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SOPs FOR QUALITY CONTROL IN SMALL SIZE BREWERIES

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ABSTRACT

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The commissioner of the work was Kahakka Brewery, which is a small sized brewery located in Kokkola, Finland. The company did not yet have complete methods on how to ensure good quality of their products, which was the foundation for this work. The aim of the work was to create SOPs for the brewing process, and in this way improve the quality control of the process.

The brewing process is a complex and sensitive process, and every step is important and has to be completed successfully. Mistakes during one of the steps will have an effect on the whole process, and in the end also on the product quality. Therefore SOPs are implemented to ensure no variation in quality.

Quality management is of great importance in order to assure good quality of the products. The expected outcome of a quality management system is to produce high quality products in a consistent way. For a brewery, this equals producing quality beer constantly.

Key words
Beer, brewing, quality management, quality control

CONCEPT DEFINITIONS

Enzymes	Biological catalysts
Fermentation	A process that consumes sugar in the absence of oxygen
Grist	Grain intended to be milled
Hydrolysis	The breakdown of a compound by reacting with water
Isomerization	A compound is transformed to any of its isomeric forms
Mash	A thick mixture of water and milled malt
Proteolysis	Breakdown of proteins into smaller fractions
Saccharification	Breakdown of complex carbohydrates to simple sugars
SOP	Standard operation procedure
Total alkalinity	The buffering capacity of water to resist the change in pH
Total water hardness	The amount of dissolved minerals in the water
Wort	The liquid extracted from the mashing process

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1 INTRODUCTION

The aim of the work was to create standard operation procedures (SOPs) for Kahakka Brewery's process in order to control the quality of the products. The work includes the SOP for milling and mashing for a Helles beer, which the brewery can use as models to implement SOPs for further process steps. The SOPs are first version SOPs and there is room for the brewery to develop and improve the SOPs when needed.

Kahakka Brewery is a Finnish company located in Kokkola, Finland. Kahakka Brewery was founded in 2017, as an answer to the growing national beer market, and has 15 owners. The company focus is on new beer trends as well as the craft beer tradition in Scandinavia and Europe. The aim of the company is to meet the customer requirements on quality craft beer and the company is proud to bring Central Ostrobothnia to the global beer-map. The brewery has two start-up products, Neri Pils and Kahakka Pale that were introduced to the public in the combination with a beer festival held in Kokkola in August 2017, where Kahakka Brewery was one of the organizers. (Kavilo 2018.)

The aim of this thesis was to study the field of Quality Management, and how to implement it in a brewery in order to achieve good quality of the products. The goal was also to define what quality is and why it is particularly important to ensure good quality of products. The task was also to become familiar with the brewing process itself, and with malting of the barley, which is used as the raw material in the brewing process. This work describes the malting and brewing processes step by step, so that it is easy to understand the processes. At the simplest level, malting and brewing stands for the conversion of starch into alcohol.

The malting process is just as important as the brewing process in order to make high-quality beer. Malting takes place in three steps, which are steeping, germination and kilning. The malting process takes approximately 4 to 6 days to complete, depending on the requirements of the produced malt.

The brewing process itself is a sensitive process, and every step is important and has to be completed successfully. Mistakes during one of the steps will have an effect on the whole process, and in the end also on the product quality. It is important that the malt used as raw material in brewing has a good quality, because the malt itself has a direct effect on the quality of the beer. High quality beer is brewed when the brewing process is carefully optimized and a good quality malt is used as raw material.

These days, quality is extremely important for breweries, and if the quality of the beer is poor it may result in loss of customers. Therefore it is important for a company to define what quality means for them, and what needs to be done in order to achieve respectable quality. Quality management systems are implemented in order to help companies achieve the quality goals they have set for themselves, and also helps in determining the responsibilities for the quality manager and the employees in terms of quality control.

2 MALTING OF BARLEY

The malting process is just as important as the brewing process in order to make a high quality beer. The three main stages included in the malting process are; steeping, germination and kilning (GRAPH 1). The process transforms barley into a resource for brewing and source of nourishment for yeast. The malting process takes normally 6 to 10 days, depending on the required qualities of the produced malt. (Bamforth 2003; Mallet 2014.)

The goal of the malting process is to soften and modify the structure of the barley grain so that it is easier to mill in the brewery. Malting can be considered a pretreatment process of barley before it enters the brewery. It is possible to brew beer from untreated barley, but it is difficult to work with it and the beer will have a grainy character. (Bamforth 2003.)

GRAPH 1. The malting process (adapted from Bamforth 2003)

Cultivated barley is a cereal crop that is used in the process of making malt and it is closely related to wild barley. Barley is an important cereal food crop, and is cultivated mainly in Europe and North America. Barley grows in two-row, four-row and six-row form, but only two- and six-rowed barley are used for brewing beer. A scheme of the two- and six-rowed barley is presented in Figure 1. The two-rowed barley is typically used in Europe, and the six-rowed barley is preferred in North America. European brewers prefer the two-rowed barley because it has a malty flavor and better starch-husk ratio. There are some differences between these two types of barley. For example, the two-rowed barley kernels are larger and more uniform than the six-rowed kernels. (Boulton 2013; Goldammer 2008.)

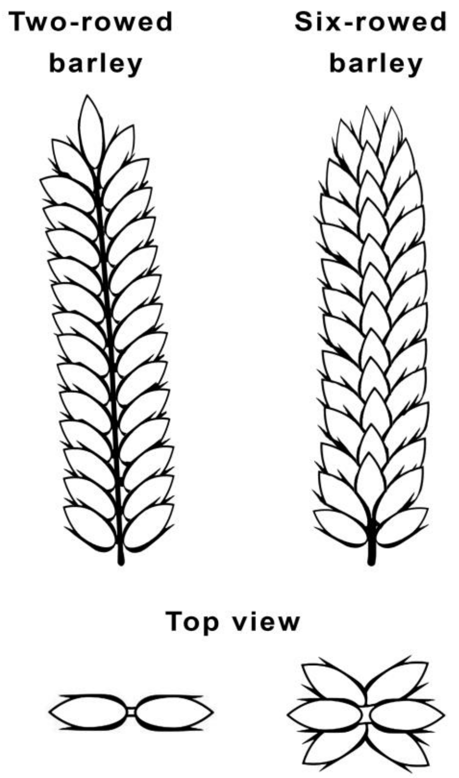


FIGURE 1. Two- and six-rowed barley

2.1 Steeping

The purpose of this process step is to increase the moisture content of the barley from approximately 12 to 45 %. In the first step of malting, barley is steeped in water, which will enter the grain (FIGURE 2). The water will enter through the micropyle and will then spread to the embryo. The embryo produces hormones that will travel to the aleurone, which is the tissue surrounding the endospherm, which contains starch. The hormones produce enzymes, which will chew down the cell walls in the aleurone and then enter the endospherm. The enzymes will digest the walls of the aleurone and some of its protein. As a result of hydrolysis, the grain becomes softer and easier to mill in the brewery. (Bamforth 2003.)

