Module 3

3.6 Packaging

3.6.1 Small packaging
3.6.2 Large packaging
ABSTRACT

In this Module 3.6 (Packaging) of the Diploma in Brewing, we will examine processes of packaging into can, bottle and keg.

Firstly, we take a look at packaging into small pack, with particular emphasis on the design and operation of a filler to fill bottles and cans.

Secondly, packaging into large pack - with emphasis on cleaning and filling of kegs.

These are followed with a review of the basic plant features and control procedures from filtration through to filled containers.

Finally, we will look at sterile filtration and the theory of pasteurisation, with emphasis on the basic operations of both a flash and tunnel pasteuriser.

LEARNING OUTCOMES

On completion of this section you should be able to:

1. Understand the basic principles of design and operation of a filler to fill bottles and cans.

2. Understand the basic principles of design and operation of a filler to fill kegs.

3. Understand the basic plant features and control procedures from filtration through to filled containers.

4. Understand the basic principles of pasteurisation and the additional precautions required for a sterile operation from filtration through to sealed container

PREREQUISITE UNDERSTANDING

Basic scientific knowledge and terminology.
### 3.6.1 SMALL PACKAGING

#### Introduction

A small pack operation refers to the packaging of any container from which you can directly consume a product.

Small pack is produced in glass, metal or plastic. A very small quantity has recently been produced in Tetra Pak type board but the beer contains very little gas.

In order to produce package beer in its basic form, a filler will be required. The oldest form of filler was the siphon type and the label was applied by hand. Siphon filling was manual in operation and a bulb was used to create the flow into the bottle. The beer at this stage was not carbonated but was primed to allow a secondary fermentation to take place in the bottle, so giving it the condition required for serving. The prime had to be calculated against the time of the year to give perfect and naturally conditioned beer over a 14 to 21 day period. It is still possible to purchase naturally conditioned beer but it will now be bottled using a counter-pressure filler on a more modern line.

As filling techniques became faster and more sophisticated, inevitably other machinery which supplied and took containers to and from the filler also became necessary and had to keep pace. For example, basket type pasteurisers were introduced for bright beer that required a good shelf life when exported. This could no longer be a batch process for the sake of speed, and this then led to the development of in-package or tunnel pasteurisers as we know them today.

With the introduction of non-returnable bottles, cans and now PET bottles, lines become faster and more complex. A typical line would be made up of the following:

#### DEPALLETISER

These can operate at high or low level. High level depalletisers are faster as the cycle time is shorter. Depalletising can be for crates, cartons or bulk delivery. For crates each layer on the pallet is normally clamped by a head and lifted onto a table from where they are driven onto a conveyer and orientated with the narrow edge leading in preparation for de-crating. The motion can either be reciprocal between columns or robotic. For bulk delivery of new bottles, each layer can be clamped using a pneumatic cushion and lifted onto a conveyer, or more commonly swept at high level onto a conveyer. Cans are swept at high level onto a conveyer.

#### UNPACKER

During this operation bottles are removed from crates or cartons. This can be done using a reciprocal, continuous (vertical or horizontal) or robotic machine. The heads can be fitted with clamps or inflatable tulips (so called as they are tulip-shaped). The tulips fit over the bottles and are inflated in order that they may be lifted. In some cases automatic bottle sorters are installed after the unpacker.

#### WASHER/RINSER

**Bottle washer**

On a returnable bottle line a bottle washer is necessary to remove:
- Dirt
- Dust
- Product Residue
- Insects
- Moulds
- Bacteria
- Yeast
- Odours
- Labels/Foils

And then present a shiny clean bottle to the filler for filling.

A washer follows the same rules of cleaning, as does any other cleaning operation. The effectiveness of cleaning relates directly to the use of time, detergency, temperature and mechanical action. In simple terms the more you have of any of these elements the better the cleaning operation will be.

Over the years the environment and the
economy have been a major factor in washer design through re-use of rinse water, recovered caustic, and better jetting which, in turn, gives less degradation of caustic and shorter soak time.

**Soak Time** It has been proven that the best length of time for soaking is 24 minutes. However, most washers today only have a soak time of half this. This is possible due to much better self-cleaning jets, and better label removal systems that are available today.

**Detergents** Alkaline cleaning agents with additives are commonly used. The cheapest and most effective agent is sodium hydroxide; however it is only really good at digesting the protein matter so additives are required for wetting (surfactant), dispersing matter, capturing the magnesium and calcium ions before they form a scale (sequestrient) and finally anti-foam properties.

The normal strength of caustic is 1.5 to 3% and this will depend on the bottle condition. It is also normal to raise the caustic strength when removing aluminium foils in order to prevent the formation of aluminium oxide scale which is virtually impossible to remove once formed. The additives used to give the sequestering and surfactant properties could include polyphosphates, EDTA, glucanate and phosphonate. It is also possible to use a polymer type additive to prevent further damage to scuffed bottles and also to protect ACL (Applied Ceramic Labels) during washing.

Most washers today use proprietary detergents. These are ready mixed detergents which are dosed into the washer automatically when the caustic level is detected by a conductivity probe to have dropped. It would be cheaper to add caustic and additives separately as the caustic is used at a faster rate than the additives. However, this gives handling problems so is not favoured.

Caustic has a useful life, it will in the end become ‘tired’. It is not uncommon to keep using the same caustic for some considerable time and be fooled into thinking that the strength is equivalent to the alkalinity measured. This is unfortunately not so, due to the increase of carbonates in solution. The following general rules should be noted:

- Approx 150,000 bottles can be washed in each cubic meter of detergent limited by the rise in carbonates in solution
- This can be measured against a carbonate concentration which should not exceed 0.7%
- Laboratory titration usually only measures alkalinity. This should be corrected for carbonates. (Carbonate can be taken out with barium chloride as barium carbonate is insoluble)
- For this reason conductivity probes, which measure alkalinity, are never entirely accurate and need to be calibrated during the life of the caustic solution

**Temperature.** The temperature must high enough to destroy bacteria. Also the cleaning effect is better at a higher temperature. The Arrenhius Rate Law relates to the rate of reaction and demonstrates that the effectiveness of the detergent will approximately double for every 10 °Celsius rise in temperature. The optimum temperature for cleaning would be between 80 and 85 °C as dirt starts to saponify (become oily) above this temperature, and there is also a danger that some plastic bottle pockets or inserts may distort with higher temperatures.

Thermal shock must also be taken into account. If there is a sudden rise in temperature greater than 35 °C or sudden drop greater than 25 °C this could cause breakage. In this climate the most common incidence would be to leave bottles outside in the freezing temperatures during winter and then to load them directly into the washer.

**Mechanical Action** This is produced by high pressure jetting of internal and external surfaces. The effectiveness of jetting in modern bottle washers has enabled a substantial reduction in soak time. Label extraction is also substantially better allowing labels to be more easily removed.
Label Extraction
Earlier models with a label extraction system used an Archimedes screw installed vertically to extract and drain labels before they were discharged.

This was extremely messy and has now been replaced by a simpler and more effective unit which strips the labels off each bottle and deposits the labels onto a moving mattress or a rotating drum. The labels are then pulped before removal. The label and glue quality is important. The label needs to stay in one piece up to the point of removal. As a result they need to be printed on wet strength paper. A label, without this quality, would break up to tiny fibres which would then be impossible to remove from the washer with the label extraction unit.

Factors Affecting Label Removal
A major part of bottle washing is in the effective removal of labels. The following summarises the key elements to their efficient removal.

- Correct concentration, condition and temperature of detergent
- Type of paper used – wet strength necessary
- Glue type – casein is best. Some synthetic glues will not be penetrated by caustic
- Paper finish – printing inks, varnishes and foil all slow down penetration of detergent
- Condition and storage time for bottles returned
- Design of bottle pocket
- Shape of label – oval slightly easier to extract
- Strength of detergent pump and design of label extraction system

Quality Control
With the advent of Total Quality Management (TQM) most of the day to day quality checks are carried out on the shop floor as a routine. Some checks are now carried out automatically, and caustic strength checks would certainly fall into this category. Even with this, however, manual checking is still advised but only needs to be carried out once per shift. The following checks are advised:

- Caustic strength in main detergent tank should be checked automatically (normal) and/or each shift manually
- Titrate with phenolphthalein to check for caustic carry over every two hours
- Washed bottles should be checked visually for brightness and clarity on a daily basis
- For sterile packaging; a sample needs to be taken from the final rinse tank daily and this checked for any microbiological infection. Sterilant levels also need to be checked.

Bottle and can rinsers
With the popularity of one trip bottles (NRBs or Non-Returnable Bottles), bottle rinsers are now more commonly used. Rinsers have always been used on canning lines and PET lines. In Germany, where a returnable policy is established, PET bottles can be returnable and will be washed using a conventional bottle washer operated at a lower temperature (maximum 65°C), so as not to distort the plastic. Sniffers (utilising gas chromatography) are also used to inspect the bottles as plastic will absorb nasty odours such as paraffin.

Rinsers can be dry or wet. The most popular glass or PET riner is the rotary type which is ‘blocked’ with the filler. For cans the rinser is linear. The cans pass through a scroll and are inverted rinsed with air, followed by water and are then drained. Rinsing with ionised air only is also possible, and is becoming popular for cans. However, good interlocks are necessary for air rinsers in order to ensure that the operation is continually effective, as none of the ‘tell-tale’ droplets can be seen. One of the benefits will be that there is no water contamination. Apart from being a quality benefit, the quantity of water trapped in a water rinser could be in the order of 1.5-2.0ml, so air rinsing could also have a surprising effect on the waste. This needs to be adjusted for. Other benefits are being able to carry out automatic can inspection after the rinser without having to worry about droplets of water in the can giving false rejects and also the obvious one of using less water.
FILLER
See section Filling Principles for Carbonated Beverages to follow.

PASTEURISER
See section Pasteurisation Theory to follow.

LABELLER
Labelling is a key part of the packaging process – without any form of label, legislation cannot be met and it would be impossible to sell the product!

Metal containers are normally pre-labelled but still need to be coded with the best before date and, if applicable, the batch code. Bottles need to be labelled by the packager.

The key reasons for labelling are:
• Sell the product
• Inform the customer
• Comply with legislation
• Protect the integrity of the package

Labelling comes in many forms. The main forms of labelling for bottles (unless mentioned) are:
• Paper (pre-cut or reel-fed)
• Metallised paper (pre-cut or reel-fed)
• Embossed paper
• Foil
• PSL(Pressure Sensitive Label) or Self Adhesive Label(OPP - Orientated Polypropylene or paper)
• Wraparound plastic labels (OPP)
• Sleeves (PVC or PET), also for cans
• ACL (Applied Ceramic Label using silk screen printing)
• Acid Etching for glass only
• Thermal transfers for glass only

For glass bottles the most popular form of labelling is with the pre-cut paper label. This is fast, proven and cheap. In order to move the product up-market the label could be metallised (has a coating of aluminium) perhaps a foil added to the neck of the bottle for a smart finish.

The foil is, however, not as popular as it was, as drinks are frequently consumed from the neck of the bottle. The glue never completely dries so this will affect flavour of the beer when the crown is removed and the neck of the bottle is placed in the mouth.

The premium look is now often created through using a PSL label which has a clear look giving the impression that the image has somehow been baked on to the bottle. This gives the product an extremely smart image. However, it is expensive so is usually associated with products sold at a premium price, such as premium beers and Flavoured Alcoholic Beverages (FABs). The application is normally with a specialised labeller, but interestingly, label and glue manufacturers have recently been developing products that allow the application of a PSL using a wet glue labeller.

PACKER
The crating operation is identical to the crating operation, only in reverse.

MULTIPLE PACKAGING
Packaging into crates is only suitable for the returnable trade. Multiple packaging, which is often referred to as soft packaging, is suitable for one trip packaging, and is extensively used to sell the product. Kraft and corrugated board, and plastic are used in different forms in order to collate the containers into 4s 6s 8s 10s 12s 15s etc and these in turn are packed into a units of, normally, 24 or 30.

PALLETISER
The reciprocal and robotic palletisers are similar to the depalletisers. High level palletisers will also operate faster. The issue with high level palletisers is being able to feed them faster enough. As a result, twin lane feeds are often used. The pallet is on a lowerator, and as it receives each layer, the pallet moves down to receive the next one. Hydraulic lowerators are faster than their mechanical equivalent but it means digging a hole in the floor to accept the hydraulic cylinder. Low level palletisers require more mechanical effort in order to lift each layer and sweep it onto the top of the pallet.
Typical line flow diagrams would be as follows:

**Returnable bottle line**

**RETURNABLE BOTTLING LINE**

Delivery → Buffer Stock → Depaletiser → Cans → Decanter → Label pulp → Inspect → Rejects

Beer → Filtration → Inspect → Rejects

Treatment → Pasteuriser → Inspect → Rejects

Labels → Labeller → Accept

Crate Accumulation → Palletiser → Pallets → Warehouse

**Non-returnable bottle line**

**NON RETURNABLE LINE**

Delivery → Buffer Stock → Film wrap/layer pads/trays/top boards, etc.

Beverage → Depaletiser → Washer → Filler/capper → Rejects

Inspection → Pasteuriser → Rejects

Flash pasteuriser/sterile filter → Inspect → Rejects

Treatment → Pasteuriser → Rejects

Labels → Labeller → Inspect → Rejects

Board → Collation Unit → Tray/shrink or Carton packer → Pallets, top boards, etc

Pallets → Palleteiser → Board & Shrink

Walhouse

**Canning line**

**CAN LINE Flow Diagram**

Can Delivery → Buffer Stock → Depaletiser → Rejects

Clean Water, Rejects, Palleteer/Strapping

Can Inspection → Rejects

Waste to Drain, Drying, Can End Palleteer & Paper

Filling → Filter/steriliser → Rejects

Full Can Inspection with tagger

Replace → Inspector

Pack → Production

Waste Water

Rejects

Environmental Waste

Hi Cone, Tray, Shrink, Sleeves, No Wristbands

Shrink Packer → Reels, Palleteer, Top Boards, Film
**Filling Principles for Carbonated Beverages**

There are a number of types of filler on the market. However, one principle always applies, and that is carbonated beverages must be filled under pressure in order to keep the gas (carbon dioxide and sometimes nitrogen) in solution. Fillers employing this principal are called barometric or more commonly counter-pressure fillers. Another type of filler would be a vacuum filler which is normally used for wine or spirit filling. Previously, gravity fillers were used, but these do not give such a clean fill.

**Beer filing**

For beer, filling is more difficult than for other carbonated beverages because of two unique qualities:

1. Head retention
2. The damaging effect of oxygen

There are three benefits in filling Carbonated Soft Drinks (CSDs) or Flavoured Alcoholic Beverages (FABs) when compared to beer. Firstly, one can carbonate en-route to the filler; secondly, as there is no fob created during filling, fill height adjustment is much easier; and thirdly, oxygen absorption is not normally a problem.

For beer filling it is necessary to remove oxygen from the container before filling. This is done by pre-evacuating a glass bottle or CO2 flushing a PET bottle or can before filling. Pre-evacuation is carried out by applying a 90% vacuum twice which will give a 99% pure CO2 gas in the bottle before filling. It is possible on electronic fillers to have three pre-evacuations but this is not normally used because:

1. There is a reduction of filling capacity of the filler, and therefore output
2. The gain is only 0.9% CO2 purity which is not really significant

Flushing with CO2, as is the case for PET and cans, will generally give a result above 90% CO2 purity, but it will be lower than that achieved with the pre-evacuation of glass bottles.

