Papain

Papain (a proteolytic enzyme) theoretically acts by reducing protein molecular size and so increase polypeptide solubility. It is dosed typically at 2-6ml/hl of beer. It may be added on transfer from FV to MV though this is not common nowadays as it is less effective than adding later at filtration. 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 pasteurisation and the enzyme will be retained in the final product and also might adversely affect head forming proteins. It is liable to remain active if the beer has been subjected to less than 20 PUs.

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 can be used throughout the process – cold storage tank, transfer to filter and trapped on a filter mixed



A 2m Seitz Orion plate and frame filter, showing manual filter cake removal.



Photo: iStock/CarvalhoBrazil

with the kieselguhr or used in a stand-alone recovery filter. Dosing rates are typically 10-40 g/hl on transfer from FV to MV, and 20-70 g/hl when added at filtration as a single use material or recovered material. When intending to remove both protein and polyphenol the beer may be treated with silica hydrogel and PVPP, resulting in a beer which is haze stable up to 18 months.

Filtration

There are three types of filtration:

- Rough: remove all the particles that would make the beer cloudy.
- Polishing: remove all yeast and bacteria so that the beer is sterile.
- Stabilising: prevent non-biological haze formation in package.

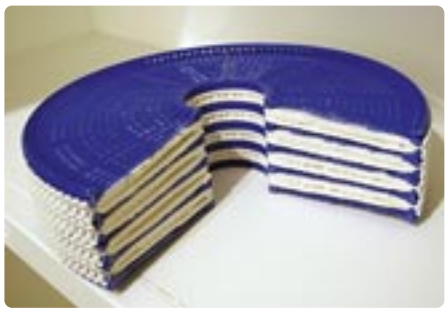
The loading onto the filter (particles in suspension) can be reduced by:

- Long maturation times to allow good clarification by settling.
- Centrifuging.
- Finings to increase sedimentation.

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. Traditionally, beer has been filtered using filter aids (kieselguhr), though more recently regenerative filter aids have been developed. These reduce powder purchase costs, waste disposal and improve safety aspects, although at the additional cost of a regeneration process. There are four common types of filter that are used:

- Plate and frame filter.
- Horizontal leaf filter.
- Candle filter.
- Cross flow filtration.



A cut-away lenticular filter.

Polishing filtration

Lenticular filters utilises the depth filter effect with a fine pore filter sheet or a fine filter powder to trap very small particles including micro-organisms and are often used for polishing by larger brewers while microbreweries use them as the main form of primary filtration. In all cases, these filters are used because:

- Limited or no powder requirements.
- Simple operation.
- Flexible sizes.

The filter sheets are of modular design, allowing for varying volumes or flow rates. With a plate filter used to house and support the filter sheets in high volume/flow rates. The filter sheets are supported and separated by polypropylene support discs.

Stabilising filtration

Stabilising agents such as silica gel and PVPP can be dosed into the beer on its way to the filter. Alternatively, filter sheets can be impregnated with a stabilising agent. 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 can be trapped; 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 (usually followed by final polish or membrane filtration). This type of filter traps micro-organisms between the narrow fibres of the sheet. There is also an electrostatic effect whereby the microbes adhere to the fibres.
- A membrane filter (sheets or fine tubes) uses a very fine sieve where particles are held back on the surface of the membrane which has extremely small pores in it (0.45µ).
- Cross flow filtration is capable of producing beer which is considered almost sterile.

There are several benefits of using a sterile filter system over the alternative, pasteurisation. There is a significantly reduced risk of developing (aged beer) papery and cardboard flavours that result from pasteurisation. High levels of dissolved oxygen or excessive numbers of pasteurisation units (PUs) will also negatively impact the flavour.

Pasteurisation

$$PU = t \times 1.393^{(T-60)}$$

The other option for microbiological stabilisation is that of pasteurisation. The process is a heat treatment where the beer is subject to extreme temperatures (55-72°C) for a short time. This is accomplished in two ways, 'flash pasteurisation' where he beer is passed through a heat-exchanger (60°C) type system for around 30 seconds, or in packaging where the can or bottle passes through a series of chambers spraying hot water (70°C) for around 15 minutes and later cooled, 'tunnel pasteurisation'. Industry standard is approximately 15PUs.



A flash pasteurisation unit. Photo:GEA Brewery Systems.