The time needed for steeping the grain is approximately two to three days. When the steeping is complete, the grain should be evenly hydrated and show signs of germination, namely that the tips of the rootlets are emerging from the grain. During the malting process only 5 to 10 % of the starch in the endospherm is lost. Starch is the source of sugars used in fermentation, and therefore it is important that as much starch as possible survives the malting process. (Bamforth 2003.)

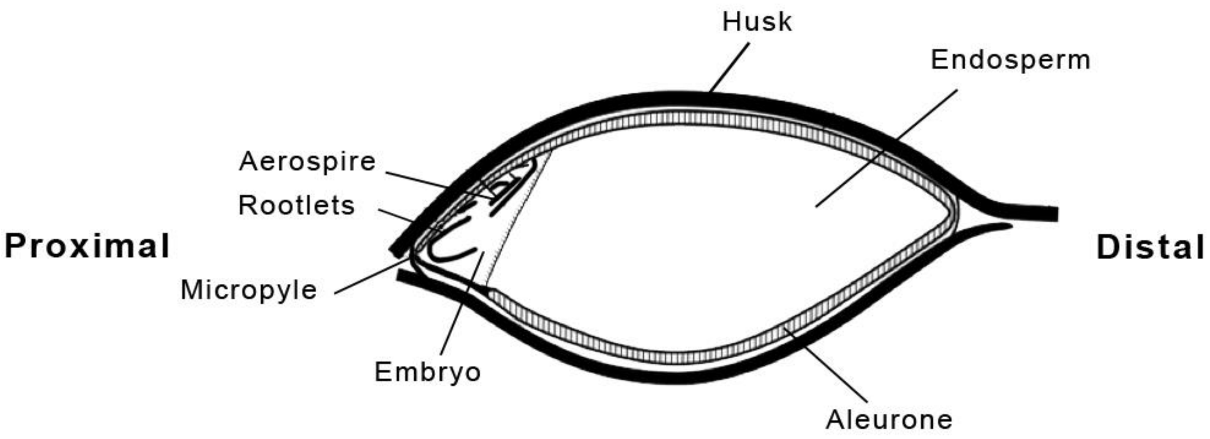


FIGURE 2. The barley grain (adapted from Bamforth 2002)

2.2 Germination

In this process step, the cell wall and the proteins are degraded into small soluble molecules. These molecules then move to the embryo for nutrition. Using the food, the embryo starts to grow and produce rootlets and a shoot, which is called the aerospire. Extreme development of the rootlets is not desired, because they consume material which otherwise could be sold to the brewer. The rootlets move out from the micropyle, and this is the first sign of germination.

The aerospire grows in the opposite direction from the roots, under the husk, and eventually emerges out of the distal tip. If the aerospire does appear from the distal tip, it is a sign that germination has gone too far. (Bamforth 2003.)

During germination the grain is allowed to grow under controlled conditions, where the internal structure of the grain is altered. In order to control the growing conditions, fresh, humidified and temperature controlled air is pulled through the bed of grain regularly. If necessary, chilled water can be used to cool down the supplied air, in order to maintain the temperature. (Mallett 2014.)

2.3 Kilning

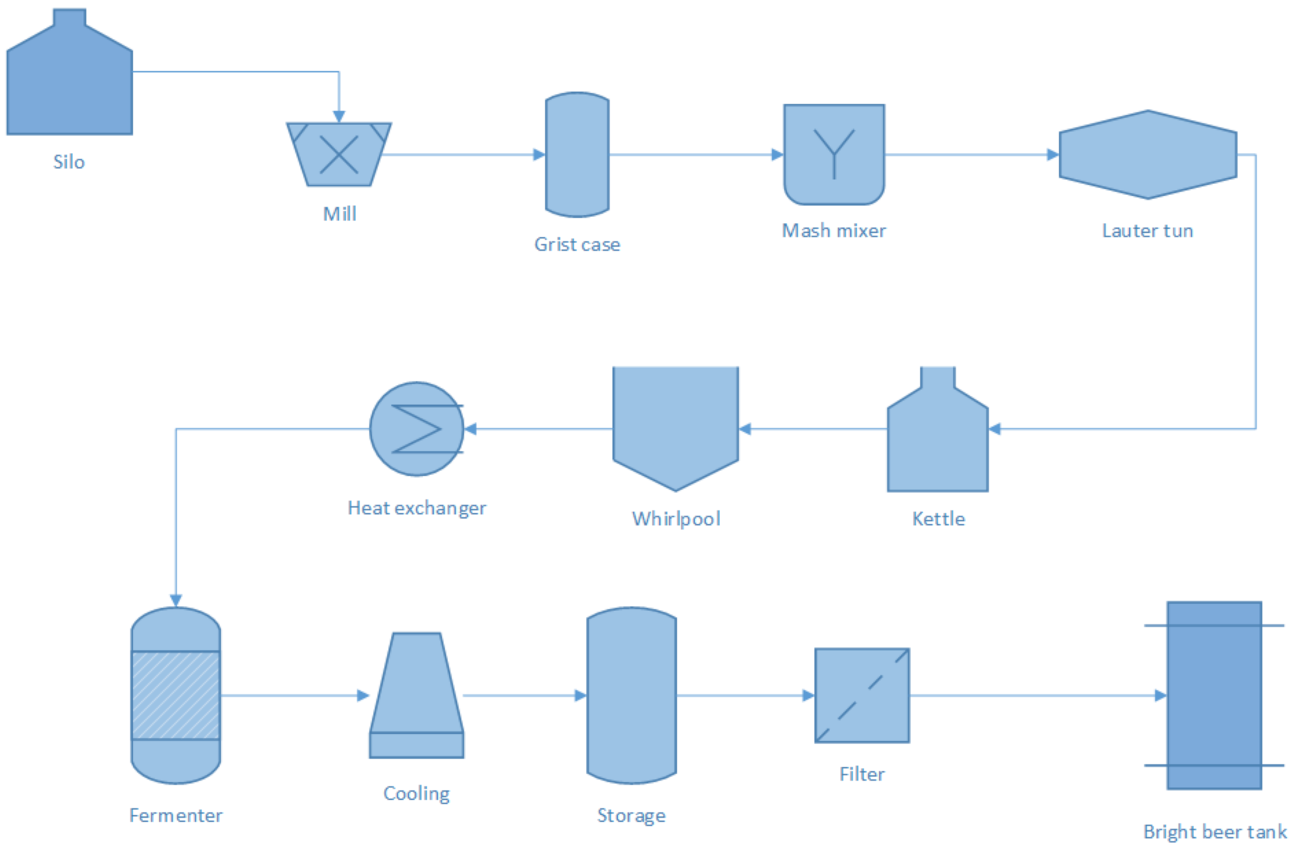
After germination, the grain is dried in a process operation called kilning. The aim of kilning is to drive off water from the grain, so that the moisture content decreases from approximately 45 % to below 5 %. The enzymes produced in germination are sensitive towards heat, especially in high moisture levels, and it is important that they survive the process. To ensure that the enzymes survives the process, kilning is started at low temperatures, about 50 °C and when half of the water content has evaporated, the temperature can be raised. The temperature is raised at a certain time interval, depending on what type of malt is produced. The maximum temperature used in kilning is around 220 °C. Kilning continues for one to two days, and during this stage of the process the final flavour and colour of the malt are determined. When the kilning process is completed, the malt is cooled down and small rootlets are removed. (Bamforth 2003.)