When filling beer into glass bottles, therefore, a pre-evacuation or flushing facility will be required. It is also possible to limit oxygen uptake by using a long tube rather than short tube filler.

With a long tube filler, the beer is filled from the bottom of the bottle and then rises gently with only the top surface in contact with the gas space in the bottle.

With a short tube filler, the beer flows down the outside of the tube, and it is then deflected by a spreader rubber fitted to the tube. This directs the flow of beer down the inside sidewall of the bottle. The whole of the surface area of the beer flowing down the side of the bottle is therefore in contact with the gas space during filling.

The following two diagrams illustrate the differences, and demonstrate how the beer is exposed to the gas that it is displacing. It can be seen that with the long tube filler only the top surface of the beer is exposed so, as a result, the oxygen uptake is less than it is with a short tube filler.
The long tube filler shown in this illustration shows the filling of a PET bottle. This assists in reducing the uptake of oxygen because pre-evacuation is not possible with PET.

The popular choice for bottle beer filling is a short tube filler with pre-evacuation, and with double pre-evacuation good oxygen levels can be achieved. There is very little PET bottling, most of it is in returnable or non-returnable glass bottles. Short tube fillers are easier to maintain and tubes and change parts are cheaper. Waste will also be slightly lower as the tube will carry less beer when it is withdrawn from the bottle.

Fillers can be mechanical or electro-pneumatic. The main difference is that, on the mechanical version, the filling cycle is operated by trips and cams which are located at set points around the circumference of the filler. The trips turn the levers on the filling heads, and the cams operate the vacuum and snift valves. So, in order for the filling cycle to complete, the filler must continuously rotate. The fill level is controlled by the length of vent tube (short tube) which returns the gas to the filler bowl. When the beer covers the end of the tube it prevents the return of gas and therefore stops the filling operation.

With the electro-pneumatic version the filling cycle is programmed for each filling head. The filling cycle does not, therefore, depend on the rotation of the filler for the cycle to operate. This is an advantage when the filler stops with bottles on it, as the filling cycle will continue to beer shut off. On the mechanical filler the beer valve can be open and one is dependent on a perfect seal between the valve and bottle to prevent over-fill. The fill level is sensed by a probe and this shuts off the supply of beer to the bottle.

Fillers can also be volumetric. With these fillers the volume beer can be metered via a magnetic flow (magflo) meter or alternatively each head is fitted with a cylinder of a given volume. The volume released by the cylinder is programmed via a float or conductivity probe. A filler designed for volumetric filling does not need a ring bowl for beer, but may well be fed from a constant pressure tank as controlled conditions are required for an accurate and smooth operation. Volumetric fillers are not used for glass bottle filling as levels may differ due to the different content levels for each bottle so giving a ragged appearance on the shelf. Although this should not be the case for
one trip bottles, it will certainly be the case for returnable bottles. Volumetric filling is commonly used for PET due to the elasticity of the bottle and, more recently, for can filling as it easier to programme volumes.

The remaining categories for fillers are sterile and aseptic. The two terms, although similar in meaning, have very different meanings when it comes to filling. Sterile filling is a term used for filling when it is important to ensure there is little or no pick up of infection during filling. This would apply when beer is filled after being flash pasteurised or sterile filtered. Generally a modern standard filler can be used for this type filling, because they are easy to clean, and a disciplined cleaning regime is all that is necessary to ensure good product. The filler may be placed in a guarded area which is kept clean. Aseptic filling is what it means. The filler is enclosed in a bug free environment. This would normally mean a separate room which is fitted with a sterile air filter and the air is changed frequently. The room will kept at a slight positive pressure to ensure no ingress of dirty air.

Beer is quite a robust product due to its alcohol and hop content which both act as antiseptics. However, it needs to be remembered that non-alcoholic beers are not as robust, so tunnel pasteurisation or aseptic filling may have to be considered for products in that category.

The Filling Cycle
Different types of fillers have already been discussed. It is now understood, therefore, that fillers used for beer are counter-pressure fillers and are generally short tube. For glass bottle fillers the air is displaced by CO₂ using pre-evacuation. Vacuum (90%) is normally applied twice leaving 1% air in the bottle. For plastic bottles and cans, the air is flushed out as vacuum would crush these bottles. The container is then pressurised until the pressure is equal to the pressure in the filler bowl; on equalisation, the valve will open allowing the beer to flow down the inner side of the container. As soon as the beer reaches the tip of the vent valve the return gas passage will be blocked so allowing an immediate pressure build up in the bottle which will, in turn, stop the beer flowing.

**Stage 1 and 2 – Double pre-evacuation and counter-pressure**
Stages 3, 4 and 5 – Filling, shut off and snifting
Each filling valve will fill at a slightly different speed. The shut off trip needs to be placed just after the slowest filling valve to avoid ragged filling. The container is then snifted to release the top pressure. This is done via a button valve which rides along a cam which gently pushes the button in and therefore slowly releases the pressure. When the container exits the filler, a jetter (normally hot water), in the case of bottles, is used to excite the beer and expel the air from the headspace with fob. The jetter is set so that the overflow is just taking place as the crown, or any other closure, is placed on top of the bottle.

For cans, fobbing over will not work as the top opening is too large. Also it is not possible (Krones have tried and failed) to close couple a filler with a can seamer. For cans therefore the air is expelled in two stages. Firstly, there is a bubble-breaker which literally bursts the bubbles lying on the surface of the beer in order to release any air that may be trapped. Secondly, while seaming is taking place, gas – normally CO₂ is blown under the lid as seaming takes place. This is known as under-cover gassing.

Filling system:
1. Inert gas
2. Beverage
3. Relief

1. CO₂ gas rinsing
2. Counter-pressure
3. Lowering of filling tube and filling
4. End of filling
5. Close valve and lift tube
Container closing

Bottle Crowning
The crown is still the most popular form of closure for beer. It is both capable of holding the pressure in the container as well as venting gas safely when it is removed prior to consumption. The crowning machine (often called the ‘crowner’) is blocked with the filler and runs in synchronisation with it. The high level crowner hopper dispenses a crown down a chute, through a tube which ensures the correct orientation of the crown, and onto the bottle. The crowning head then applies a vertical load to the crown to ensure that the sealing pad (insert) is compressed between the metal and the glass of the bottle. While this load is maintained, a specially profiled hardened die is forced down over the skirt of the crown creating the seal. The finished diameter of the crown is critical with a tolerance of only 0.6mm (28.7 +/- 0.3mm). Although there are other types of closure such as the Roll on Closure (ROC) this is not covered by the syllabus. Crowners should always be kept clean. Dust build up from the crowns can congeal and effect performance as well as creating a contamination risk. Some fillers have crowners with cleaning in place (CIP) installed. This makes the cleaning operation much more complete.

Crown tolerance is measured using a ‘Go No Go’ gauge. This could be a 3 hole gauge with hole sizes of 28.4mm, 28.7mm and 29.0mm.

![A Double Seam](image)

It should be difficult to pass the 28.4mm gauge over the crown. If it slips over the crown, it is too tight and this could lead to bottle breakage when the crown is removed. If the 29.0mm gauge does not go over the crown, it is too loose and this will give leakages. A full set of bottles off the crowner should be checked each shift and after a changeover.

Can Seaming
This is a more complicated procedure. The can seam is known as the ‘Double Seam’ and is defined as ‘the curl on the can end containing sealing compound and the flange on the can body are interlocked and rolled flat, forming five folds of metal. The sealing compound between the folds gives an airtight seal. Every angle, radius and dimension of the can end, including the sealing compound, also can body, seaming chuck, and seaming roll groove profile must be correct to ensure a hermetic seal. A profile of a seam is shown below:
The seamer must be synchronised with filler so as to ensure a smooth transfer of cans from one machine to the other. In order to achieve this, the filler is driven by the seamer via a cardan shaft. With the introduction of servo motors it is now possible to have separate drives which are synchronised electronically.

The cans enter the seamer and pick up a can end from the can end feeder. More than one feed will be required should the speed be greater than 1600cpm. Ends are only called for when cans are present. The software needs to be good as the scan time for trigger mechanism is only 2 milliseconds. The can end is controlled by the knockout rod pad while the lower lifter, synchronised with the knockout pad, lifts the can end and can body into position on the seaming chuck. This position is called the make-up point. As contact is made with the seaming chuck, the can starts to revolve with the seaming chuck and lifter.

Under cover gassing to eliminate oxygen takes place just prior to the make-up point. It is important that gas at low pressure and high volume is used so as to achieve maximum effect without disturbing the end transfer.

In order to form a double seam two operations are required. These are referred to as the ‘first’ and ‘second’ operation. Each operation uses differently profiled seaming rolls which then form the seam in two operations as illustrated below:

The profiles used are established between the can and seamer manufacturers.

After the make-up point as described above, the can body and can end are held together on a seaming chuck by a vertical pressure applied by the lower lifter or base plate table as the can passes through the machine. During the seaming cycle after the can end and can body meet, the first-operation seaming roll contacts the can end and begins curling it around the can body flange. The second-operation seaming roll then takes over and tightens and irons out the seam between the can body and can end forming an airtight hermetic seal between the end and the body.

In order to check the seam a ‘tear down’ of the
seam is carried out. There is a non-destructive method using an x-ray and also a projector which can project the profile of a cut seam onto a screen where measurements are then carried out. The x-ray method can be carried out on-line but the unit is expensive. The projector method can be inaccurate. Can manufacturers still prefer the tear down analysis as this is the most accurate and will always be used as the benchmark.

**Bottling and Canning – Plant Features**

**Beer Supply**
Before entering into the detail of oxygen pick up and other quality issues at the filler, it is worth discussing the quality of the beer supplied to the filler.

**Chill Haze and Oxygen**
It is essential that all chill haze is eliminated in bright beers. Chill haze forms in beer and is caused by protein coming out of solution at cold temperatures, and then re-dissolves as the beer warms up. The following rules apply:

- Filter at -1° to -2°C
- Use a trim chiller
- Ensure that chill haze already captured in the filter is not allowed to re-dissolve

For oxygen control, make sure there is no ingress of air during transfers. The following are guidelines to assist in ensuring that this does not happen:

- Handle the beer gently
- Use de-aerated water at level of 20ppb O₂ for chasing and purging beer. Oxygen levels in water can vary between 10-20ppm depending on the temperature of the water (*Purging* takes place before the transfer of beer, when de-aerated water will displace the air in the beer main. This will then be gently displaced by beer. *Chasing* takes place after a transfer when it is necessary to empty the beer main of beer).
- No leaks! If there is any leaks on beer or gas pipework, air will be pulled into the flow as the beer or gas travels along it. This is known as the venturi effect.
- Redoxing tanks. This is the elimination of oxygen from the bright beer tanks (filtered beer tank) or any other tank (such as a bottling tank or buffer tank) which the beer is then transferred into before packaging. The most effective method is to fill the tank brim full with water and then blow it out with CO₂. This usually frowned upon due to the significant waste of water resulting. As a result, this is done by pressurising the tank to working pressure (1-2bar) and then releasing the pressure to atmosphere. This is done two to three times in order to purge as much air as possible.
- Transfer beer along a rising main with a vent at the end of the run to allow all air bubbles to be vented.
- No decants. This is not a practice generally followed. Decants contain high levels of oxygen. There are really only two ways of dealing with them, either dump them, following the environmental practices in place, or add them to the fermenter.

**Beer Preparation**

**Contamination and beer condition**
Not all beer is filtered. Some beers, such as stout may only be centrifuged and then fined. The clarity is then measured as brightness.
Once the final beer is prepared, it can be either bottled directly from the tank that it has been filtered into or from a further tank to which it has been transferred. This will be the case if the primary tank is too far away from the filler.

It is extremely important that the beer to be packaged is in the right ‘condition’. This means that it is at the right temperature, meets the specification and that it, importantly, has the correct CO₂ content. The word condition derives from the earlier days of brewing when beer was packaged with a small quantity of yeast and fermentable matter, and it was then allowed to come into ‘condition’ before it was consumed. Cask beer is, of course, still prepared in this way.

In order to ensure that beer is in perfect condition it is important that the tanks are:

- Clean, sterile and empty before filling – records kept
- CIP systems are interlocked so as to ensure that no errors such as accidental dilution or chemical contamination can take place
- Temperature is controlled either by insulating or jacketing vessels
- All pipework is insulated

Low temperature is important to keep the gas in solution, and as understood from Henrys Law, pressure also plays a significant part. It is crucial that the beer is stable during packaging. Temperatures are usually -2°C up to 4°C and top pressure 1.0 to 1.7 bar in order to keep CO₂ levels of 5 to 6 g/l in solution.

In order to assist it is advised to keep the following rules

- Carbonate the beer using a carbonator which will ensure that the CO₂ goes quickly into solution. If chilling the beer before tanking, carbonate before the chiller. Any CO₂ not in solution before the beer reaches the tank will most likely be wasted, and it will also take longer for the beer to settle down
- Bring beer into the tank with the correct equilibrium top pressure applied
- Maintain the correct top pressure to keep gas stable in solution
- Ensure that there is no fobbing. Fobbing can take place due to erratic gassing, poor transfer or degassing. When the CO₂ content is too high, dubious methods are used to degas the beer. One method is to transfer the beer against zero back pressure and another is to ‘bump’ the beer with CO₂, with CO₂ being introduced through the bottom of the vessel with no top pressure. This practise is not good for the beer for the following reasons:
  - It reduces the head positive factors in the beer
  - Fob can foul the vacuum and pressure safety valves on top of the vessel
  - Collapsed fob can lead to ‘bits’ being present in the beer
- It is much better to have it right in the first place. Automatic systems are available and their use is encouraged. At worst blending is still an option if there is sufficient beer.
- Smooth bends and correct transfer speed* are important
- Keep the beer in tank for at least 3-4 hours before packaging in order to allow the beer to settle and stabilise

*If the beer is transferred at velocities of 1.5m/s or more, excessive turbulence will occur, and this will excite the beer. Turbulence is reduced by slowing the velocity of the beer flow, and this is achieved by increasing the diameter of the beer main for a given flow rate. Beer pipework should be designed to take beer at speeds around 1.2m/s. Some project engineers will go as low as 0.8m/s to achieve a really low turbulence.

Turbulence is required during Cleaning In Place (CIP). Filler manufacturers will achieve this by doubling the flow rate for CIP fluids.

Transfer of Beer to the Filler

After the beer has been carefully prepared, it now needs to be handled gently so as not to spoil it at the last hurdle. So often things go wrong, because operators take short cuts, and then end up with a disaster which leads to poor quality and waste. Some filler
installations are extremely sophisticated but the same basic rules apply.

- Ensure that the filler is properly cleaned. In general a full CIP is required once each week as an absolute minimum. This may also be required if changing over, for example, from a stout to a lager. Otherwise the filler needs to have been properly rinsed using hot and cold water. The crowner must also be cleaned with special attention paid to the chute to prevent crowner dust congealing

- Purge all pipework and filler (all channels) with cold de-aerated water from the tank which is providing the beer

- Isolate the filler

- Change to beer (first make sure that it is the right beer and that it has been checked!), and displace all water with beer up to the valve isolating the filler. This should be done using tank pressure only i.e. not using the beer pump

- Blow out all water from the filler with the gas being used for filling (usually CO₂ but could be N₂ for nitrogenated beers). Allow pressure to build up three to four times to ensure filler is emptied of water

- Having set up the filler for filling, bring beer gently into the filler against the filling pressure – pump now required

- Having set the filler up in preparation for filling, it is then normal to remove at least the first two rounds off the filler to ensure that there will no diluted beer going to market

If these general rules are followed the filler should start in control and not lively. Before crowning and after filling, it is important that the beer is jetted with a high pressure jet to drive out the air from the headspace. The jet should be set to give foaming so that it just overflows before crowning. There will be a beer loss of between 1-2ml and if none is lost the beer is not being jetted properly! The water used for jetting must be clean and sterile. This has never been well managed in the past, so hot water jetting at approx 85°C is now commonly used.