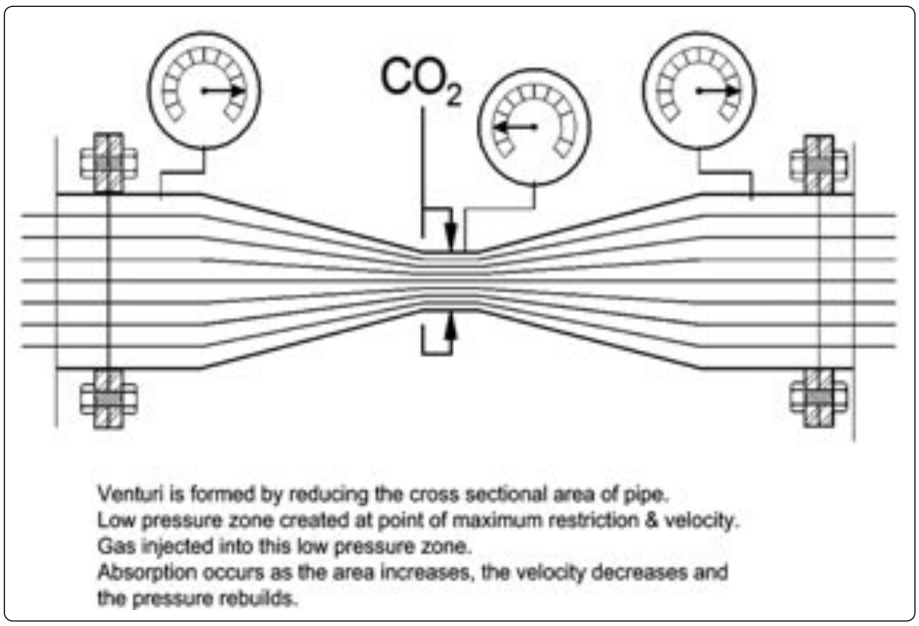


Diagram of a venture injector.

Carbonation

Carbonation

Just as we have seen a multitude of maturation, clarification and stabilisation techniques. Below are some of the common carbonation techniques.

Forced carbonation

One of the most common techniques for carbonation is the method of forcing gas into the beer. This allows the exact amount of $C0_2$ and/or N_2 desired in the beer. There are three common forced techniques:

- Venturi: The gas is injected in the low pressure zone in the venturi and the gas dissolves because of the increase in the pipe diameter, the pressure increases and the flow velocity reduces.
- Sintered diffusers (candle): The effect of passing gas through the candle immersed in a liquid is the formation of a very many fine bubbles as fine bubbles are more readily absorbed.
- Nozzles: 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.

Forced carbonation may be carried out at several stages during the process after maturation. Most common is for it to be carried out prior to filtration. Many brewers carbonate on transfer 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 CO_2 levels at the infeed to a packaging machine. In selecting the point in the process at which to inject gas, consideration is given to the factors that promote gas absorption; low temperature and high pressure.

Package conditioning

Often referred to as bottle or cask conditioned, the principles are relatively simple, however, there are several ways to achieve the intended result.

- Fully-fermented beer is placed into the package (bottle, cask or keg) a fermentable source (sugar or malt extract) is then added into the product, if the beer is unfiltered then there may be no requirement for yeast to be added. If the yeast is removed then the same strain of yeast as the primary may be used or alternatively specialised bottling yeast is added.
- Beer is chilled within 1-1.5° Plato of final gravity in the primary fermenter. The beer is then transferred to the package with yeast and allowed finish fermenting, creating carbonation. This method is most often used in cask beers, however, it may result in under-attenuated beer, high off-flavours (diacetyl) or exploding casks if stopped too early.
- In a mixture of techniques, fermenting beer (krausen) may also be added prior to bottling to provide secondary fermentation and carbonation.

Bunging (Spunding)

A method that uses the residual sugar in the beer to carbonate the beer – similar to the second method described above. Towards the end of fermentation where the gravity is within 1-1.5° Plato, the tank valves are closed to create a sealed container (but with pressure relief/safety valves incorporated). Henry's gas laws will impact rates: gases ($C0_2$/N_2), temperature, time, and headspace. A priming sugar could be added at this stage to increase the carbonation. The potential drawback is that under-attenuated beer may be created due to the pressure stopping the fermentation, if applied too early, by causing stress on the yeast. ■

Krausening

A very common method in German lager production, the carbonation is achieved by adding up to 25% of wort from an active fermentation during maturation in a closed tank. The resulting vigorous secondary fermentation will not only help increase carbonation to the desired levels, but aid in the removal of off flavours and beer flavour consistency.

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