Malts that will go to the production of ales are kilned to a higher temperature than the malt that will go to the production of lagers. Malt that is kilned in higher temperatures has a darker colour. This is because the amino acids and sugars released from proteins and carbohydrates during the germination stage are combined and form melanoidins. It is the melanoidins that affects the colour. The higher the temperature during kilning, the more amino acids and sugars are formed, and the darker the colour of the malt. Additionally, also the flavour of the malt is affected by the kilning temperature. If the malt is kilned to an especially high temperature, it is possible to make extremely dark beers. (Bamforth 2003.)

On the other hand, malts for lager beer are not modified as much as malt for ales. This means that the malt contains less amino acids and sugars. The malt is also kilned in relatively mild temperatures, which means the malt develops less colour and a different flavour. (Bamforth 2003.)

3 BREWING

The typical grist material for brewing is malt, but there are others too, for example rice, roasted malt and corn. Maltings and breweries are usually not on the same site. There are so called brewer- maltsters, which are breweries that make their own malt, but it is more common that the brewery purchases their malt from a separate maltster. The brewing process is a sensitive process, and each unit operation needs to be performed correctly in order to have an efficient and trouble free process. The process steps of brewing are shown in Graph 2. (Bamforth 2003.)



GRAPH 2. The brewing process (adapted from Bamforth 2003)

3.1 The brewing process

The brewing process begins with milling the malt. The goal is to produce a particle distribution best suited for the further process operations in the brew house. The jaw gap on the mill should be approximately 1,30 mm. The malt should for the most part be transformed to a flour, so that the particles are small enough to be hydrated. Hydration of the particles will activate the enzymes, and form a complex between the substrate molecules and the solvent (FIGURE 3). The substrate molecules are mainly starch. For some breweries it is also important that the husk of the malt mainly stays intact after milling. The husk material is used as a filter bed in later process operations. When the milling is finished, the grist is stored in the grist case before continuing to the mash mixer. (Bamforth 2003; Bamforth 2000.)

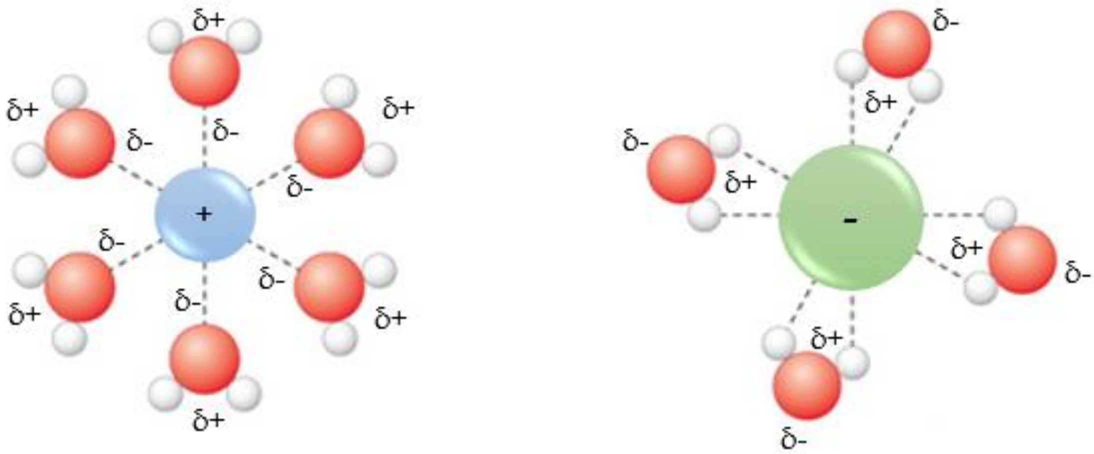


FIGURE 3. A complex with a positive ion and a negative ion

In the mash mixer the grist is mixed with warm water to begin a hydrolysis process. The mashing is typically started at relatively low temperatures, around 50 °C, to make sure the heat sensitive enzymes are able to work. After about 20 minutes the temperature is raised to 65 °C. The temperature needs to be at least 65 °C because it is at this temperature that the starch is gelatinized. Mashing involves the transformation of the starch from a crystalline structure to a disorganized state, easily accessed by the amylase enzymes. These enzymes are responsible for converting the starch into fermentable sugars. The amylase enzymes mainly survive the higher temperatures, and 65 °C is held for approximately one hour before the temperature is raised again. This time the temperature is raised to approximately 76 °C and this stops the activity of most enzymes. The high temperature also lowers the viscosity and reduces particles sticking together, which means the mash is now more fluid. (Bamforth 2003; Barth 2013.)

When the mashing is finished, the produced sugar solution, called wort, is separated from the used grain in a vessel called the lauter tun. The grain husk is used in this process to keep the grain bed from becoming too compact and blocking the flow of wort. In the lauter tun the aim is to recover as clear wort as possible, which contains as much of the extract from the mashing as possible. It is important that the wort would be high in concentration in order to maximize the throughput of the fermentation. (Bamforth 2003; Barth 2013.)

Wort usually flows directly from the separation process, in this case the lauter tun, to the kettle. It is in the kettle where the wort boiling is carried out, and the hops are added. The hops are usually pre-processed before entering the brewery. In the pre-processing, the hops are milled and pelletized, which makes them easier to handle in the brewing process. The boiling of wort aims to concentrate the wort. This means that it will drive off unwanted flavour molecules and inactivating any enzymes that could have survived the mashing and wort separation processes. The boiling also sterilizes the wort. (Bamforth 2003.)

The next stage in the brewing process is the whirlpool, where the wort is allowed to swirl for approximately an hour. The whirlpool has a central cone at the bottom of the vessel, and the centripetal forces make the dim particles collect in the cone, leaving a bright wort on top. After the wort is cleared, it has to be cooled down. This is done by using a heat exchanger, also called Para flow. (Bamforth 2003.)

Before adding the yeast, a small amount of oxygen has to be added by bubbling it into the wort. The fermentation process itself is anaerobic, but the yeast does need some oxygen in order to grow. The main task of fermentation is to convert sugars into alcohol. The rate at which the sugars are converted into alcohol depends on the amount of yeast that is added. Fermentation of ale can be as fast as two to three days, when the fermentation of lagers can take up to four days. Brewery fermentation is not simply about converting sugars into alcohol, but also about producing a favourable mix of flavour compounds. (Bamforth 2003.)