### Beer Contamination at the Filler

The table below reiterates what has already been stated, but it also gives the consequences.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Possible Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>De-aerated water has not been used to purge the line and filler</td>
<td>Oxygen pick up</td>
</tr>
<tr>
<td>All air has not been eliminated from the line</td>
<td>Oxygen pick up</td>
</tr>
<tr>
<td>Beer line is not properly purged of water</td>
<td>Dilution</td>
</tr>
<tr>
<td>Water has not been properly blown out of the filler with the operating gas (normally CO₂)</td>
<td>Dilution</td>
</tr>
<tr>
<td>There is no in-line filter. Size 10-20 micron depending on beer</td>
<td>Particulate matter in beer and blockage of valves</td>
</tr>
<tr>
<td>No covers on conveyors between the washer or rinser and the filler</td>
<td>Possible contamination of bottles and therefore particulate matter in beer</td>
</tr>
<tr>
<td>Bottles with residual liquid from bottle washer</td>
<td>Dilution or contamination</td>
</tr>
<tr>
<td>Glass faults – no Empty Bottle Inspector or not working</td>
<td>Glass contamination or inclusion</td>
</tr>
<tr>
<td>No auto-flush for bottle breakage</td>
<td>Unless strict procedures are in place, glass contamination may occur</td>
</tr>
<tr>
<td>Erratic filler – top pressures, poor CIP etc</td>
<td>Ragged filling and erratic oxygen levels</td>
</tr>
<tr>
<td>Jetter not set up to give good fobbing</td>
<td>Oxygen pick up</td>
</tr>
<tr>
<td>Dirty crowner</td>
<td>Possible contamination from congealed dust</td>
</tr>
<tr>
<td>Bubble breaker not functioning</td>
<td>Oxygen pick up</td>
</tr>
<tr>
<td>Under cover gassing not set up</td>
<td>Oxygen pick up</td>
</tr>
<tr>
<td>Over greasing of seamer</td>
<td>Contamination and poor head retention</td>
</tr>
<tr>
<td>First two to three rounds have not been removed from the filler</td>
<td>Dilution and oxygen pick up</td>
</tr>
</tbody>
</table>

### Sterile Filling

Sterile filling is more achievable today as standard machines are designed to be hygienic and are much easier to clean. Also beer has
natural antiseptic qualities with alcohol and hops – this helps! However a great deal of care and attention is still required. The main differences in approach on a line without an in-package (or tunnel) pasteuriser are:

- The beer to be packaged must be sterile i.e. completely clear of all beer spoilage organisms
- The filler installation and layout must be hygienic
- The environment around the filler must be free of any organisms which could infect the beer
- The bottles and closures need to be sterile
- Cleaning and CIP regimes need to be totally disciplined
- The training of personnel in hygiene and methods of operation need to be carried out to ensure total understanding and commitment
- Micro back up from the laboratory is essential

**Sterile beer**
The beer can be sterilised in two ways:

- Sterile filtration
- Plate (or Flash) Pasteurisation

Both these methods are described in the section on section Pasteurisation Theory. Each type has its benefits. Sterile filtration will produce beer that has no heat damage, and can be installed in-line to the filler making the operation much simpler. However, the process needs to be closely monitored and filters need to be well maintained. The method chosen today is usually plate pasteurisation as it is easier and cheaper to manage; also there does not appear to be any detectable heat damage for the discerning beer taster!

For comparison purposes, the capital cost for the installation of a sterile filter would be about 50% higher and running costs approximately 3 times greater. With a plate pasteuriser, however, a sterile buffer tank needs to be installed in order to balance the system. This is because a plate pasteuriser cannot give an instantaneous change in supply as the filler slows down, speeds up and stops!

Another advantage is that with a plate pasteuriser the bottles can be packaged at a higher temperature which can go up to 15°C, depending on the gas content. This is important when it comes to labelling as the bottle needs to be condensate free (dry surface). Beer from a sterile filter will be around 4°C when bottled, so a bottle warmer may be required to warm up the bottles before the labels are applied.

**Filler installation and layout**
Good design practices must be followed from the exit of the pasteuriser or sterile filter right up to the filler. This will include:

- No CIP dead legs. Points where the solution will not pass when being circulated
- Valves or caps on T’s less than 1.5 pipe diameters away from the junction
- CIP flow rates designed to give high levels of turbulence (velocities > 2m/s ideally 2.5 m/s)
- Use of hygienic fittings and valves
- Make pipe runs as short as possible
- Do not create traps – all pipework should be able to self-drain
- All gas in contact with the beer is sterile – filtering with a 0.25 micron filter should be sufficient, and as close to the point of use as possible. Simple cleaning facility (steam) and easy filter replacement must be considered

In the case of the Sterile Buffer Tank all fittings, including temperature and level probes, need to be flushed along with the internal surface of the vessel. The sample cock needs to be a membrane type. Ensure that the programmes for CIP, flushing, beer intake, changeovers and finish have been precisely specified to ensure no contamination.

The bottle rinser must be blocked with filler to ensure a short, synchronised transfer from the rinser to the filler. With a can filler this is not possible so extra care must taken in the transfer of the cans from the rinser to the filler.

**Filler Environment**
The environment around the filling area must be hygienically clean. There are two lines of thought on this:
1. Make sure that the packaging hall, and especially the area around the filler, are easy to clean, and can be seen as visibly clean – light coloured tiled floors and walls are best. The hall should be fed with filtered air.

2. As an extra precaution the filler is enclosed with a gap at the bottom to allow proper cleaning of the floor. The enclosure is fed with filtered air and a positive pressure is maintained inside the area.

The important thing is to not allow the enclosure to give a false sense of security. The internal area must be kept clean and the air filters properly maintained. Any breakages and beer must be quickly washed away with sterile water and the same strict cleaning regime kept in place.

If non-alcoholic beer (NAB) is packaged, an enclosure is strongly recommended as the beer is much more vulnerable to infection without the alcohol.

**Sterility of bottles and closures**

Bottles can either be returnable or non-returnable. Returnable bottles will have been treated at a high temperature, and so long as they are shiny clean, they should be infection-free. However, all this good work can be spoilt if the final rinse water is contaminated. It is normal therefore to treat the water with a low level of chlorine 2 to 3ppm, to ensure sterility. Many brewers will not allow chlorine to be used due the danger of chlorophenol (like TCP) being formed in the beer should it come in contact with the residual chlorine. As a result chlorine dioxide at 0.25 to 0.5 ppm or PAA (Peracetic Acid) at 150 to 250 ppm is more commonly used. For new bottles the same applies – the water, as an extra precaution, could be passed through a 0.45 micron filter (or less), or be UV (Ultra Violet) treated. It is also possible to use steam rinsers or rinse bottles with sterile air. Steam would not be suitable for PET bottles. Chemical treatment with Chlorine Dioxide or PAA is advised as this treatment is residual. (Remains in contact with the surface).

It is now a common approach to deliver a sterile bottle to the filler. It is also possible to purchase a sterile filler which actually steam sterilises the bottle before filling, as part of the filling cycle. The downside is that the bottle breakage increases as the bottle is still hot when the cold beer meets the glass.

Crows or caps can be sprayed with 300ppm PAA (Peracetic Acid ) or be treated with UV. However, general advice is to keep them dry in a clean storage area. Dry crowns will not carry infection.

**Cans and can ends**

The same principles apply for the rinsing cans. However, cans are not breakable so can be steam sterilised. A filler can be purchased which sterilises the can with steam as part of the filling cycle. Ends can be UV sterilized before seaming, however if they are kept dry UV treatment may not be necessary. Sprays, as used with crowns, are not easy to apply during end transfer.

**Cleaning and CIP**

There is no correct way – the important thing is that it is effective in preventing infection and this will be discovered through trials. For sterile filling, there will be a need for more cleaning time and this will affect the utilization of the line. With sterile filling, it is good practice to run the bottles out of the filler every two hours, and then hose down the filler externally with water which has been treated with PAA or chlorine dioxide. This could take 5-10 minutes which is equivalent to a 4 to 8% loss of utilisation. A full CIP, or internal cleaning; needs to happen at least twice a week when continuous running. It should also take place after stops, or at beer changes. The CIP will consist of a rinse, caustic wash, another rinse, and then finally a rinse with PAA or chlorine dioxide treated water. External foam cleaning needs to take place after CIP.

**Training of personnel**

No person should be allowed near the filler without the proper training in hygiene and operation. It is important that an assessment of each individual is carried out after training,
and that only certified people are allowed to operate or maintain the plant. The 'Sitting next to Nellie' technique is not appropriate for this kind of operation. A certain amount of classroom training in hygiene and operation must be given to the operators and engineers first. It is also important that proper, simple and straightforward work instructions with diagrams are prepared for the operation, so as there is no misunderstanding about what needs to be done. The implications of not carrying out instructions must be clearly understood.

Micro back-up
So as to ensure that a sterile product is not going to be contaminated it is important that all points of contact such as pipework, valves, pumps and vessels are absolutely clean and infection free. A good discipline must be in place for sampling especially as there is a delay of 4 to 7 days before it is known whether a product sample is free of infection. Sampling regimes must also be traceable. At one brewery a bar-coding system was used. A summary of some good practices are:

- An adequate sampling room which allows at least two samples from each batch to be kept for the given shelf life for the product.
- An extra one to two samples to be passed through a membrane filter and incubated anaerobically for 4-7 days and aerobically for 2-4 days.
- Two samples to be taken for forcing tests and kept in warm storage (25-30°C) for a period of 4-6 weeks.
- Continuous samples are collected from the line feed to the filler every 2 hours from a continuous membrane sampler.
- Swabs are taken from plant after cleaning for bioluminescence testing to ensure cleanliness.
- Tests carried out on the water supply, water from the rinser, water from the tanks and filler after cleaning. Also checks on gas supplies used CO₂ (perhaps N₂) and crowns. Indeed anything that will come into contact with the beer.

3.6.2 LARGE PACKAGING

Introduction

The development of the keg has enabled the export of quality draught beer around the world. This is provided that the beer in keg is microbiologically and physically stabilised, treated reasonably during the distribution chain and dispensed with the correct clean equipment correctly set up. The keg has also enabled draught beer to be dispensed in outlets with spasmodic low sales rates, which would preclude cask conditioned beer.

Two main areas will be covered in this section:
1. Basic principles of design, operation and control of combined keg cleaning/filling machines.
2. Basic plant features and control procedures from filtration through to filled containers

Basic principles of design, operation and control of combined keg cleaning / filling machines

The following areas will be covered:
- Basic principles of design of keg filling lines.
- The choice of detergent, its concentration and temperature
- Typical regimes during the cleaning, sterilizing and filling cycles
- The relative merits of inverted versus upright filling
- Methods of controlling keg fill levels
- The merits of using gases other than CO₂, as the top pressure gas in kegging operations
- Washing and Filling Monitoring

Basic Principles of Design

As with all packaging lines the filler is the key machine on the line, which is supported, by the other machines. The filler should be the slowest machine on the line i.e. bottom of the V with machines upstream and downstream rated above the filler taking into account not only their speed but also their availability. Availability takes
account of the reliability of each machine. Generally the rating of each machine away from the filler is increased by between 5% and 10% on keg lines.

**Line Layout**
The ideal layout is a ‘U’ to minimise pallet and fork lift truck (FLT) movement. One FLT can feed empties and take away fulls. Some keg plants are fully automated and are run by the one operator, the FLT driver.

**Line Components**

**DEPALLETISING**

Although depalletising can be done manually, it is more common to use a depalletiser. Three types of multiple container handling aid are used: flatbed pallets, belly pallets and locator boards. If locator boards are used then a clamp truck is required to enable handling of the containers. Conventional depalletisers either need to be able to clamp and lift the containers off the pallet from known locations or in the case of flatbed pallets a sweep arm can be used. Robotics are being used for handling empty kegs, pallets and full kegs.

**KEG TURNER**

If a depalletiser is used then the kegs' orientation needs to be checked and possibly adjusted. This can be done by passing the keg under a flap with a horizontal axis, which detects the presence of the Barnes neck. The keg needs to be orientated with the spear and Barnes neck facing downwards. This is carried out by gripping the middle of the keg, lifting it off the conveyor and rotating it. Camera systems are also used and apart from orientation can check for cap still present, foreign keg, foreign spear, missing spear, bent chime, bent neck and excessive debris.

**CAMERA INSPECTION**

Camera systems are used to check for cap still present, foreign keg, foreign spear, missing spear, bent chime, bent neck, leakers and excessive debris. There is normally a reject station downstream of the camera unit.

**EXTERNAL KEG WASHING**

This is carried out by passing the keg through a tunnel containing a series of high pressure sprays of up to 200 bar. Pre-wetting can take place, and can include the use of ultrasonics. The use of warm water at around 55°C helps external washing, as does the use of detergents, though care must be taken not to corrode aluminium kegs. There is a risk of legionella especially with warm external keg washers, it is therefore important that this risk is assessed and a regime installed to minimise the risk.
It is important, in order to avoid later confusion, that the label is cleanly removed at this stage. Label design is therefore important, and strip gummed labels sometimes manufactured from hot water sensitive paper can facilitate easy removal. If a label is not applied to the keg then low pressure cleaning can be used.

**SPEAR TORQUE CHECK**

Some keg lines are fitted with a checker for ensuring that the spears are torqued to the correct value. Unfortunately there is a tendency in the trade for attempts to be made to tamper with kegs, and therefore this is quite a useful way of checking that quality problems will not be experienced due to loose spears. The torque device should be set around 47.5 Nm (35 foot pounds). Pneumatic motors have traditionally been used but are now being replaced by servos which can achieve accuracies of +/- 1Nm. If the whole keg population consists of safety spears, then this type of device is not needed, although some method of detecting broken plastic collars would be useful.

**HYDROCARBON AND PRESSURE TESTER**

Unfortunately not only do people try to mechanically tamper with kegs in the trade but also occasionally kegs get filled with substances other than those put in by the brewery. On some occasions even residues of petroleum based products have been found in kegs. Obviously normal keg washing might not remove traces of these products, and therefore there is a real product contamination risk. One way of trying to control this risk is to put a station in with a sensor for detecting the presence of these organics. This detector is based on optical resonance, and care is required in setting up, as traces of alcohol in residual beer will also risk detection. This station also tests the pressure in the keg returning to the brewery, and will only allow kegs on if there is more than 5 psi in the keg. If there is less than 1/3 bar (5 psi) then it is assumed that there is something wrong with this particular container and it is rejected. The advent of safety spears has dramatically reduced the number of rejects from this station. The hydrocarbon and pressure tester can therefore be used as an alternative to the automatic spear tightening. It is possibly preferential, because it gives the opportunity for the container to be inspected off-line.

**KEG WASHER AND FILLER**

Early keg racking lines had separate washer and filler units. The very early lines washed the spears separate from the keg bodies. Current designs either have the washer and filler in one unit or closely coupled. Keg washing and filling machines are in either a linear or rotary configuration. Economic construction costs indicate that linear lane configurations should be used for outputs less than around 500 containers per hour with both configurations considered for outputs above this figure. These machines will be discussed in more detail later on.

**ROTARY KEG TURNER**

This is used to turn the kegs the right way up.