After fermentation, the beer is cooled down in order to stabilize and clarify it. In most breweries the beer is cooled down to a temperature as low as -1 °C for approximately three days. The beer is cooled down to such a cold temperature in order to remove the cold- sensitive proteins. When the beer is cooled down it goes through filtration and into storage, called bright beer tanks, to await packaging. (Bamforth 2003.)

3.2 The characteristics of beer

Beer is produced of malt, hops, yeast and water, and they all bring different features to the beer. Malt is the ingredient that flavours the beer more than any of the other ingredients. The selected malt types will determine the flavour, colour, body and aroma of the beer. Commonly, malts are classified as base malts or specialty malts. The base malt constitutes for a majority of the total grain bill, and specialty malts account for a smaller percentage of the grain bill. The only exception is in brewing wheat beer, when 100 % of the grain bill can consist of wheat malt. (Goldammer 2008.)

Base malts contribute to the most enzymatic capacity to convert starch into fermentable sugars. Base malt also contributes to the highest extract yield. The specialty malts provides the beer with unique characteristics such as flavour, colour and body. Specialty malts contribute with a very low amount of enzymatic capacity, and are used in smaller masses compared to the base malt. Specialty malts can be classified as light-coloured malts, caramel malts, dry-roasted malts or unmalted barley, which are referring to the way they are produced. (Goldammer 2008.)

Hops, which are a minor ingredient, are used for their flavouring, bittering and aroma improving capability. Hops contain α-acids, which are converted to isomerized α-acids in the kettle. α-acids are not bitter and hardly soluble in beer, but isomerized α-acids are four times more bitter, and more soluble in beer. Although there is only one hop species used in brewing (Humulus lupulus) it has a number of cultivars, and each with its own set of characteristics. Hop varieties can be divided into aroma hops and bittering hops, of which the bittering hops have high levels of α-acids. Aroma hops, with a low content of α-acids, gives characteristic hop aromas to beer. Isomerized α-acids are fairly soluble in wort, and therefore the beer will stay bitter. Isomerized α-acids also stabilize beer foam and prevent bacteria from growing in the beer. The three significant components of α-acids are humulone, adhumulone and cohumulone, of which it is humulone that contributes with a significant amount of the bittering effect of the hop. (Goldammer 2008.)

Each of the three α- acids are isomerized with the help of heat in boiling of wort, and each is transformed to two forms, namely cis- and trans-forms. Resulting in six isomerized α- acids. The ratio between the cis- and trans-isomers in a traditionally hopped beer is 68 % cis-isomers and 32 % trans-isomers. The cis-isomers are considered more bitter, but more significantly, the trans-isomers deteriorate considerably faster. Researchers determined that circa 75 % of the trans-isomerized α-acids degraded in beer stored at 28 °C within the first 12 months, but during the same time only 15 % of cis-isomerized α-acids degraded. The result works as a reminder for brewers, who only use conventional hops, of selling the beer when it is freshly brewed, and the importance of cold storage. Brewers who use pre-isomerized extracts benefits since the extract contain a higher percentage of cis-isomers, and hence more stable. (Hieronymus 2012.)

Yeast is one of the most important ingredients in producing beer. Yeast is responsible for converting sugars into alcohol, but also carbon dioxide and other compounds that contributes to the flavour. There are a significant amount of varieties and strains of yeast. In the past, the yeasts were divided into two categories, ale yeast and lager yeast. Ale yeast is the top-fermenting type and lager yeast is the bottom-fermenting type of yeast. Lager yeasts give the beer a characteristic sulphurous aroma, while the ale yeast contributes to a more fruity and malty beer. (Goldammer 2008; White 2010.)

Ale yeasts are considered as top-fermenting yeasts because they rise to the surface during fermentation, creating a thick yeast head. Ale yeast grows best in temperatures between 10 and 25 °C, and the fermentation is rather rapid. Ale yeasts create a beer with a relatively high alcohol content and are rich in esters, which is regarded as a typical character of ale beer. It is possible to mix two or more strains of ale yeast to ensure rapid fermentation. Lager yeasts work best at lower temperatures ranging between 7 and 15°C. Lager yeasts grow slower than ale yeasts and with a smaller amount of surface foam. The lager yeast strains tend to settle on the bottom of the fermenter towards the end of the fermentation process, and that is why lager yeasts are referred to as bottom-fermenting yeasts. Lager yeasts produce a larger amount of hydrogen sulphide and other sulphur compounds. Sulphur compounds produced during fermentation are volatile enough, so that the fermentation activity will drive them from solution together with the CO_2. A large amount of the sulphur levels will be reduced by the time the costumer will drink the beer. When fermenting with lager yeasts, it is standard practice to use only one strain of yeast, a pure strain cultivated from a single cell. In some cases, it is possible to use two strains of yeast that has different flocculation capacity. The two strains are used in different fermenters, and then mixed on the way to the lagering cellar. The strains need to be used for fermentation separately in order to prevent one of the strains to take over the other. (Goldammer 2008.)

Yeast feeds on carbohydrates to grow, and the sources of the carbohydrates in the malt extract will influence the fermentability of the wort. Yeast uses low molecular weight- sugars such as mono- and disaccharides as nutrition to grow, but polysaccharides are not used. The sugars used by the yeast are fructose, glucose, sucrose, maltose and maltotriose, (FIGURE 4) and together they account for 75 to 85 % of the extract. The additional 15 to 20 % consist of non-fermentable products for example beta-glucans, dextrins and oligosaccharides. As a principle, the simple sugars are more fermentable, than the more complex longer-chain sugars. There is a connection between the mash temperature, and the types of carbohydrates that are created in the mash. Higher temperatures will favour enzymes which produce complex, more difficult fermentable sugars. The main parameters used to adjust wort fermentability is time and temperature. Although the sugar conversion may occur rapidly, additional enzyme activity may affect the wort fermentability. (Goldammer 2008; White 2010.)

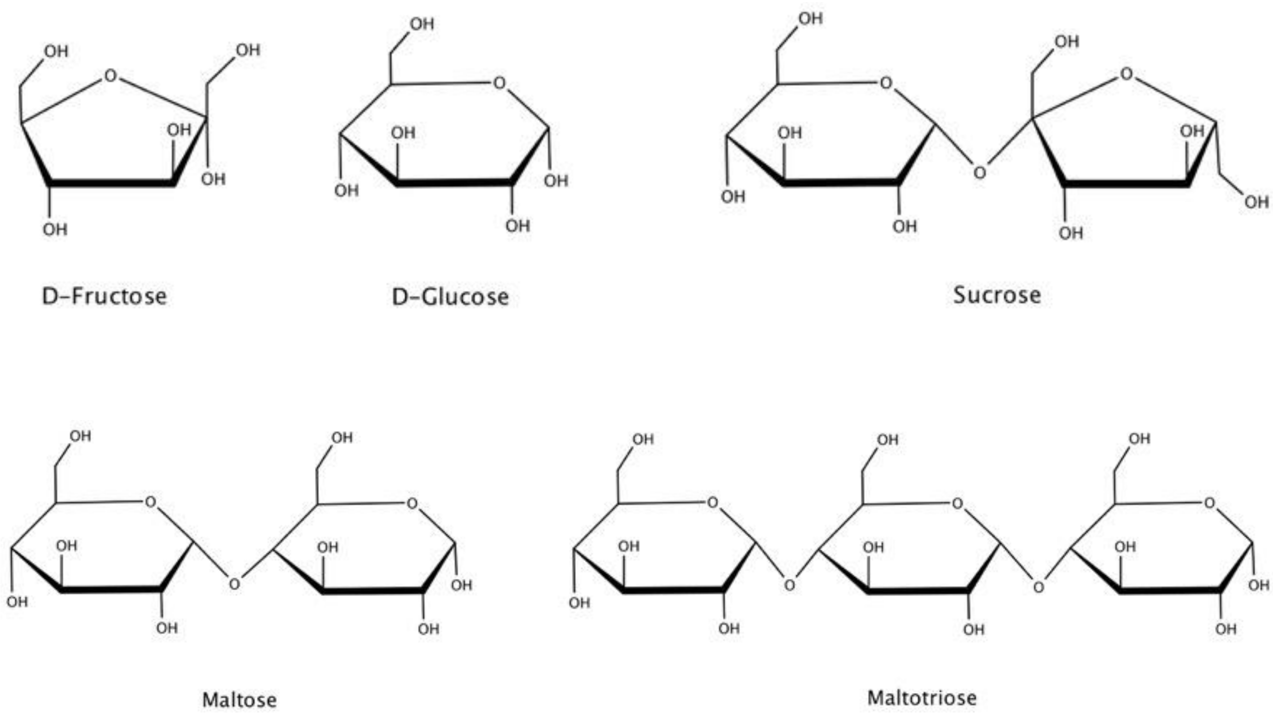


FIGURE 4. Fermentable sugars

3.3 Formulating a grain bill

Before the start of brewing, a grain bill needs to be formulated. A grain bill includes the raw material, which the brewer will use for brewing a certain style of beer. The most simple grain bill consists of one single malt type, but a grain bill usually includes a few different types of malt. A grain bill always includes base malt, which makes up for the majority of the grain bill. In addition the base malts, specialty malts can be added to the grist to produce certain flavours in the beer. The base malt contains the starch from where the fermentable sugars come from. The base malt forms the base for all beers, regardless of beer type. (Mallett 2014.)

When formulating a grain bill, it should be considered how much fermentable extract should be present in the wort. The fermentable extract correlates directly to the alcohol content of the finished beer. Brewers that aim for a specific wort concentration will begin with calculating how much malt will be needed to hit the target concentration. Base malts have the potential to release approximately 80 % of their dry mass into the wort. Wort contains approximately 4 % water, so 100 g wort would contribute to approximately 80 % of 96 g of extract, under ideal conditions. Different malts have different quantities of moisture and extract. By summing up the contributions of each component of the grist and taking brewhouse efficiency into consideration, it is possible to estimate the performance of the mash. Efficiencies between brewhouses vary widely and depend on the design and engineering of the brewhouse, as well as the mash profile. (Mallett 2014.)

When mashing is carried out, hot water at a specific temperature draws soluble extract from the grain, changing the density of the water and creating wort. The scientific unit of Plato (°P), can be used to measure liquid density, and the frequently used reference tables are based on the sugar percentage of a solution. When 14 g of sucrose is mixed with 86 g of water, it results in a 14 °P solution. This solution is denser than water, a 14 °P wort has a density approximately 1,057 times the density of water. (Mallett 2014.)

4 THE MAIN PROCESS STEPS IN BREWING

The brewing process can be divided in two phases, the hot side and the cold side. The hot side is the brewing process which involves milling, mashing and boiling of the wort. The product of the hot side, the hopped wort, contributes with food for yeast in the second phase, which is the cold side. The cold side involves fermentation, cooling and bottling of beer, and starts when the brewer cools down the worth with the help of a heat exchanger, adds the yeast and the fermentation starts. The main process steps of brewing can be considered to be mashing of the malt, boiling of the wort and fermentation. (White & Zainasheff 2010.)

4.1 The impact of water during the mashing process

Water is essential in beer brewing. Approximately 90 % of beer consists of water and an efficient brewery will use from 4 to 6 litres of water to produce one litre of beer. Small size breweries typically use much more water. Water is not only used for beer production, but also for heating and cooling as well as cleaning. The mineral content in the brewing water contributes significantly to the flavour of the beer, and therefore the water needs to be evaluated whether it is suitable for brewing water for a certain beer style. (Goldammer 2008.)

There are various types of water sources and all sources have different chemical profiles, and therefore give different characteristics to beer. The first requirement for brewing water is that it has to be clean. Water from one specific source could contain substances unfit for brewing, such as chlorine, dissolved gases or organic compounds that could affect the flavour of the beer. In general, water suitable for brewing should contain a minimum of 50 mg/l of calcium to improve the mashing performance, effective fermentation and clarification of the beer. Alkalinity levels of the brewing water vary depending on the acidity of the mash malt composition and the desired character of the beer. For lightly coloured beers, water with low alkalinity is preferred, and the need for alkalinity increases for darker beers. There could possibly be hundreds of substances in the used water supply, but only some of them are of importance to the brewer. The most significant factors to consider are water hardness and alkalinity, because they affect the mash pH. (Palmer & Kaminski 2013.)

4.1.1 Water hardness

Total water hardness refers to the amount of dissolved minerals, such as bicarbonate, calcium and magnesium, in the water. Total hardness is expressed as ppm or mg/l of calcium carbonate ($CaCO_3$) in the water, which determines the degree of hardness/softness of the water. The alkalinity and hardness of water is frequently explicated as $CaCO_3$, because when 100 mg of calcium carbonate is dissolved in one litre of water using carbonic acid (H_2CO_3), the alkalinity and hardness of calcium will both be 100 mg/l. On a water quality report, the water hardness is listed as "Total hardness" or "Hardness as $CaCO_3$". Water hardness classifications are presented in Table 1. (Goldammer 2008.)