**CHECK WEIGHER**

Each keg is weighed in order to ensure that the Large Container Code of Practice on container filling is observed. Generally speaking, a 50 litre keg would be rejected if it contained less than 49 litres. In order to monitor the actual keg filling it is advisable to take 5 kegs off each filling head/lane and measure the average contents. By doing this, the magnetic or turbine meters can then be adjusted to ensure correct filling on each filling head/lane.

**LABELLER AND CAPPER**

Labelling and capping can either be done by hand or by machine. The label is applied to the top of
the keg. Information on the label includes, identifying the beer brand, best before date, batch number, time labelled, bright beer tank plus possibly sequential numbering of containers from the start of that rack, and of course the volume of dutiable beer and the alcohol percentage. The keg cap is there to protect the top of the spear and keep it clean, and also to identify the beer and provide ideally some form of tamper evidence. Keg caps are either pressed on or shrunk sleeved using hot air. A cap presence detector can be fitted to reject uncapped kegs. These detectors are electrical resistance devices, which work by trying to complete an electrical circuit using the metal part of the keg head, the circuit not being made when a cap is present. One solution to the problems with label removal is not to apply a label. The packaging information can be printed onto the keg cap. This approach does mean that the packaging details can become separated from the keg when the cap is removed. One backup is to have each keg fitted with a RFID (radio frequency identification) ta, which is read at the time of packaging and stores the packaging information digitally on the packaging line.

CONVEYORS
Keg conveyors tend to use link chain, often made of plastic rather than steel. Conveyor design has moved towards use of curves rather than 90 degree bends and transition points. Lubrication is required for the chains usually through dip troughs.

PALLETISER AND UNITISER
Kegs are then palletised on to the appropriate pallet configuration. This is normally done automatically to avoid manual handling. The palletiser thus needs to be able to handle the range of pallets and keg sizes and configurations required. Many palletisers are installed with a unitiser installed after the palletiser to stack pallets usually two or three high.

Washing and Filling Machines
Washing and filling machines can either be designed on a linear or rotary basis. The linear layout comprises of lanes each capable of washing and filling arranged in parallel. Output is increased by adding more lanes. The rotary layout consists of rotary wash carousels (one or two) prior to a rotary filling carousel. Output is increased by adding more wash and fill heads to the carousels.

The linear racker consists of the following components:

- **Mainframe** - generally made of stainless steel, and consists of a robust structure holding all the components plus infeed and outfeed conveyorage. The infeed can either be in the form of an oval carousel or, more generally now, a single conveyor with stops to position a keg in front of each lane, plus ideally additional stops between lanes so that up to twice as many kegs as there are lanes are positioned ready for feeding on to the lanes as close to the lanes as possible. If the lane furthest from the infeed conveyor draws off its empty keg then all the stops drop and the kegs advance one down the conveyor.

- **Racking head assembly** - consists of valves, pipework and probes with up to two racking heads, the first for counter-pressuring the keg and possibly cooling it, and the second for filling with beer by both meter and conductivity.

- **Wash-head assembly** - consists of valves, pipework and probes with between three and six wash-heads stations.
- **Top clamp assembly** - pneumatically sprung plate to hold the base of the kegs firmly, so that the keg head is held on to the head assembly during processing.

- **Connection head assembly** - connection point between machine and kegs, and provides a firm seal.

- **Puller assembly** - for moving kegs on to the racker and accurately locating them so that they can then be moved from head to head. This is a vertical pneumatic bolt on the infeed end of the walking beam which comes up inside the keg rim and movement of the beam draws the keg into the lane locating the Barnes neck against a locator plate.

- **Drive and lift assembly** - generally walking beams which move the kegs from head to head. The walking beams are also used to push the filled keg onto the discharge conveyor. A photoelectric cell is used to ensure a keg is not discharged onto a keg moving along the conveyor. On large installations the discharge conveyor is split in two to speed up discharges.

- **Pneumatics panel** - centrally mounted to each lane, which used to be positioned above the machine and is now positioned alongside the beam.

- **Electrical panel** - end panels with the electrics for the lane, and also a central SCADA control station for all the lanes. An example of a SCADA control screen is shown below.

The rotary racker consists of the following components:

- **Carousels** - One or two rotary wash carousels plus a filling carousel. The desired cleaning regime & line output
decide whether one or two wash carousels are required. The construction of the carousels is very similar to that used for a bottle or can filler.

The structure needs to be designed to support the weight of the kegs being processed with the pitch dictated by the maximum diameter of the kegs to be handled. A two carousel unit is shown in Fig 14 with the wash carousel on the left. If there are two wash carousels then frequently at the end of the first carousel the keg is filled with 5 litres of caustic to cover the bottom of the keg and the spear area so that it can soak for approximately 2 minutes during the transfer from the first wash carousel to the second.

- **Infeed and Discharge Indexing System** - an infeed indexing system is required, similar to a bottle and can filler, to time containers entering the carousel and coincide with the availability of processing stations. The infeed mechanism consists of a gate with infeed and outfeed starwheels, indexed to the carousel rotation.

- **Keg clamping and head location** - A pneumatic top clamp is used with the platform lowering the inverted keg onto the processing head.

- **Washing and Filling Heads** - unlike the linear machine all of a carousel’s processing operations are carried out by each individual head on that carousel.

- **Central bearing and service manifold** - the services and product pass through a rotary ‘O’ ring seal arrangement. These seals are fitted with tell tales to indicate ‘O’ ring failure and also to avoid cross contamination. An example of the washer seal configuration is shown below.

- **Drive** - This is normally a geared drive.

- **Pneumatics and electrics** - each station on the carousel requires pneumatic valves to
supply services, these tend to be gathered round the central spindle under the carousel platform. This area needs to be kept clean with good access for maintenance. Electrics for each head are in a panel above the platform.

Both linear and rotary rackers have the following common features:

- **Service Centre for the CIP fluids** - Generally at least three tanks are required for hot water final rinse, dilute detergent and recovered water for pre-rinsing. The hot recovered water on its way into the recovered water tank can be used to heat up the incoming final rinse water.

- **Wash Heads** - keg spear valve open sensor and keg residual pressure detector. Failure results in no processing operations taking place on that keg. Removal of residual product and cleaning fluids from the keg is monitored either with a conductivity probe or flowmeter on the wash head outfeed.

- **Fill Heads** - keg spear valve open sensor plus meter on beer feed to control flowrate plus volume of beer in. In addition there is a pressure sensor on the displaced gas main from the keg to control counter-pressure. The filling head also has the facility to flush the filling head and outside of the keg spear with hot water prior to the start and after the filling process. This is done to reduce risks of microbiologically contaminating the beer going into the keg from the filling head, the top face of the keg spear and also cross contaminating the next keg.

 Linear rackers tend to be used for outputs up to 500 kegs per hour and both linear and rotary for greater outputs. Linear installations generally have a maximum output of 65 by 50 litre kegs per hour. However if the heads are in tandem, then the maximum output that can be achieved from a linear keg plant is 120 kegs/hour/lane when filling 50 litre kegs, with a maximum of 14 lanes. Tandem lanes involve the doubling of the number of processing heads on each lane with kegs being processed through the machine in pairs.

 Rotary rackers are now able to handle 100 litre kegs. Linear racker output is increased by adding lanes. Room for this expansion needs to be allowed for in the initial line layout. Output increase in rotary machines can be achieved by installing carousels with spaces for additional wash and fill stations.

 If a head breaks down on a linear machine then the lane in question can be shut down for repair whilst the other lanes continue to function. Line design needs to enable the lane to be safely isolated for this work to take place and this usually requires interlocked safety screens. A failed head on a rotary machine can only be repaired by shutting the whole machine down. Faulty heads tend to be turned off until a break in production occurs. When sizing a rotary racker, allowance should be made for head reliability i.e. an allowance is made for some heads not to be working all the time. Reasonable central bearing and seal life is essential as is head service valve seat life. Maintenance times on wash heads have been reduced from 105 minutes to 20 minutes and filling heads from 85 minutes to 10 minutes.

 Some packaging installations use clean steam from a clean steam generator for use on the internal wash and fill areas. This removes the risk of there being any traces of feedwater treatment chemicals and pipe scale in the steam. The steam is raised typically from demineralised water. Clean steam is corrosive thus components of the system should be manufactured from 316 stainless steel. Extractor tube wear can be reduced by reducing the number of times the valve is opened during the washing and filling operations. Rotary systems tend to open the spear valve less times than linear systems. Triplex linear systems have reduced linear valve openings to three.

**The choice of detergent, its concentration and temperature**

 There are four key factors which influence Keg washing:
- Time
- Chemical
- Temperature
- Mechanical action on surface.

Time and mechanical action are incorporated into the design of the line but need to take account of the cleaning chemical composition, concentration and temperature required to effectively clean the kegs to be cleaned on that line. Surface mechanical action requires a velocity above 2 m/s, ideally 2.5 m/s.

It is important that the detergent used does not corrode the keg material. Special care needs to be taken in the choice of detergent used for cleaning aluminium kegs. Thus it is likely to be a non-caustic product, possibly EDTA-based or acid based. Phosphoric acid is commonly used. The ideal detergent would contain a wetting agent and surfactant to break down surface tension and facilitate soil removal and a sequestering system to facilitate scale removal/formation. Along with detergent dilution elsewhere in the brewery, soft water is often used to enable the detergent to be formulated to achieve cleaning requirements without the need to have additional chemicals to deal with calcium salts in the water. Detergents are typically used around 65 to 80°C and the hot water around 80°C. On mainland Europe there is a tendency sometimes to have an acid-wash to neutralise the keg and ensure no scale builds up. A good way to ensure scale build-up does not occur is to use soft water for all keg washing operations.

Kegs return from trade filled with carbon dioxide and this will react with a caustic based detergent converting hydroxide to carbonate. The effectiveness of the detergent is therefore reduced. To improve cleaning efficiency a second caustic rinse is often necessary.

Beer is not acidic enough to remove water hardness from the metal surface of the keg. Water hardness remains on the inner surface of the keg from steam. Kegs have been found with layers of “beer stone” up to 4mm thick because breweries were using too shorter washing cycles with the wrong detergents over an extended period of time. The use of an acid rinse can solve these problems. If a keg population is badly scaled then a regime is required to avoid partial scale removal which could result in scale particles in the product.

**Typical regimes during the cleaning, sterilising and filling cycles**

An example of the operating sequence is shown, with a schematic of the beer supply and a keg washing pipework layout. A typical process times on each head of a linear racker is shown, this example does not have a reclaim rinse tank.
Separation of keg cleaning onto multiple cleaning heads has reduced the risk of contamination in the kegs. Valves on old keg lines were usually not block and bleed valves and broken or leaking valves were notoriously difficult to detect. Separating cleaning fluids into different heads reduces contamination risk and allows the final rinse water in these systems to be reduced to 5 litres of water. Some linear washing machines reverse flow the detergent during the cycle to improve cleaning of the spear valve assembly.

The throughput of a keg line is usually determined by the capacity of the filling head and is calculated to the average volume of all kegs used. The total washing cycle time determines the number of washing heads to fulfil an agreed treatment cycle depending on the individual brewery’s requirements. Washing cycles are not reduced by speeding up keg lines once smaller kegs are filled. The cleaning regime with respect to contact time for a unit area of keg surface is the same irrespective of the size of the container. The steam cycle does need to allow enough steam to enter the container for the desired heat transfer to take place.

Steam was used to blow out all liquids during the treatment process because it allowed probes to analyse the discharge temperature of media to achieve a reliable signal when a keg is empty. The disadvantage was that during the treatment time any remaining residue due to incomplete washing was burned to the surfaces, adding to the risk of “beer stone layers” inside the kegs. Sterile air is used to blow out media from the kegs. Only after the keg is thoroughly clean is steam introduced into the keg for sterilisation.

Modern keg lines theoretically do not require any steam sterilisation; the detergents and rinse cycles used expose any point of metal surface, which has been in contact with the product, to more than 16,000 pasteurising units. Steam is extremely useful. At the end of the washing cycle the keg is full of air which needs to be removed before filling. The use of steam makes oxygen removal more efficient. Steam also provides peace of mind provided the correct regime is used. The components of a keg provide challenging routes for cleaning fluids thus steaming is sensible. These surfaces include:

- Inside walls of the keg.
- Inside of the spear tube.
- Outside of the spear tube.
- Spring loaded housing of the spear.

Cleaning the outside surface of the spear requires the cleaning fluid flowrate to be reduced so that it runs down the outside surface of the spear rather than hitting the base of the keg and fanning out to the walls. Pulsing...
takes place in cycles of about 1.5 to 3 seconds. The pulse increases turbulence on the keg wall, enables more effective cleaning of the spring loaded housing and also improves drainage around the spring loaded housing.

Modern lines reduce the energy consumption during washing as much as possible. The role of detergent is the removal of contamination, whilst the role of the final rinse is the removal of chemicals only. Detergents circulation requires high mechanical action thus supply pressures between 3.0 and 3.5 bar are used. In the final water rinse, mechanical action is not as critical because high pressure and large flow speeds would only result in unnecessary consumption of water. Rinse waters are normally supplied at pressures between 1.8 and 2.0 bar only.

After detergent cleaning the keg is steamed, which will bring the keg up to about 125°C.

The steam used must be saturated so that it condenses easily giving up the latent heat of vaporisation. It is this energy release which carries out the sterilisation. The ideal temperature is 130 °C. Care must be taken not to overheat the kegs as the rubbers in the spear assembly start to breakdown above 135 °C. After steaming the keg is counter-pressured before filling. In Japan kegs are externally cooled to 4 to 5°C. At the start of this counter-pressure sequence the outside surface of the spear is also steamed. Published papers report on installations which use hot water instead of steam, either 85°C for 4 minutes to achieve 16000 PUs or 90°C for 1 min to achieve 20000 PUs. If steam is not used, then it is vital that the keg reaches these temperatures. Good monitoring of the temperature and the cycle time is therefore vital ensure that effective cleaning and sanitisation. The advantage for the use of this approach is extended seal life.

Temperature Profile for Keg Cleaning

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Rotary Washing Cycle
The filling cycle is a three stage process with beer being introduced via the gas ports, so that the keg fills in the inverted position from the top up towards the base. The first phase is slow until the gas ports are covered. This is followed by a standard fast fill and then completed with a final slow fill which enables quiet cut-off and reduces carry-over into the tube on to the spear, thus reducing fob losses. The beer is metered through magnetic or turbine flowmeters with a repeatability of about ± 0.5%.

At the end of the filling cycle any remaining product in the gas vent main from the filling head is purged through to the beer and fob recovery system. Fob needs to be handled so as to ensure that there is no microbiological risk. If fob returns are processed on the keg plant, then they can be filtered through a cartridge filter to collapse the foam prior to proportional injection on the feed to the pasteuriser. The amount of fob coming back to the fob tank is about 0.5% of the total filled.
Inverted versus upright filling
Early keg racking systems used to fill kegs in the upright position the connection to the filling machine being via a keg head coupling with flexible hoses. Beer was introduced down through the spear with gas displaced via the gas ports. Disadvantages of this method include:

• Washing cycle needs to be carried out with the keg inverted for satisfactory drainage
• Longer fill times or higher beer velocities entering the keg which can cause fobbing, higher losses & more variable fills
• Possible CO₂ loss due to fobbing

For these reasons modern rackers operate with an inverted keg, and fill via the gas ports with the displaced gas going out of the keg via the spear.