TABLE 1. Water hardness classification

Water hardness classification	$CaCO_3$ mg/l
Very soft	**< 50**
Soft	**50 - 100**
Medium-soft	**100 - 200**
Moderate hard	**200 - 400**
Hard	**400 - 600**
Very hard	**> 600**

Total water hardness is defined as the sum of calcium and magnesium hardness multiplied by 50, which is the equivalent weight of $CaCO_3$. Total hardness is measured as $CaCO_3$, according to equation 1, where the brackets indicate the concentration (mg/l) of calcium and magnesium, which are divided by their equivalent weights. The total hardness equation converts the concentrations of the individual substances to their $CaCO_3$ equivalent. If other metal ions such as iron, zinc, manganese and chromium are present in significant amounts, they would also contribute to the total hardness and would be added to the equation in a corresponding manner. The recommended concentration as $CaCO_3$ in brewing water is from 150 to 500 mg/l. (Palmer & Kaminski 2013.)

$$\text{Total hardness} = 50 * \left(\frac{[\text{Ca}]}{20}\right) + \left(\frac{[\text{Mg}]}{12{,}1}\right) \qquad (1)$$

Calcium is typically the ion that determines the softness/hardness of the drinking water, and is useful for many enzyme, yeast and protein reactions in the brewing process. In mashing, calcium reacts with malt phosphates, forming precipitates which involve the release of hydrogen ions (H^+). The hydrogen ions lower the pH of the mash. Lowering of mash pH is critical since it provides the right environment for α-amylase, β-amylase and proteolytic enzymes, which will enhance proteolysis and saccharification. Proteolysis is the reduction of proteins to smaller fractions, such as polypeptides or amino acids. Enhanced proteolysis and saccharification will result in increasing extract yield. (Palmer & Kaminski 2013; Goldammer 2008.)

During boiling, calcium will lower the pH value. A lower pH reduces the isomerization and extraction rate of α-acids, and therefore the wort will be less bitter. It is essential to have calcium ions present during boiling because it helps in the precipitation of proteins, which otherwise could result in the formation of beer haze. (Palmer & Kaminski 2013; Goldammer 2008.)

During fermentation, calcium increase yeast flocculation and sedimentation. Calcium elevates clarity, stability and flavour in the finished beer, and though calcium is flavour neutral, it can reduce the slightly sour flavour of magnesium. The recommended concentration of calcium in the brewing water is from 50 to 150 mg/l, but beer can be successfully brewed with calcium amounts outside the suggested range. (Palmer & Kaminski 2013; Goldammer 2008.)

In water, magnesium ions act similarly to calcium ions, but they are not as effective in reducing the mash pH because magnesium salts are more soluble in water. During fermentation, magnesium is important because of its benefits to yeast metabolism. Reportedly, magnesium carbonate gives a more sharp bitterness to the flavour than calcium carbonate. In general, malt contains the necessary amount of magnesium needed in the brewing water, which has a recommended concentration of 0 to 40 mg/l. (Palmer & Kaminski 2013; Goldammer 2008.)

4.1.2 Water alkalinity

Total alkalinity is a measurement of the buffering capacity of water to resist the change in pH. Alkalinity is the parameter of most importance to the brewer, because it has the greatest effect on mash performance. Total alkalinity as $CaCO_3$ is defined as the volume of acid required to titrate the sample to a pH value of 4,3, where carbonate and bicarbonate are converted to carbon dioxide. (Palmer & Kaminski 2013.)

German brewing scientist Paul Kolbach discovered through a set of experiments in 1953 that 3,5 equivalents (Eq) of calcium reacts with malt phosphate and is able to neutralize 1 Eq of water alkalinity. Kolbach also determined that magnesium works similarly, but to a reduced extent, needing 7 Eq to neutralize 1 Eq of alkalinity. The alkalinity that is left in the water, and is not neutralized, is called residual alkalinity (RA). The residual alkalinity is the difference between the carbonate (carbonate + bicarbonate) hardness and non-carbonate hardness, which is presented in equation 2. Residual alkalinity is frequently expressed as milliequivalents per litre (mEq/l). (Palmer & Kaminski 2013.)

$$\text{Residual alkalinity (RA)} = \text{Alkalinity} - \left[\left(\frac{\text{Ca}}{3{,}5}\right) + \left(\frac{\text{Mg}}{7{,}0}\right)\right] \quad (2)$$

If the RA value is zero, it indicates that the water will not change the mash pH. A positive RA value indicates that the water will affect the mash pH by increasing it. If the RA value is negative, it means that the water will decrease the pH of the mash. (Goldammer 2008.)

4.2 Mash pH

pH is the measure of the hydrogen (H^+) ion concentration of a solution, and is measured on a scale from 0 to 14, where 7 is considered neutral. With the help of pH measurements, it can be determined how acidic or basic (also called alkaline) different substances are. On the pH scale, values lower than 7 are increasingly acidic and values greater than 7 are basic. The pH scale is logarithmic which indicates that a solution at pH 4 is ten times more acidic than a solution at pH 5. Mash pH is important when it comes to understanding mash chemistry. (Palmer & Kaminski 2013; Goldammer 2008.)

The mash pH is important because it is a considerable factor for enzyme activity and it has an influence on the final pH value of the beer. Various factors affect the mash pH, and many of them are based on the malting process and barley variety. These are factors that the brewer cannot control. The factors that the brewer can control are brewing water composition, salt or acid additions and the reliability of sampling methods. (Palmer & Kaminski 2013.)

4.3 The importance of enzyme activity during mashing

During the mashing process, the starches gelatinize, enzyme activity converts starches into fermentable sugars and soluble materials dissolve. The product of the mashing process is a wort with a fixed gravity (OG). The fixed gravity is a ratio between fermentable and non-fermentable sugars and proteins that affect the biochemical and physical changes during fermentation. (Goldammer 2008.)

The mashing process is carried through over a period of time at different temperatures to activate the enzymes. Enzymes are biological catalysts that initiate chemical reactions. There are several enzymes present in the mash, and each initiates a specific chemical reaction. Enzymes in the mash are categorized in three groups, which are acidifying enzymes, protein-degrading enzymes and starch-degrading enzymes. (Goldammer 2008.)

4.3.1 Acidification

Acidification of the mash is done by the phytase enzyme. Phytase is active between 30 °C and 53 °C, and it breaks down insoluble phytin, which is a complex organic phosphate that contains both magnesium and calcium, to phytic acid. During the mashing process, phytase activity is greater with unmodified malt, than with highly modified malt. Because most breweries use well modified malts, it is not necessary to do the acidification in mashing, and in this way shorten the mash time. (Goldammer 2008.)

4.3.2 Protein degradation

The majority of the protein degradation occurs during the malting process. In mashing, protease enzymes reduce high-molecular-weight proteins to more simple amino-acids by breaking the bonds between proteins, in a process called proteolysis. Proteinase and peptidase are the two main enzymes of the protease group. (Goldammer 2008.)

Albumins, which are a family of proteins, are dissolved in the wort along with insoluble globulins. It is the responsibility of the proteinase enzymes to degrade albumins and globulins into more simple medium-sized proteins, peptones and polypeptides. The reduction of albumins and globulins to smaller proteins is important for reducing the haze of the beer. Haze is additionally caused by polyphenols (tannins) originated from the husk of the malt and hops. (Goldammer 2008.)