Methods of controlling keg fill levels
There are two key factors to be considered when controlling keg fill levels. The first one is controlling how much beer enters the keg, the second is keeping the beer in the keg once it is filled. Early keg filling machines used to brim fill the kegs. This meant that due to the over-measure in size kegs were overfilled and valuable beer given away. The solution to this was to meter fill the kegs. The first meters to be used were turbine meters. Problems were discovered included calibration variation from meter to meter due to the variable slip past the turbine. This slip also varies at different flowrates. Each meter needed to be individually calibrated for the line in question. Also meters were in contact with the beer. Magnetic flowmeters have considerably improved filling accuracy and sterility.

The second aspect of fill level control is to ensure that the beer that enters the keg stays there. In order to achieve this, the correct counterpressure is required along with good counterpressure control and fill speed control. The correct counterpressure varies according to the dissolved gas specification. The counterpressure needs to be slightly in excess of the equilibrium pressure of the gas mixture in question. Release of gas from the keg is controlled by the counterpressure control system. When the keg fill starts this system needs to move from a static position to one of dynamic control. If this control system is not working properly the control can hunt causing an excessive loss of counterpressure and fobbing in the keg. To facilitate this, the beer infeed flowrate is directly controlled via the flowmeter to provide a slow quiet start to the fill followed by a fast fill for the majority of the keg and a slow fill at the end to prevent overfill and beer loss down the spear. Using an infeed flow control valve has been extolled as producing a faster and more accurate filling process with savings in counterpressure gas. More accurate control of dissolved gases during the filling process is also claimed.

Fill performance should be monitored not only via the checkweigher records but also by checkweighing five kegs from each head and adjusting the flowmeter setpoint and fill control accordingly.

The merits of using gases other than CO₂, as the top pressure gas in kegging operations
Traditionally, CO₂ was the main gas used. Some keg lines counterpressured with sterile air although there were concerns about dissolved oxygen. The other gas, which was used with stout and is now used extensively is nitrogen (N₂). Nitrogen was used with stout because of its ability to produce a head of small tight bubbles along with a softer palate. Nitrogen has also been used, in addition to its head properties, to allow the increase of top pressures in the keg in dispense systems. The extra pressure allows the beer to be lifted higher from the cellar without increasing the CO₂ content of the beer through equilibrium. There are also the ales where a tight bubbled head and tumble (bubble pattern in glass during settling) are characteristics of the product. Nitrogen can also affect the apparent body of the product.

Mixed gas (CO₂/N₂) mixtures with up to 70% nitrogen are used. Mixed gas filling on non-nitrogenated products also enables higher counterpressures (circa 3.5 bar rather than circa 2 bar on CO₂ alone) and higher filling speeds avoiding fobbing.

In the Process Technology Section Dalton’s law of partial pressures is explained. This states that ‘pressure of a gas in a mixture is equal to the pressure, which it would exert if it occupied the same volume alone at the same temperature’. Thus the total pressure is equal to the sum of the partial pressures. Two other useful relationships are Avogadro’s hypothesis and Henry’s law. Avogadro’s hypothesis states that ‘equal volumes of different gases at the same temperature and pressure contain the same number of molecules. i.e. 1 gram mole will occupy 22.4 litres at standard temperature and pressure (STP). STP = 273°K and one atmosphere’. Henry’s law states that ‘the amount of gas absorbed by a given volume of liquid at a given temperature is directly proportional to the pressure of the gas (P) i.e. P = H x mole fraction’. Where H is Henry’s constant for the molecule at that temperature. Racking systems can have the facility to have a product specific back pressure set-point to help optimise filling rate and minimise fobbing.

**Basic Plant Features and Control Procedures from Filtration Through to Filled Containers**

The following topics will be covered in this section:

1. Hygienic Plant Design and Operation
2. Primary and Secondary Filtration

**Overview**

Plant features and control procedures for keg racking and cask filling share some common features plus in addition some unique features and emphases.

Common plant features include the use of holding tanks for beer prior to packaging, the optional use of an infeed buffer tank on the packaging line, a fob collection and handling system and hygienic design combined with effective CIP.

Common control procedures include; within specification microbiological control of both product and package, avoidance of contamination from contaminated returned containers, other products, fluids and gases, product in package meeting physical chemistry specification and contents requirement plus correct labelling.

Keg racking requires bright beer to pass through a micro stabilisation process either sterile filtration or plate pasteurisation. Keg beer carbon dioxide levels are higher than cask with the opportunity for the use of mixed gas top pressure systems along with possible nitrogenation of the product.

**Beer Dilution**

There are two aspects to beer dilution. The first is process design to prevent dilution of product out of physio-chemical specification and the second is deliberate dilution of high gravity brewed product to achieve the desired in package physio-chemical specification.
Dilution of product out of specification can occur through interfaces, tank residues and water in associated pipework throughout the process to the filler including the filler. Procedures need to ensure that this does not happen.

High gravity product dilution requires a supply of de-aerated brewing water (DAW) which is within microbiological, haze, flavour and carbon dioxide specification. The dilution system needs a control system which is sufficiently sensitive to ensure that product at the start and end of the run is within specification. This can be achieved using a batching tank of adequate size with good mixing, combined with a feed forward control system with rapid enough stable response characteristics. Both the product and DAL lines will be metered with variable speed pumps and control valves to ensure that within specification control is maintained at the product flow rates and dilution percentages required.

**Carbon Dioxide and Nitrogen control**

When beer leaves the fermenting vessel, it will be saturated with CO₂ and will typically have a CO₂ content between 2.0 and 3.2g/l. Nitrogenated products of the same package type will have a lower CO₂ specification than non nitrogenated products. Control procedures are required throughout the brewery to both add and remove CO₂ and nitrogen plus to maintain gas levels within specification. Both CO₂ and nitrogen can be removed by rousing a vessel with either gas with reduced pressure. CO₂ because it is both chemically combined and physically dissolved in the liquid is more difficult to remove using CO₂ than with nitrogen.

It is preferable to set CO₂ specifications in g/l rather than volumes as the former is absolute whereas confusion and errors can occur between production/ packaging sites as to the temperature standard used for the volumes.

The process of gas removal produces foam, which in the case of bright beer presents a potential haze risk from collapsed foam. It is therefore preferable to aim to remove gas if required pre filtration. This process if carried out late in the maturation process will stir up tank bottoms leading to a potential filtration problem. Therefore any gas adjustments during maturation should be carried out as early in the process as possible. Elimination is the best approach so not only should fermenter pressure be as low as possible (preferably atmospheric) when the vessel is cooled at the end of filtration, but dissolved oxygen pickup during transfers needs to be eliminated so as to avoid purging to bring the beer back into specification. Receiving tank pressures post fermentation also need to be adjusted so as to prevent or create gas pick up or loss by setting at equilibrium pressure correctly. Top pressure gases can be CO₂, nitrogen or mixed gas i.e. a pre-set mixture of CO₂ and nitrogen. Mixed gas should be used where turbulence occurs, and a high pressure is required to minimise foaming whilst avoiding the risk of CO₂ pick up e.g. within a keg during filling and when handling beers which have been nitrogenated to minimise the risk of nitrogen loss.

Typical mixed gas mixtures used are:
- 50% nitrogen and 50% carbon dioxide for Bright Beer Tanks
- 40% nitrogen and 60% carbon dioxide for Kegging Plant when kegging non nitrogenated beers.
- 90% nitrogen and 10% carbon dioxide for Kegging Plant when kegging nitrogenated beers.
- 40% nitrogen and 60% CO₂ for keg dispense non nitrogenated beers
- 70% nitrogen and 30% CO₂ for keg dispense nitrogenated beers.

It is important to ensure that the correct equilibrium pressures are used according to the gas specification for the product and its temperature. The use of the correct pressures is just as important during dispense into the glass.

The most efficient way of carbonating beer is at the time when there is turbulence. CO₂ will also dissolve more easily in a cold liquid rather than a warm one. Therefore the ideal time to carbonate the beer is whilst it passes through the chiller. CO₂ is injected via a sintered candle prior to the chiller. The turbulence and drop in temperature
enable the CO₂ to be easily dissolved. The resulting CO₂ content of the beer post chiller is measured in-line. The measured level of CO₂ in the beer is compared with the set point, and an automatic valve is adjusted on the CO₂ feed to the sintered candle to adjust the CO₂ flow into the beer, so as to enable the target carbonation level to be achieved. Nitrogenation can be carried out in the same way, although because nitrogen is only physically dissolved plus it’s lower solubility higher pressures are required. Nitrogen injection prior to the chiller feed pump helps using the turbulence to facilitate mass transfer into the liquid.

One carbonation monitoring device is the Embra carbo check. This has a membrane which preferentially allows CO₂ gas to pass through into a chamber whence the CO₂ pressure within the chamber is accurately measured. The temperature is also measured, and combined with the pressure measurement, the amount of CO₂ dissolved in the beer can be calculated. As other gases such as nitrogen can slowly pass through the membrane, in order to prevent errors creeping in due to these other gases, every 15 minutes the gas chamber is pumped out and the instrument recalibrated. In order that the Embra works effectively a back pressure valve is required in the beer main downstream of the sensor.

An alternative method of both carbonating and nitrogenating beer is to use a hydrophobic membrane. This is similar to a cross flow filter using a membrane with a smaller pore size and enables mass transfer into the liquid to take place without excess gas injection. The pressure set on the gas side of the membrane only needs to be the equilibrium pressure. The gas level in the liquid adjusts to the equilibrium pressure of the gas on the gas side of the membrane enabling not only dissolved gas adjustment increases but also small adjustments decreases. For larger adjustments down a vacuum needs to be drawn on the gas side to take away the gas passing through the membrane from the liquid. These membranes offer the opportunity of not only accurate gas adjustment within the brewery but also in the outlet at the time of dispense. One container in the cellar could dispense products of different gas levels over the bar through different parallel dispense systems.

**Oxygen Control**

The presence of oxygen downstream of the fermenting vessel causes both flavour and haze changes. Oxygen presence, prior to and during packaging, leads to the development of cardboardy/papery flavours in the product. This oxidation also aids the joining together of proteins, leading to unacceptable haze levels. It is therefore essential that, both during and following transfer from the fermenting vessel, oxygen pickup is minimised, and preferably eliminated.

The aged cardboard flavour, which develops in packaged beer, is believed to be due to the formation of unsaturated aldehydes, especially trans-2-nonenal. These aldehydes are produced by the oxidation of beer components such as alcohols, isohumulones and unsaturated fatty acids. Recent work has indicated that the presence of iron and copper also play an important role. These metals plus nickel do also have important roles in foam formation and stability, but can also cause gushing and haze problems. Recent analysis of haze material has indicated that these heavy metals in the haze material occur at concentrations of 1,000 to 80,000 times more than that of the beer.

Target maximum dissolved oxygen level post fermenter prior to packaging ideally should be less than 0.1 ppm. If this figure is exceeded at any time, then it can be reduced by purging the beer with either CO₂ or nitrogen. However, some damage will have been done prior to the removal of the oxygen.

Low oxygen levels are achieved by good plant design combined with good housekeeping. Oxygen is removed from pipework, tanks, hoses and bends prior to contact with beer. Effective vortex breakers (Candy EP 1991) are required in tanks along with the elimination of plant faults which can cause pick-up e.g. leaking pump glands.
The move to hard piping systems using double-seat valves has helped in minimising dissolved oxygen pickup along with beer loss and time savings.

In the case of filtration, if deaerated water is not available, then the precoat and bodyfeed solutions need to be by purged with low-pressure CO₂ or nitrogen through a sintered candle.

**Control of Beer Foam**

The amount of beer foam produced is directly related to the CO₂ content and method of pouring a beer. Head retention and foam cling, i.e. lacing, depend on the surface active constituents, which come out of the beer to the surface of the bubble. These compounds typically are high molecular weight proteins and also alpha acids. These proteins are very closely related to those which can produce hazes, and therefore the method of stabilisation needs to be carefully selected and controlled to ensure that the foam properties of the beer are not adversely affected. Typical treatments, which affect head retention, are treatment with tannic acid and proteolytic enzyme. It is important when selecting all materials to be used through the process, that they are checked to ensure that they will not adversely affect beer foam. This includes the selection of detergents. Higher fatty acids, linoleic acid and oleic acid concentrations as low as 0.1 ppm can adversely affect beer foam. It is important to ensure that beer is poured into clean glasses, as traces of grease can quickly suppress beer foam. It is also vital to ensure that the correct dishwasher rinse aid is used, as this can have a disastrous effect on beer foam. Poor foam characteristics tend to be a problem more with lagers than ales and beer foam can be enhanced by the addition of foam enhancers such as propylene glycol alginate to bright beer.

**Particulate matter generation and control**

Particulate matter generated by the brewing, fermentation and maturation processes should be removed during the filtration process through appropriate primary and secondary filtration. Assuming that this is achieved with the secondary filtration removing particles not removed by the primary filtration plus preventing carryover of any filter aid particles or stabilising agent particles such as polyvinylpyrrolidone (PVPP), then further particulate matter generation should be avoided.

Particle generation can come from the following causes:
- Collapsed beer foam – use quiet fill, avoid gas adjustment on part full tanks
- Dirty tanks and pipework
- Additions post filtration eg head stabilisers, colour, post fermentation bittering, proteolytic enzyme

**Microbiological Control**

Good microbiological control of keg beer and cask beer share common principles with one exception. With keg beer there is the opportunity to remove undesirable organisms by filtration with the potential for microstabilisation by plate pasteurisation.

Keg beer requires within specification removal of microorganisms by the filtration processes plus prevention of contamination post these processes into the sealed package. Micro-organisms must be controlled to a level such that, throughout the declared shelf life of the product, microbial growth has no deleterious effect on product flavour and appearance.

**Process Plant Hygiene**

**Key Requirements**
- No CIP ‘Dead Legs’. That is points where the CIP fluid cannot reach.
- Valves on ‘T’ pieces are no further away from the main pipe join than 1.5 diameters of that pipe.
- CIP Flow Rates > 2m/s, ideally 2.5 m/s
- Adequate CIP Frequency
- Efficient Monitoring of cleaning efficacy

**Tank and pipework Design**

It is one of the implicit objectives of the
processes covered in this discussion that the product should pass through without risk of microbiological contamination from beer spoilage organisms. In order that this can be achieved, it is important that every piece of equipment which comes into contact with either the beer, nitrogen/CO2 or interface/ CIP water is designed so that it can be effectively in-place cleaned.

All pipework is designed so that not only are there no dead-legs, but also so that the maximum ‘T’ length to the valve is no greater than 1.5 pipe diameters from the join.

Liquid velocities are also carefully considered, as follows:
- Filtered beer < 1m/sec
- Unfiltered beer < 2m/sec
- CIP > 2m/sec

**Service Hygiene**

**Key Features:**
- Gas, water plus vent pipes NOT to be a source of infection
- Filtration for gas
- Water microbiological control (UV, Chloride Dioxide)

When looking at plant hygiene it is important not to overlook the microbiological condition of the services, which interface with the product. Consideration therefore needs to be given to the design of the supply systems for water, gases plus vent pipes. Not only should the particular service not microbiologically contaminate the product but also the system downstream of the control measure needs to be able to be in place cleaned. A monitoring system needs to be in place to ensure that the microbiological status of these services is known.

For water, microbiological control is important. Chlorine dioxide is usually used at around 0.5ppm. However, should it then pass through demineralisation or reverse osmosis systems, it needs to be removed using sodium metabisulphite. Base exchange systems are endemically infected with pseudomonas so post treatment is advisable either with chlorine dioxide or UV. If UV is used then there should be an intensity meter with corrective action taken if the intensity falls below an agreed level e.g. 70%.