The polypeptides and peptones are not useful nutrients for yeast, but are important for foam stability and therefore responsible for head retention, as well as for palate fullness. The optimum temperature range for proteinase is between 50 and 60 °C, and has an optimum pH range of 4,2 to 5,3. It is the responsibility of the peptidase enzyme to degrade the peptones and polypeptides to smaller proteins, peptides and amino acids. Peptides and amino acids are useful yeast nutrients and are essential for yeast growth. Peptidases has an optimum temperature range between 45 and 53 °C and they are active at a pH of 4,2 to 5,3. (Goldammer 2008.)

4.3.3 Starch degradation

The most important reaction that happens during the mashing process is the conversion of starch molecules to fermentable sugars and unfermentable dextrins. The enzymes responsible for starch conversion are α-amylase and β-amylase. Together, the α- and β-amylase are able to convert 60 to 80 % of the starch to fermentable sugars. Limit dextrinase is an enzyme that breaks down limit dextrins, but has low effect at mashing temperatures of above 60 °C, since its optimum temperature is 40 °C. Therefore a large amount of the dextrins pass over to the finished beer. (Goldammer 2008.)

α-amylase rapidly reduces both soluble and insoluble starch by splitting complex starch molecules into shorter chains, which are dextrins, maltotriose and partially-fermentable polysaccharide fractions. If given a long enough time, α-amylase can degrade most of the dextrins to maltose, glucose and limit dextrins. α-amylase is more resistant to higher temperatures than β-amylase. α-amylase has an optimum temperature range between 72 and 75 °C, but it is destroyed at 80 °C. It has an optimum pH range of 5,6 to 5,8. (Goldammer 2008.)

β-amylase is the other enzyme capable of degrading starch in the mash. β-amylase is more selective, and can break off two sugars at a time from a starch chain. The disaccharide produced by β-amylase is maltose, which is the most common sugar in malt. β-amylase is more heat sensitive than α-amylase, and has an optimum temperature range of 60 to 65 °C, and it is rapidly inactivated at 70 °C. The optimum pH for β-amylase is 5,4 to 5,5. Because the α- and β-amylases have different active temperatures, many mashing systems use at least two temperature rests for starch conversion. (Goldammer 2008.)

4.4 Boiling of wort

Boiling of wort provides many functions. Wort is boiled for approximately one hour, and it serves functions such as sterilization of wort, precipitation of proteins and disposing grainy characters that originates from the barley. Water evaporates during boiling, and therefore the wort becomes concentrated. (Bamforth 2002.)

When the wort enters the kettle, it contains numerous micro-organisms, such as yeast and bacteria, which can result in unwanted off-flavours and other problems. Therefore it is important to boil the wort at a temperature above 100 °C for at least 45 minutes. Boiling of the wort also inactivates residual enzymes responsible for protein and carbohydrate degradation, which may have survived the mash out. During the boiling process, protein precipitation occurs when the wort loses its turbid character. When proteins coagulate, material breaks out of suspension and precipitates. If proteins are allowed to remain in the wort, it can affect the pH, fermentation, clarifying properties and the taste of the beer. During boiling, the wort becomes darker in colour. The colour change is because of the formation of melanoidins (pigments), the caramelization of sugars and the oxidation of polyphenols. (Goldammer 2008.)

The melanoidin production, which is also called the Maillard reaction, takes place when reducing sugars originated from carbohydrates react with amino acids derived from proteins during the mashing process. In the malting process, the production of melanoidins is most active, but it continues during mashing, and approximately one third of the melanoidins form during boiling. Melanoidins develop in the malt during kilning of the malt, and give high-kilned malts their colour and malty flavour. (Goldammer 2008.)

Another source of colour development is the oxidation of polyphenols. Polyphenols are frequently referred to as tannins and can be derived from hops and malt husk. High-carbonate water may accelerate colour formation by enhancing the extraction of polyphenols from hops and husks. Selecting two-row malts, with a thinner lighter husk, will result in reduced existence of polyphenols. (Goldammer 2008.)

4.5 The importance of yeast and fermentation

Fermentation is the process step where fermentable carbohydrates are converted into alcohol, carbon dioxide and other by-products. It is the by-products that have a significant effect on the taste, aroma and other properties in the finished beer. The used yeast strain is a main contributor to the character and flavour of the beer. The overall reaction of the fermentation is the conversion of glucose ($C_6H_{12}O_6$) to ethanol (C_2H_5OH) and carbon dioxide (CO_2), which is shown in equation 3. (Goldammer 2008.)

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 \quad (3)$$

What occurs during fermentation is that yeast ferments a solution from a sugared solution to an alcoholic solution. The benefit is the lowered pH value, which will protect the fermented products against harmful bacteria. The by-products, such as esters, sulphur compounds and high molecular weight alcohols are the flavour compounds which make the beer taste the way it does. For fermentation to work, the brewer needs the right sugars, healthy yeast, controlled temperatures, nutrients and proper equipment to monitor the fermentation progress. (White & Zinasheff 2010.)

Yeast is the most important part of fermentation. Yeast is responsible for converting sugar to alcohol, carbon dioxide and by-products. Yeast does this in order to create energy and increase material for reproduction. There are various strains of yeast, but the preferred strain is the one that will provide the beer with the best flavours. Regardless of the selected strain, the yeast is required to be healthy and pitched to the right quantity for optimal fermentation. (White & Zinasheff 2010.)

The pitching of yeast to the right number of yeast cells to initiate fermentation is essential in order to constantly produce a superior product and steady quality. The pitching rates regularly vary between 5 and 20 million cells/ml depending on the specific gravity of the wort. Generally, the pitching rate is one million viable cells per degree of Plato (°P) per ml wort. For instance, a 14 °P wort requires 14 million cells/ml. Some brewers pitch the yeast slightly below this level in order to promote the formation of new cells. (Goldammer 2008.)

5 QUALITY MANAGEMENT

Quality management can be defined with the help of seven quality management principles (QMP), which are customer focus, leadership, engagement of people, process approach, improvement, evidence- based decision making and relationship management. These QMPs are not in a priority order, and the importance of each principle varies depending on the organization. The QMPs can be used as a foundation for quality management which can help guide the improvement of an organization's performance. ISO 9000, ISO 9001 and other quality management standards are based on these seven quality management principles. (International Organization for Standardization 2015.)

As a field of study, quality management has developed considerably from the start of statistical process control in the 1950s to Total Quality Management in the 1980s to today's focus on Six Sigma and Lean management (FIGURE 5). The brewing industry was not completely engaged with the study of quality management in the 1950s, which was left for the automotive industry at that time. When the brewing industry became more familiar with quality management in the 1960s, also the overall product quality improved. (Pellettieri 2015.)

There are a few theorists that have had a considerable influence on what good quality management is and how to achieve it. These gentlemen are W. Edwards Deming, Joseph Juran and Philip Crosby. W. Edwards Deming is considered one of the gurus of quality management. Deming developed statistical quality control methods that significantly improved productivity in the 1940s. After the Second World War Deming went to Japan and introduced his philosophies and methods, and was influential in Japanese manufacturing and industry. (Pellettieri 2015.)