**Washing and filling monitoring**

Keg plants are installed with condition monitoring systems to monitor the performance of each lane. This takes the form of analysing by head the number of faults and rejects, and enables the operators to assess easily whether maintenance work needs to be done on a lane either at the end of the rack or even during a rack. Ideally these systems should be designed to enable information to interpreted as easily as possible.

Washing and filling performance can be checked using a window keg or preferably using a monitoring keg. A keg with windows can enable wash cycle flows and the quietness of fill to be observed. This is assuming that safe access can be made to the plant to be monitored plus the orientation of the windows enables safe viewing of the processes. Monitoring kegs normally have three sensors, two temperature and a pressure sensor. The sensors enter the keg via the base adjacent to the logging equipment and battery.
There can also be a switch to detect the clamping operation which monitors the movement of the keg from head to head. The temperature sensors are set up to monitor the temperature of the base of the keg close to the end of the spear (T₁) (i.e. washing inlet, filling outlet) plus the temperature at the top of the keg close to the spear valve (T₂) (i.e. washing outlet, filling inlet). A third temperature sensor (T₃) is sometimes installed to monitor the temperature of the wall in the top of the keg as far away from the spear valve as possible. Data is downloaded from the logger either using an infra-red reader post the washing and filling operations or a mobile phone can be used which enables real-time viewing of the data.

Unrecognised problems can be much more insidious than the chronic problem such as steam distribution problems as a result of not using a ring main. Three examples are considered:

Negative pressures in the keg. A steam-purged wash or rinse cycle which permits excessive purging of the utility will heat every keg well above 100°C during purging and fill it with almost pure steam. A following ‘cool’ detergent wash or rinse at say 80°C or 60°C, will instantly condense the steam and create a high vacuum inside the keg. Apart from ‘sucking in’ excessive quantities of the following utility, and consuming excessive energy; such a vacuum presents a significant risk of inspiring non-sterile atmospheric air if the head and closure seals are not in good condition.

The negative pressures will occur in every keg, in every lane. Just occasionally an infection may be introduced or contamination caused because of poor seals or ‘suck-back’ from any of the lines connected to the tapping head. This could occur in any lane, and if the negative pressure condition is not known and dealt with, it will be exceptionally difficult to pinpoint such an apparently random occurrence.

One cure is to re-program the racker control, reset sensors (pressure, temperature, conductivity) to eliminate the excessive purging which is the basic cause. Alternatively, air purging could be used for early washes.

Inadequate purging. If a utility is not fully purged at the end of its cycle, it may be carried over to the next head or cycle; and this can cause recurring contamination or bad taste problems. A quantity of detergent could be carried over in every keg, which at minimum will be lost from detergent recovery and contaminate the rinse water. At worst, it may taint the beer.

The fault may be a defective probe, or inadequate purge time.

Low steaming temperatures. Disinfection will be seriously affected if adequate steam conditions – a composite of temperature, time, and steam quality – are not applied. Disinfection is discussed in more detail later. Discovery of such conditions is a stimulant to rapid corrective measures to improve purging and raise temperatures. If the controller is easily programmable, the necessary re-adjustments will be straightforward and low cost.

Another problem of steaming is where little or no time is allowed for the keg metal to heat up, and final temperatures are much lower than theoretical.

Keg hygiene
The keg should be a sealed hygienic unit, and in practice most are – they circulate with reasonably short frequency, and are not contaminated or tampered with in trade. However, the keg leaving the brewery also leaves the brewery’s control; and there is no guarantee that it has not been tampered with later, kept out of circulation for a year, or suffered some damage; and therefore every keg must be regarded as potentially contaminated.

Different recognised problems arise with ‘export’ beers, where the keg may routinely be away for 6 months or more. Particular problems also arise with qualities like weiss beers and live ciders, and packaging managers are well aware
of the disciplines needed to ensure that these potentially heavily soiled kegs are identified. If any such export kegs, or those with a burden of solids, are racked on the same lines as ‘normal’ qualities, it is usual for separate intensive washing and disinfection cycles to be applied.

**How do you measure and assure keg hygiene?**

The simplistic answer is to define a minimum standard for washing and disinfection. The next stage is to ensure that the plant is set up to meet or exceed that standard (and to alarm or stop if it falls below), with this verified frequently.

In practice, it is impossible to check every keg, and assurance can only derive from reliable plant operation and verification by confident regular statistical sampling. Keg hygiene will be assured if all infections and beer spoilage organisms are destroyed and there is no contamination from carried-over utilities or the steam itself. This is not sterility, but will normally eliminate cloudiness, bad taste, and most other direct causes for returned beer.

The classic test for hygiene is the laboratory ‘sterile rinse’; and properly conducted, this will measure the effectiveness of the racker disinfection regime – at that time, on that lane or head. It is widely recognised that to deliver credible results and avoid atmospheric or other contamination, the whole procedure has to be conducted with scrupulous care. It is a skilled operation, culturing takes days, and there is the logistical difficulty of what to do if high counts are returned.

Also the rinse test gives no indication of over-treatment, so for example, a racker cycle using 3 times as much detergent or steam as is really necessary (and with increased operating costs pro-rata), would not be distinguished from an adequate energy-efficient and minimum-cost cycle.

A test taking days provides a good historical record but by the time the results are available a large amount of contaminated product could be packaged and distributed.

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**STERILE FILTRATION AND PASTEURISATION**

**Sterile filtration**

Sterile Filtration is an alternative method to pasteurisation for achieving the desired microbiological stability in package. This process involves the removal of sufficient product spoilage organisms from the product to ensure that for at least during the stated life of the product, insufficient microbiological growth can take place for microbiological spoilage to occur. Sterile filtration has the advantage of avoiding heat treatment of the product and thus any possible flavour deterioration from heat treatment. Like flash pasteurisation sterile filtration occurs before the product is put into the package and thus there are risks of microbiological contamination occurring downstream of the sterile filter. This section will look at the ways of achieving this.

**Process Specification**

The process requirements need to be defined for the product concerned, notably:

- Feedstock maximum microbiological and non-microbiological load including concentrations and particle sizes.
- Filtrate maximum concentration and details of product spoilage organisms allowed to be present in the filtrate without microbiological failure occurring during the stated product life.
- Product viscosity and flow characteristics i.e. is the flow variable and/ or intermittent.

Microbiological load reduction from feedstock to filtrate is often referred to as the Log Reduction Value (LRV). Sterile filters should be capable of reducing micro load by >99.9999999999%. LRV is illustrated below.

- Sterilising filters can remove >99.9999999999% of bacteria
- Removal efficiency better defined as titre reduction or \( Tr \)

\[
Tr = \frac{\text{No of organisms at inlet}}{\text{No of organisms at outlet}}
\]

- \( Tr = 10^{12} = 10^{11} \frac{10}{10} = 10 \)

- \( Tr = 10^{12} = >10^{12} \frac{0}{0} \) (Also stated as LRV = >12)

**Filtration Mechanisms**

Cartridge filtration uses the four mechanisms for separating suspended solids from fluids:

1. Direct interception
2. Charge effects
3. Inertial impaction
4. Diffusional interception

The last mechanism mainly works where the fluid is a gas.

Direct impaction occurs where the pore or the opening between fibres is smaller than the particle thus trapping that particle. Particles tend to carry a negative charge thus if the filter medium can be induced to have a positive charge (zeta potential) then the particle is electrostatically attracted & retained by the fibre. Asbestos used to be an attractive medium for use in filter septums prior to the discovery of the health risks from using this material. Keiselghur has a weak charge and is sometimes used for this purpose as are certain nylon e.g. Ns6 Posidyne. Inertial impaction occurs because of the tendency for particles to travel in straight line compared with the fluid which takes the path of least resistance through the media and will divert around the fibre. The particle thus impacts with the fibre where it remains. This mechanism occurs less as the differential densities of the particles and fluids decrease. Hence this mechanism is more effective with gases than liquids. Diffusional interception utilises the random movement of particles (Brownian motion) to enable the particle to deviate from the direct path through the septum & to collide with the media where the particle is retained. This mainly happens when the fluid is a gas and even with gas filtration this effect can be negated if the channel in the media is filled with liquid.

Thus the key features, which effect filtration, are:
- Pore geometry
- Membrane thickness
- Surface charge

Doubling the membrane thickness will double the LRV.

**Filter Types**

A wide range of cartridge types are available. The cartridges can either have cylindrical or disc format, and are sometimes back washable.

There are two main concepts of filter media design:

1. Non fixed pore filter media
2. Fixed pore filter media

Fixed pore filters are made up from either several layers of filter medium or a single thicker layer. These filters work mainly on direct interception with some adsorption by inertial impaction and mainly with gases by diffusional interception. The pore size can be larger than the removal rating, however the pore size is controlled during manufacture. This combined with sufficient depth enables release of collected particles to be minimised under impulse conditions.

Membranes are produced by casting nylon based material. Bubbles come out during the solidification process, leaving channels. The optimum membrane rating is 0.4 \( \mu \), 0.45 \( \mu \) absolute. Some membrane filters consist of two layers of membrane materials of the same rating, and others of different ratings, e.g. the first 0.65 \( \mu \) and the second 0.45 \( \mu \). Membranes are usually made from Nylon66, polyethersulfone (PES), polyvinylidene fluoride (PVDF) or polyaramid.

During the last ten years improvements in manufacturing techniques have led to a fourfold increase in the throughputs of some membrane cartridges.
Removal Ratings

Unfortunately there is no generally accepted rating system, which can lead to confusion. The most frequently quoted ratings are:

- Nominal Rating
- Absolute Rating

Nominal rating has been defined by the National Fluid Power Association (NFPA) as ‘An arbitrary micron value assigned by the filter manufacturer, based upon removal of some percentage of a given size or larger’. The lack of proper definition and poor reproducibility make this rating of dubious use. The general method is for a contaminant to be introduced upstream of the filter element and the effluent flow downstream of the filter is analysed. This method is gravimetric rather than a particle count test and gives no indication of the sizes of the particles which have passed through the filter. These can sometimes be considerably larger than expected. The test results can also be distorted if the contaminant loading is considerably higher than that to be presented to the filter in normal operation. In this case the removal efficiency at the lower infeed loading can be lower than that indicated by the rating. Typically the absolute micron rating of a cartridge is at least ten times and sometimes up to thirty times higher than the comparable nominal rating.

Absolute rating is defined by the NFPA as ‘The diameter of the largest hard spherical particle that will pass through a filter under a specified test condition. It is an indication of the largest opening in the filter element’. This rating can only be assigned to an integrally bonded medium. There are several recognised tests for establishing the absolute rating. These tests are known as challenge tests as these tests are destructive and the filter cannot be used afterwards. The tests involve pumping through the filter a suspension of a readily recognised contaminant e.g. glass beads or a bacterial suspension. After the test has been carried out glass beads on the membrane downstream of the collection vessel are examined under a microscope to determine the size of the largest spherical bead which has passed through the filter. The size of this bead establishes the absolute rating of the filter.

More recently a test has been developed using automatic particle counters before and after the test filter. The Beta ($\beta$) Rating System test measures the total particle count change across the filter with a contaminant suspension at several different particle sizes.

The Beta value ($\beta$) is defined as:

Number of particles of a given size and larger in the filter infeed stream

Divided by

Number of particles of a given size and larger in the filter outfeed stream

$\%	ext{ Removal Efficiency} = \frac{\beta - 1}{\beta} \times 100$

This relationship is illustrated below:
Usually a $\beta$ of 5000 to 10000 can be used as the operational definition of an absolute rating.

This approach enables the meaningful comparison of different cartridges. The diagram below shows the $\beta$ curves for three different cartridges.

### Filter Flow Characteristics

The key factors effecting flowrate and cartridge life are:
- Pressure Drop
- Surface Area

On a new cartridge as the flowrate or product viscosity increases so will pressure drop. The pressure drop across the filter will also increase as the pores become blocked. This increase in pressure drop is normally linear until close to the dirt capacity of the filter when the increase becomes exponential. The dirty capacity is normally measured using a reproducible contaminant, which is usually A.C. Fine Test Dust. A.C. Fine Test Dust is a graded, naturally occurring dust composed of 68% SiO$_2$, 16% Al$_2$O$_3$, and 4.6% Fe$_2$O$_3$. The fine grade has 39% of its mass in particles less than 5 micrometers in size and 73% in particles less than 20 micrometers in size. When specifying the system it is important to be aware of the minimum filter outlet pressure requirements. For example is the receiving tank pressurised, what is the pressure drop between the filter outlet and the receiving tank?

In order to increase flowrate, reduce pressure drop or increase cartridge life the surface area can be increased. In fact doubling the area at constant flowrate can increase the dirt capacity by up to a factor of four. This is illustrated below.

This is because at the lower flowrate per unit area the dirt thickness can be almost doubled. This relationship is described in the equation below:

$$
\frac{T_2}{T_1} = \left[ \frac{J_1}{J_2} \right]^n
$$

Where:
- $n$ is the extension life factor and $1 \leq n \geq 2$
- $T$ is the throughput in litre
- $J$ is the flow density litres per minute per square metre
The life extension factor is reduced nearer to 1 if:

1. The filter cake is compressible
2. The filter cake becomes finer than the filter medium
3. The solids collected are not relatively uniform in particle diameter.

Increasing the filtration area increases the housing size, the cost of a fresh charge of cartridges and the possible losses from the system. One solution is where practicable to pleat the media. This can lead to an increase in filter area of more than thirteen times compared with a straight cylinder.

Another way of increasing effective filtration area is by increasing the voidage (free space). When this is done it is important that the strength of the filter medium does drop below the point where failure can occur.

**Pre-Filtration**

In order to extend the life of the sterilising filter it is usual to install a pre-filter. If this is not correctly sized then the sterilising filter life will be prematurely short. A correctly sized pre-filter enables a smaller sterilising filter with optimal life. For beer the pre-filter could be 1.5μ absolute and the sterilising filter 0.45μ absolute. If the cartridges are to be steamed, then the steam should also be filtered, as should the liquor used for flushing with a similar filter (c 1μ).

**Housings**

Stainless steel is the usual construction material and needs to be crevice-free along with the ability to be emptied with minimum beer loss. The housing needs to be capable of being quietly filled, thus a bottom inlet is preferable. A vent at the top allows complete elimination of gas from within the shell, and can also be used for blowing down the filter at the end of filtration. Inlet design needs to ensure that the flow does not impinge on the filter medium. Inlet and outlet connections need to be of a large diameter to minimise pressure drops with the inlet and outlet in the base to minimise risk of oxygen uptake. Typical sanitary housing components are shown.

Pressure gauges are required either side of the filter to monitor the pressure drop, and these should be of the diaphragm type. Careful consideration is required as to how the filter is going to be cleaned. If backwashing is being considered then the liquid used should be free from particles, and thus is likely to need filtration itself. If the filter is to be steamed then this should also be filtered. At the time housing design is selected, a decision needs to be made as to the design of the cartridge end fitting to be used for sealing the cartridge into the housing. Consideration of this aspect of design is essential, as, should the cartridge not seal into the housing properly, then liquid which contains particles, either biological or non-biological, can bypass the
filter media. With larger scale sterile filters then automation becomes feasible. Cartridges can be grouped in clusters, which enable the cluster to be integrity tested and automatically isolated should the cluster fail.

**Integrity Testing**

Pasteurisation can be monitored with feedback during the process by measuring temperature and time at that temperature. A similar method is required with sterile filtration as retrospective feedback from micro results is not satisfactory. In order to meet this requirement nondestructive integrity tests have been developed which enable the cartridges to be tested prior to the start of a run post CIP and sterilisation. These tests involve the use of an integrity tester dedicated to that particular filter housing or group of filter housings. A gas supply is normally connected to the tester and the tester then connected to the inlet side of the housing usually the top. The outlet side is then opened to atmosphere and gas then introduced with the housing pressure on the inlet side carefully monitored automatically by the integrity tester. System resolution is around 2mbar. The tests include bubble point, pressure decay and forward flow pressure decay. The bubble point test involves measuring the pressure, which overcomes the surface tension resistance of the liquid in the pores of the cartridge. The pressure is a function of the size of the largest pore. This test is qualitative rather than quantitative, but it gives an indication as to the size of the largest pores in the membrane.

Pressure decay with forward flow involves pressurising the inlet side of the housing to a set pressure, adjusting the gas flow to maintain that pressure and allowing the system to stabilise with constant flow and pressure followed by stopping the inlet gas flow and measuring the rate of pressure decay. For that particular housing and cartridge type, the acceptable rate of decay is known. A faster rate of decay indicates that the total area of the pores are larger than they should be and thus fail the test. The results can either be digitally stored or recorded on a magnetic card.

**Filter CIP**

The objectives of filter CIP are not only to remove any material embedded in the filter, but also to sanitise the filter. Some trap filters are now designed so that they can be backwashed at flow rates up to 1.5 times the standard filtration flow rate. As stated earlier, it is important that the cleaning fluid is free from particles, and also might need to be filtered itself.

If the cartridge has not been designed for backwashing, then it probably will be damaged by the use of this practice. Alternatively, these filters can be cleaned in the forward flow mode, either with hot liquor, or sodium hydroxide. It is important not to force particles further through the filter media such that they are released into the product stream during subsequent filtrations.

Filters should either be sanitised with steam or with a sanitiser during the CIP final rinse. In the case of pleated cartridges it is important to ensure that the correct glue is used which is capable of standing the CIP temperature. If steaming is to be used then the steaming life of the cartridge should be considered, as it is possible that a very expensive cartridge might need to be replaced because its steaming life has been reached, and yet its operational active life has not.

**Membrane CIP/Sterilisation**

When sizing the filtration area for a sterile filtration system it is absolutely essential to specify not only the maximum pressure drop across the filters and flow rate required, but also the filtration run length in between CIP/sterilisation. In order to set this specification, consideration must be made as to the filterability of the products to be passed through the system, as there can be considerable variation from product to product. If the product is being filtered into a bright product tank such problems can be less
disastrous, but if the product is being filtered directly on to a filler then line efficiency and output can be immediately affected. Filter CIP/sterilisation is carried out not only to clear material from the filters, if possible, but also to ensure that the filter and downstream pipework is sterile and will not cause microbiological contamination. More of the membrane filters available now are able to be backwashed, ideally at greater than the forward flow velocity. As mentioned earlier, it is absolutely essential that the liquid used for this is free from particles down the size rating of the filter being backwashed, and therefore a similar sized membrane filter is required on the liquid feed. It is also important not to introduce infection downstream of the sterilising filter.

Sterilisation of the membrane filter can be effected using steam, hot liquor, or chemically. The steaming life of some membrane filters can be as low as 16 hours with each cycle lasting 20 minutes at 121°C. It is important that if steam is used, that this is also filtered to remove any particulate matter. Steaming will therefore dictate the life of these expensive cartridges which may have to be replaced after 48 cycles.

If hot water is used, then this should be used at 80°C +/- 5°C, and chemical usage can include combinations of 0.1% to 0.2% sodium hydroxide plus 100 to 200 ppm chlorine, peracetic acid at 150-200 ppm, or sodium metabisulphite at 250 ppm. The advantage of using some chlorinated alkali as part of the cleaning and sterilising regime is that it will break down and remove proteinaceous deposits on the membrane.

Cross flow filtration

This type of filtration involves the pumping of the unfiltered product tangentially to a membrane which allows the product to pass through and stops product solids, i.e. protein, yeast and bacteria.

The early membranes were ceramic and were designed in such a way that they had a high pressure drop across the membrane of around 4 bar leading to high energy costs plus heat input. Polypropylene membranes were then developed with reduced pressure drop of around 1 bar. At the same time ceramic membrane development using small ceramic particles in the wall of the membrane backed up by larger particles enabled a reduction in pressure drop in these membranes as well. The ideal membrane pore size is around 0.5µ. Early membranes of only 0.2µ were available resulting in a loss of head retention. Polypropylene also has the disadvantage that the maximum temperature for CIP is 50°C. The use of PTFE would be preferable and could withstand up to 280°C. One of the key problems has been fouling of the membrane leading to increased energy costs and reduced fluxes. Reverse flow pulses do improve the situation. Methods of increasing turbulence round the membrane pores have been developed using vibration from a torsion spring. As a filter septum which must have higher integrity than a cartridge septum, cross flow could well be the ideal filtration method for producing sterile product. Further work is obviously required with respect to the reliability and repeatability of the process, and membrane life must be an important factor in the cost-effectiveness of this method of filtration. Current indications are encouraging.
The successful development of cross flow filtration will not only provide longer lasting high integrity septums, but will also provide low cost filtration and microbiological stabilisation which will be more environmentally friendly due the absence of diatomaceous earth.

Pasteurisation Theory

Aims of Pasteurisation
The aim of product by inactivation of pasteurisation is to prolong the shelf life of the
• All micro-organisms capable of growing
• Enzymes which may cause undesirable chemical changes

Pasteurisation theory was developed around 1865 by Louis Pasteur, and involves the reduction of micro-organisms by heating to a limited temperature. Thus its objective is to ensure that the process has minimal effect on the physical stability of the beer combined with maximum biological stability. Beer spoilage organisms are not pathogenic, and therefore the key decision with respect to pasteurisation is to the level of treatment required to meet the desired specification, i.e. the degree of risk of product spoiled by beer spoilage organisms reaching the customer.

Pasteurisation should not be confused with sterilisation, which is the inactivation of all micro-organisms and requires a much harsher heat treatment. Pasteurisation is a statistical kill-rate of micro-organisms as defined by the formula below. Sterilisation is an absolute heat treatment process and will produce a fully stable product with shelf life of several years but the taste and appearance of the product will be significantly impaired. For beer products, pasteurisation is sufficient to achieve stability because micro-organisms such as spores, which survive heat treatment, are unable to grow in beer due to its alcoholic and chemical make-up.

To achieve an effective pasteurisation result 5 key factors need careful consideration:
1. Pasteurisation temperature
2. Pasteurisation time
3. Micro-organisms present by type
4. Concentration of micro-organisms present
5. Chemical composition of product

Pasteurisation level
The level of pasteurisation required depends on the resistance to heat of the micro-organism concerned; this is called the “thermo-tolerance” and is defined by two main factors:

Decimal reduction time, D (minutes)
This is the time needed at a given temperature to inactivate 90% of the viable population. This varies for each type of micro-organism present. Typical values for beer spoilage micro-organisms at 60°C are $D_{60} = 1$ to 5 minutes with 2 minutes being a typical average.

Temperature dependence value, Z (°C)
This is the increase in temperature required to reduce the D-value by 90%. This also varies for each type of micro-organism present. Typical values for beer spoilage micro-organisms are $z = 3$ to 8 °C with 6.94 °C as the accepted standard for most beer spoilage organisms.

In theory, these two values should be determined for each micro-organism present and combined to give an overall D and Z value for each product. In practice, since the types and quantity of micro-organisms can change daily, this would require so much analysis that the beer would become spoilt during the time it took to complete the calculation! So, typical values as stated above are used together with the general pasteurisation formula devised from the work carried out by Louis Pasteur.

He proposed the concept of measuring the effects of heat and time on micro-organisms in pasteurisation units (unit de pasteurisation, UP) where 1 pasteurisation unit (PU) corresponds to the holding the product at a temperature of 60°C and for a period of 1 minute.

This is now accepted as the standard definition of a Pasteurising Unit.
This is summarised in the current pasteurisation unit formula as:

\[ PU = t \times 1.393(T - 60) \]

Where:

- \( PU \) = number of pasteurisation units
- \( T \) = holding time in minutes
- \( T \) = Holding temperature in °C

\[ 1.393 = 10 \frac{1}{Z} \]

- \( Z \) = Temperature increase to reduce D-value by 90% (°C)

\( D \) = Decimal reduction time (time at a given temperature to inactivate 90% of viable micro-organisms)

PU is referred to as PE in Germany (Pasteurisations Einheit)

From this, there are some useful rules of thumb, which can be used on routine basis:

- An increase in temperature of about 2°C doubles the number of PU for the same holding time
- An increase in temperature of about 7°C increases the number of PU by a factor of 10 for the same holding time
- A PU level of 20 means that there is a statistical chance of 1 in 10 billion micro-organisms surviving. A PU level of 30 means that there is a statistical chance of 1 in a million-billion micro-organisms surviving.

The relationship between PU and temperature is shown graphically:

**The effect of pasteurisation on different organisms**

Since the theoretical PU level required does vary for each micro-organism, established practice is to vary the number of PU depending on the product type and shelf life required. Typical PU values for micro-organism concentrations up-to visible turbidity levels are given in the table below; this also shows the effect of product type – alcohol level and chemical composition.

<table>
<thead>
<tr>
<th>Micro-organism</th>
<th>Typical thermo-tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewers’ Yeast</td>
<td>1 PU</td>
</tr>
<tr>
<td>Pediococcus sporidium</td>
<td>1 PU</td>
</tr>
<tr>
<td>Lactobacillus sporidium</td>
<td>5 PU</td>
</tr>
<tr>
<td>Wild yeasts</td>
<td>10 PU</td>
</tr>
</tbody>
</table>

It is vitally important at the beginning of specifying a pasteurisation process, especially if this involves the design and construction of a new tunnel pasteuriser, to identify the number of PUs of heat-treatment required. There is a wide diversity of opinion, not only from company to company, but also regionally around the world. In Europe and especially the UK there is a tendency to specify 20-30 PU, whereas in the United States plus Japan this figure can be as low as 5 PU. Obviously the better the microbiological quality of the beer entering the pasteuriser, then the lower is the need for overkill. Therefore with the general trend in the improvements in the microbiological quality of beer prior to pasteurisation, it is highly likely that pasteurisation specifications could be reviewed downwards. However, it is important to remember that a lot of money is being invested in providing the peace of mind through a pasteuriser, and therefore it would be disastrous to have a specification, which resulted in product failure post-pasteuriser. Ideally, therefore, the pasteurisation specification should be built up based on scientific principle with an added safety margin to ensure that the risk of unusually high loads, operating variations within the pasteuriser and control variations are taken into account.
Simple calculations on the relationship between pressure, temperature and CO₂ content

There must be an understanding of the relationship between temperature, pressure and CO₂ content. This is especially important during plate pasteurisation. Henry’s Law is explained as follows:

- For a dynamic equilibrium to exist between liquid and gas, there must be no net transfer of gas across the interface.
- If either the temperature or pressure changes, the equilibrium is disturbed. As the temperature increases, the gas content reduces.
- The concentration of these gases in beer is directly proportional to the pressure of that gas in the gaseous phase.

The relationship is known as Henry’s Law and is quantified by the equation:

\[ P_{CO₂} = H_{CO₂} \cdot X_{CO₂} \]

Where:

- \( P_{CO₂} \) is the pressure of CO₂.
- \( H_{CO₂} \) is Henry’s Constant for CO₂.
- \( X_{CO₂} \) is the molar fraction of CO₂ in the liquid phase.

The same would apply for nitrogen, oxygen and other gases.

Pressures are expressed as absolute pressures. Absolute pressure equals the gauge pressure plus atmospheric pressure (normally equivalent to 100kN/m² or 1 bar). Absolute pressures are denoted with an (a), gauge with (g).

One of the best ways to confirm understanding is through an example calculation:

**Beer containing 1.9 volumes of Carbon Dioxide (CO₂) per volume of beer at STP is pasteurised at 73°C. Assuming beer has the same molecular weight and density as water, calculate the mole fraction of CO₂ in the beer and the pressure required to maintain it in solution at the pasteurisation temperature.**

**Given:**

- Henry’s constant for CO₂ at 73 C is 440 MPa (or 440 x 10³ kN/m²)

**Assumptions:**

- Molecular weight water = 18
- Molecular weight CO₂ = 44
- Specific gravity (sg) water = 1.0

Avogadro’s hypothesis states that equal volumes of different gases at the same temperature and pressure contain the same number of molecules. i.e. 1 gram mole (in the case of CO₂, 44 grams) will occupy 22.4 litres at standard temperature and pressure (STP). STP = 273K and one atmosphere.

Firstly convert the volumes into grams per litre assuming that the quantity of beer is one litre:

- 1.9 volumes of CO₂ in one litre of beer is 1.9 litres equivalent
  - 1 mole of gas occupies 22.4 litres. 1 mole of CO₂ weighs 44 grams
  - So 1.9 litres of CO₂ weighs \((1.9/22.4)*44 = 3.732\) g/l
  - Therefore number of gram moles (A) = \(3.732/44 = 0.084821\)
  - Number of gram moles in 1 litre of water (B) = \(1000/18 = 55.55556\) gram moles
  - Mole fraction CO₂ (C) = \(A/(A+B) = 0.001524\)

Henry’s law states that the amount of gas absorbed by a given volume of liquid at a given temperature is directly proportional to the pressure of the gas (P) i.e. \(P = H \times X\). Where H is Henry’s constant for the molecule at that temperature.

- Pressure (P) = 440 * 0.001524 = 0.670762 MPa = **6.7076 bar(a)**
Plate (Flash) Pasteurisation

Introduction
Plate pasteurisation is the in-line heat treatment of product in a plate heat exchanger to achieve microbiological stability before packaging. Due to the short exposure time to the elevated temperature, the process has previously been called “flash pasteurisation”. The new term is used in these notes.

A key target in plate pasteurisation is the balance between inactivation of micro-organisms harmful to human health and the effects of heat on the sensory quality of product.

The heat treatment is a combination of holding time and PU level and this will determine the pasteurisation temperature from the PU formula given under ‘Pasteurisation Theory’. This is typically in the range 71 to 74°C with a minimum level of 69°C recommended. This is because there are some micro-organisms that are very resistant to temperatures below 65°C.

<table>
<thead>
<tr>
<th>Product type</th>
<th>Typical PU level</th>
<th>Typical pasteurisation temperature, °C</th>
<th>Holding time, seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keg beer</td>
<td>15-25</td>
<td>72</td>
<td>25</td>
</tr>
<tr>
<td>Low alcoholic beer</td>
<td>50-100</td>
<td>75</td>
<td>30</td>
</tr>
<tr>
<td>Cider</td>
<td>&gt;1,000</td>
<td>85</td>
<td>30</td>
</tr>
</tbody>
</table>

Operating Parameters
The basic requirements of a pasteuriser are to maintain a constant pasteurisation temperature to ensure all of the product is exposed to the correct temperature for the right length of time and hence achieve the right PU level.

When assessing requests for accurate PU control, the starting point has to be the accuracy and response of the temperature sensor and transmitter. When 1 PU represents 0.15°C, the challenge is clear.

In reality, with intelligent application of software and selection of grade “A” instruments, a range of +/- 2 PU is now achievable over the process run.

The effect of time (derived from product flowrate) should not be overlooked even though the effect of variation is less dramatic; at steady temperature for say 25 PU, 1 PU variation results from 4% change in flow; flowmeter accuracy and response is well within this range at +/- 0.3%. The accumulative effect of instrument and system inaccuracies is shown below.

Accumulative Effect of Instrument and System Inaccuracies

The pasteuriser system will include PU monitoring in the form of temperature sensing at the end of the holding cell. Should the temperature drop below the set-point for a sufficient period then the product will not be pasteurised to the required level and the process will stop product being pumped forward for filling.

This can be in the form of diversion of product back to the inlet of the pasteuriser to be re-pasteurised or, more commonly nowadays, treated liquor pumped into the system until the correct pasteurisation conditions have been re-established. When this is confirmed by the control system, then product will be reintroduced and forward production resumed. The un-pasteurised product and the interface between product and liquor will be recovered for re-processing.

A record of the pasteurisation result will be
kept within the control system for future reference should any product quality issues arise. This used to be in the form of a chart recorder print-out but nowadays is more commonly a print out from the brewery’s SCADA system.

Other considerations
As well as the five key factors previously stated, it is essential to ensure that other physical parameters are considered.

Gas content
At pasteurisation temperature, with highly carbonated, nitrogenated or with mixed gas products, the saturation pressure required to keep the gases dissolved in the product becomes significant. This pressure is typically in the range of 10 to 14 bar gauge. This pressure is subsequently used to ensure high Tau values (see Ferment April/May 1999, pages 59, 61) at the plate surface giving more responsive control. This also reduces the need to reduce pressure across a control valve downstream of the heat exchanger.

The need to keep all gases fully dissolved in the product during the pasteurisation process is to ensure full pasteurisation of the micro-organisms present. A gas bubble in the product can provide an insulating layer around a micro-organism, which could potentially survive the heat treatment in the holding tube.

When calculating the saturation pressure required to keep all gases in solution, the partial pressure of each gas has to be accumulated to give the total pressure as defined by Henry’s Law. In addition to the added gases, there is also a partial pressure exerted by the vapour pressure of the water in the hot product. With today’s target of precise design with little risk, it is important to include this vapour pressure. Typically, this will add about 0.3 bar to the total saturation pressure required. Also additional pressure is required, above total pressure to keep dissolved gases in solution, in order to overcome flow pressure losses through the pasteuriser. They can be >1bar.

Most manufacturers will use a proprietary spreadsheet to calculate these values for all combinations of gases per product; the pasteuriser system must then be designed for the highest pressure but the actual operating pressure will be set by the recipe for the particular product to avoid operating at too high a pressure and thereby wasting electrical energy through excessive pumping.

As the table below shows, the highest pressure is for carbonated product at 5.89g/l (3 vol/vol) with a residual nitrogen level only. It is normal practice to include a safety margin of 1 to 1.5 bar on these figures depending on product type and gas mix.

<table>
<thead>
<tr>
<th>Gas Mix</th>
<th>Saturation Pressure (bar g) at Pasteurisation temperature of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>68°C</td>
</tr>
<tr>
<td>CO₂</td>
<td>90</td>
</tr>
<tr>
<td>N₂</td>
<td>65</td>
</tr>
<tr>
<td>CO₂</td>
<td>40</td>
</tr>
</tbody>
</table>

Product protection
It is desirable, if not essential nowadays, that in the event of a plate material failure, pasteurised product should be protected from unpasteurised product and product should be protected from service liquids. Both of these conditions are achievable in the plate heat exchanger by careful design.

For unpasteurised / pasteurised product, this can be achieved by boosting the pressure of pasteurised product to ensure it is always at a higher pressure than unpasteurised product, typically 0.5 bar is a minimum safety factor.

For product to heating fluid, this balance is guaranteed during normal running by the product pressure required to overcome gas saturation pressure, when using a hot water set for heating. The heating loop can be designed to relieve pressure when the pasteuriser is at rest to ensure that no over-pressure of heating water is left in the heat exchanger when there is no product pressure.

For product to coolant fluid, this balance is
readily achieved by careful design of the pressure drop in the cooling section and the position of the final product pressure-reducing valve. When this is placed after the cooling section, the pressure in the heat exchanger can always be designed to be at least 0.5 bar gauge in excess of the coolant pressure. As with the heating section, the coolant system can be designed to relieve the coolant static pressure when the pasteuriser is at rest. The effects of these pressures are shown below.

The critical point, for ensuring gas saturation pressure is exceeded, is now at the end of the incoming regeneration section rather than the holding cell as previously was the case with older designs of pasteuriser systems.

**Holding cell**
In order to ensure the correct level of heat treatment once the product reaches pasteurisation temperature, it is vital to maintain it at this temperature during the holding time. To achieve this the holding cell needs careful design with regard to heat loss.

It should be compact in design and insulated; this is also important for operator safety during both sterilisation and normal pasteurisation. To ensure a consistent residence time for the product going through it, it is important to minimise the effects of different radial passages on bends or paths of least resistance.

There are 3 main types in use today:
- Spiral tubular design
- Series of straight section tubes joined by 180° bends
- Wide gap plates in a pack in the pasteuriser

For heat loss, the wide gap plates give the least and the straight section tubes give the most. The Spiral tubular design is insulated or at least shrouded.

For residence time, the spiral tubular design gives the most consistent residence time, typically less than 5% variance, the straight section tubes gives typically less than 12% variance but the wide gap plates give typically 20% variance in holding time.

The combination of these factors mean that the spiral tubular design gives the best performance as a holding cell in a modern pasteuriser system with accurate PU control.

**Principle effects on beer quality during pasteurization**
Traditionally, plate pasteurisation has been the natural partner for a keg racker. This application still provides the majority of installations in the UK. However, driven by market demand for small-pack and led by development in European Breweries, the combination of plate pasteuriser and small-pack filler is now established.

The first small-pack installations in the UK were in the Beer and Cider industry during the 1970s and also required for beer in PET bottles.

The demand for this combination is mainly at the expense of tunnel pasteurisers and is due to the following factors:
- Thermal impact on the product
- Capital operating and maintenance costs
- Space
- Availability of sterile bottle fillers
- Reduction of downstream infection risks

Considering the main issues from above:

**Thermal Impact**
This is a measure of the total heat impact on the product (rather than pasteurisation effect on micro-organisms).
Arrhenius’s Law states that “for each 10°C increase in temperature, the rate of reaction is doubled”. Hence, a logarithmic measure when plotted against time given can be used to compare the thermal impact of different pasteurisation technologies.

When comparing plate pasteurisation to tunnel pasteurisation, the thermal impact for plate is 92% less compared to tunnel for the same PU effect. The most sensitive component to change flavour is oxygen. To avoid development of stale and papery flavours dissolved oxygen levels must be maintained to a minimum throughout the packaging process ie bright beer tank to sealed final package.

Downstream infection risks
The main infection risks downstream of the plate pasteuriser are:-

- Insufficient container washing
- Air-borne infection
- Filling and Capping machine cleanliness
- Process Gas
- Poor pipework and vessel cleaning

Other than air-borne infection, the risk with the other areas above are all controllable by effective CIP and sterilisation procedures and pose no greater risk to the product than any other method of pasteurisation.

Air-borne infection is now greatly reduced by the design of modern sterile fillers.

It should also be borne in mind that beer has a high natural resistance to infection. Therefore, completely sterile conditions are not essential to ensure a long shelf life in small-pack.

Hence, in practice, a plate pasteuriser working with a small-pack filler has been shown to give as good or better product quality as the conventional tunnel pasteuriser.

Possible plate pasteuriser problems
- Instrument Calibration
- Plate Failure
- Fob Beakout
- SCADA Monitoring Speed

The control and monitoring instruments need to be calibrated to an agreed repeatability and frequency.

Plate failure is a very serious potential problem. Risks are thermal shocking, pressure shocks and corrosion. Integrity testing needs to be carried out regularly. This can be done either using hydraulic pressure, gas detection (helium) or chemically. Whatever method is used careful planning and control is required to ensure that reliable results are obtained.

A new approach to avoiding cross contamination resulting from plate failure is the double wall plate. This consists of two plates welded together with a tell tale to indicate if one of the plates has failed.

Pasteuriser system design and control

Flow Control
The demand to vary the flow through the pasteuriser to suit container sizes or filling line inefficiencies has increased over recent years.

A range of proven control options is now available falling into three main categories:-

1. Fixed flow
2. Range of pre-set flows
3. Fully variable flow

The most suitable option will depend on several production requirements including:-

- Size of outlet buffer tank available
- Importance of no recirculation of product
- PU variation desired
- Product quality
- Type of filler

Each of these parameters needs assessing before a decision can be made on which type of plate pasteuriser system is most suitable.

All three options can offer the product pressure protection described above but options 2 and 3 lend themselves most readily to this as both require some form of flow and pressure control.

Options 2 and 3 also have an effect on the plate
heat exchanger design and performance. A reduced flow reduces the Tau value (shear stress) on the plate surface and reduces the pressure drop by a square relationship but increases the thermal efficiency by longer residence time in the regeneration section. This puts a limit on the minimum operating flow, which can still achieve the required PU variation. The minimum practical flowrate with current plate heat exchanger design and component flow ranges is 1/3rd of the maximum design flowrate. Reducing the flowrate to 1/3rd of its level will decrease the pressure drop to 1/9th of its full flow level. Tau is the shear stress between the liquid and the surface of the plate. The reduction in Tau shear stress value reduces the heat transfer coefficient but is compensated for by the increase in residence time in each section. However, the excess pressure has to be dissipated through control valves downstream of the pasteuriser.

The flowrate for option 2 is most likely to be pre-selected as part of the recipe for the product or container to be filled. However for option 3, the flowrate control becomes an integral part of the system design. As flowrate is changed, so is the residence time in the holding tube since this is a fixed length of pipework. Referring back to the PU formula shows that if the residence time is increased then the actual PU level will rise linearly. So to compensate for this and maintain a steady PU level, the pasteurisation temperature must be reduced. The PU formula shows that this is not a linear relationship but a power relationship. Hence, only small changes in temperature are needed to change the PU value. At the temperature levels normally used (72°C and 25 secs holding time) a temperature increase of 0.15°C will increase the PUs by 1.13

When controlling such small changes it is vital to ensure that the required minimum PU level is maintained but also not exceeded by more than the accepted variation of the system. The highest risk of over-pasteurisation will occur when the flowrate is decreasing and the system has an excess of residual heat in it particularly from the regenerative section of the plate heat exchanger; this is another reason for needing a responsive plate design as described above. With the appropriate control, a variable flow pasteuriser can reduce from full flow to its minimum capacity of 1/3rd flow in about 15 minutes and still maintain a +/- 2 PU tolerance.

It is vital to clean the pasteuriser at the full flow rate to maximise the Tau shear stress, which will ensure that the plate surface and all the other components stay clean.

Control philosophy
With a fully variable flow system requiring accurate PU control, it is evident from the above sections that there are 2 temperature control loops (holding cell and final product outlet), 1 flow control loop and 1 pressure control loop to design into the control system. The integration of these loops is vital to ensure that the PU set-point and control range are maintained.

The key parameter is holding cell temperature, as such small variances will produce a large change in the PU level as described above. The temperature set-point has to be altered with changing flow as does the holding cell pressure. This requires a complex cascade loop with a PU calculation included. The product outlet temperature is the only independent loop. The control of these parameters and the sequencing of the production steps is now a routine software solution controlled by a suitable PLC.

In-package or tunnel pasteurisation for small pack
An in-package or tunnel pasteuriser carries out the same task as a plate pasteuriser but after the product has been filled and sealed. It is a sort of insurance policy ensuring that all the beer in package is clean, and that any infection that has been introduced during the filling operation is destroyed. In Germany it is normal to sterile filter or plate pasteurise before filling, and then fill the bottles in a sterile environment. However, most German beer is sold locally to the brewery, so the risk of beer travelling and being left on the shelf for a long
period is not nearly so great. There is a tendency, however, with a greater understanding of sterility, for companies to be tempted to go the same way. A brewery in the UK has recently installed a non-returnable glass bottling line with a plate pasteuriser and PET lines will use plate pasteurisation due to the fact that a PET bottle can be damaged in an in-package pasteuriser.

If the process can be controlled the rewards of plate pasteurisation are great:

- For a 60,000bph line a floor area of up to 200 square metres can be saved
- Revenue costs are about 15% of an in-line pasteuriser. It is estimated that an in-package pasteuriser costs £1/hl to run. So for 1 million hectolitres, a saving of £850k per annum!
- A capital cost of circa £700k can be saved
- The product will normally taste fresher with less heat damage

One of the measures of heat damage is TIU (Thermal Impact Units). This is a measure of the total heat impact on the product (rather than pasteurisation effect on micro-organisms).

This is assessed by the temperature/time relationship based on Arrhenius Law that “for each 10°C increase in temperature, the rate of reaction is doubled”. Hence, a logarithmic measure when plotted against time given can be used to compare the thermal impact of different pasteurisation technologies.

When comparing plate pasteurisation to tunnel pasteurisation, for instance, the thermal impact for plate is 92% less compared to tunnel for the same PU effect.

On the negative side the cleaning regime for all contact points after plate pasteurisation needs to be strict. This can take time out of production. This also means stopping the filling operation every two to three hours and giving the filler an external clean for about ten minutes. Then a full CIP would be required after each product change and at a frequency of at least once every 48 hours – this would be dependent on the product. Also it will be necessary to ensure adequate laboratory cover to ensure that the process is in control.

**Flavour damage**

Flavour stability of beer depends primarily on the oxygen content of the packaged beer. Beer staling is a major topic with all brewers, and it is true to say that the mechanism for its development is not fully understood. Compounds causing the sweetish, leathery character of old beers are perhaps less understood than those causing the papery, cardboard character of 2 to 4 month old beers. This is due to unsaturated aldehydes, the most flavour active being trans-2-nonenol.

In order to ensure that beer has a good shelf life, it is important to keep the oxygen in package below 0.2ppm (200ppb) measured as TIPO (Total in Package Oxygen) and not subject the product to more heat than necessary during treatment. Many brewers insist that the exit temperature from the pasteuriser is as low as 20°C although 26°C is more normal. This is in order to prevent further deterioration during storage.

**Measurement of PUs**

If a pasteuriser is fitted with PU Control, the PUs accumulated in the product will be recorded. It has to be remembered, however, that this is a calculation which relates to a comparison between the water feed temperature to the sprays and not the sprays or product itself. In order for the calculation to take place, a programme is built up from data gathered from the actual product and container and this is put together by the supplier. The data relates to what the temperature is estimated to be at the ‘cold spot’.
Cold Spot
As the product is heated up in the container, the sprays will heat up the outer part of the container first. The speed of heat transfer will firstly be dependent on the material. As glass is a poor conductor of heat and metal is good, a can will reach the desired temperature first, so pasteurisation will take less time. Once the product takes the heat, the product against the outer walls of the container will heat up first, and as a result will rise to the top of the container causing the colder product to move down the centre to the bottom. This is known as convection.

As a result of this movement of product in the container the bottom of the container takes longer to heat up than the rest. This point is known as the cold spot and is located 6-10mm from the bottom of the container.

Measurement by travelling thermograph
Having established that a cold spot exists, this is the point at which all PUs must be measured in order to establish whether the product has been pasteurised adequately or not. It is important that the travelling thermograph is passed through at least once every eight hours for a PU Control pasteuriser and every two hours for a standard pasteuriser. The normal regime is to pass the thermograph through the pasteuriser left right and centre for each deck. For a pasteuriser fitted with spray bars, the point furthest from the pump is the most vulnerable. This is because any debris which escapes the filter will find its way to the end of the header tubes.

The thermograph or data logger has a probe which fits into the container and measures the PUs at the cold spot. It is better, in order to have a more accurate assessment, to have the containers in a cluster. It is possible to also measure the external temperature using another probe, if this is fitted. This gives the advantage of being able to identify where a temperature drop has occurred with much more accuracy, should this be necessary. Probes need to be checked for accuracy at the recommended intervals.