Deming defined statistical quality control the following way; "The statistical control of quality is the application of statistical principles and techniques in all stages of production, directed toward the most economic manufacture of a product that is maximally useful and has a market." (Deming 1953). According to Deming, the first step of statistical quality control is to study the demands of the market, and that quality has to be a concept that both the seller and the buyer understand. Deming's statistical methods help produce quality products, but also contribute to an international language in which to express quality. (Deming 1953.)

Joseph M. Juran focused more on the human side of management. Juran wrote The Quality Control Handbook in 1951, where he taught leaders how to manage their employees with quality as the goal. In 2010, the sixth edition of Juran's handbook was published, and is triple the size of the first edition. Juran also defined quality as "fitness for use", which indicates that the product meets the expectations of the customer. (Pellettieri 2015.)

The third man who helped shape the definition of quality management is Philip B. Crosby. Crosby introduced the concept of total quality management (TQM) in the 1970s and he defined quality as "free from defect". Crosby got the manufacturers to understand that quality is the responsibility of all the people of an organisation, and not only the responsibility of the quality department. TQM was a modern management philosophy during the 1990s, and it standardized the usage of tools such as statistical methods and control charts. TQM has later been replaced by other quality management methods such as the quality standard ISO-9000, Six Sigma and Lean Management, which helped to standardize the what, how and who of a quality management system. Crosby's philosophies do not only explain what quality is, but also how things should be done and who is responsible for achieving quality. (Pellettieri 2015.)

FIGURE 5. The development of quality management (adapted from Pellettieri 2015)

5.1 Defining quality

The Brewers Association (BA) Technical committee formed a subcommittee called the Quality subcommittee, which had the task of defining the quality of beer for the members of the BA. The quality subcommittee defined quality as a beer that is produced responsibly using consistent brewing techniques and wholesome ingredients. Quality beer should also have flavour characteristics that are aligned with both the beer drinker's and brewer's expectations. This definition includes traditional definitions of quality, and it is the responsibility of all brewers to produce quality beer in order to guarantee safe products. (Pellettieri 2015.)

Quality can be defined as "free from defect", which is a traditional way to define quality. With this definition on quality, the goal is to prevent unwanted flavours and meet government requirements. A good example of defining quality as "free from defect" is the Reinheitsgebot (purity law) in Germany in 1516. The Reinheitsgebot forbade the brewers to use anything else than barley and wheat malt, hops, and water to make beer. Yeast is also allowed but it was unknown at the time when the law was written, and therefore not mentioned in the law. Unmalted barley, corn, rice, sugar and chemical additives are prohibited in the law. Using specific raw materials contributed to the beer having a certain flavour profile. Therefore the Reinheitsgebot has standardized what was "free from defect" in beer. (Pellettieri 2015; Goldammer 2008.)

Another way of defining quality is "fitness for use" which assumes that the customer helps define what a quality product is. The parameters that commonly define the quality of the beer are flavour, colour, foam, bitterness and alcohol, which are what the customers most value in beer. (Pellettieri 2015.) In a simple way, quality can be defined as a correlation between what the customer wants and what the customer gets. It is all about meeting the expectations of the customer. In terms of beer, it is not that simple to define quality. What represents quality for one person may be the opposite for another. (Bamforth 2002.) There is a vast diversity of beer styles, a wide variety of raw materials and new brewing processes, which result in beers having many different flavours. As the definition of quality beer is constantly changing, the brewers have a challenging task as they need to define again and again, for the customer, what quality beer is. (Pellettieri 2015.)

5.2 Achieving quality

The practice of quality management is determining if a product is acceptable enough to be sent to the customer. Quality products in the 21st century are essential, and poor quality of a product can result in the loss of customers. The expected outcome of quality management is to produce high quality products in a consistent way. For a brewery, this equals making quality beer constantly. In a brewery's management system it is of great importance that management gaps are minimized. Possible management gaps are defining the quality, determining how to achieve the quality and who is responsible for assuring good quality of the products. There needs to be strong leadership to build a productive focus on quality throughout the company, which means that everyone in the company shares the responsibility of producing quality products. (Pellettieri 2015.)

It may be difficult for a company to know if their product has fulfilled all customer requirements. 90 % of customers, which are dissatisfied with the quality of a product will avoid the product in the future. A customer that is dissatisfied with a product will tell 9-20 other people about the poor quality of that specific product, and only 4% of dissatisfied customers will complain about the quality to the manufacturer. Therefore it is extremely important to know the customer requirements and how to achieve them. (Würzl 2017.)

A Quality Management System (QMS) helps standardize the necessary tasks and processes, determining who has the responsibilities and which necessary resources need to be used in order to ensure good quality. The quality management systems includes four steps; quality planning, quality inspection, quality control and quality promotion (FIGURE 6). Quality planning needs to be performed before the start of the production. It concerns the identification and classification of quality characteristics and definitions of quality requirements and restrictive conditions. Quality inspection is the planning of how to check the defined characteristics of a product, where to do the tests and by whom and how the test results should be further processed. In the next step, quality control, the aim is to avoid errors by using monitoring and preventive methods in order to meet the quality requirements. The last part of QMS is quality promotion, where the aim is to get all the employees to think in a quality orientated way. This could be achieved by encouraging the employees, increasing trust and giving information about objectives and decisions. (Würzl 2017.)

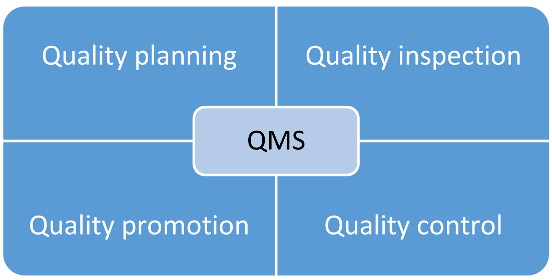


FIGURE 6. The four steps of a quality management system

5.3 Quality in brewing

In the brewing process, quality should be found at each step of the process. The brewing process is a sensitive process, with highly technical steps which all have to be linked together in a chain. At the connections between different process steps are the quality checks, which measure the process conditions and help to determine if the process is under control. A quality check can be a process input measurement (PIM) or a process output measurement (POM). If the quality check is done after a process step has completed its cycle, it is called a process output measurement. A process input measurement is a checkpoint that monitors a process during the operation. The checkpoints can be perfomed manually at the site, or automated and controlled with the help of a process logic controller (PLC). The ability to measure both PIMs and POMs will result in a better product quality. (Pellettieri 2015.)

The term quality control (QC) means that the process output is controlled with the help of measurements and tests. Quality control should not be confused with quality assurance (QA), which means controlling the measurement via calibration or a standard. For instance in a brewery, a QC point would be measuring the pH of the mash. QA would be what to do if the pH is not within the specifications and process parameters have to be changed. QA is part of the back up to ensure that the quality checks remain in control. (Pellettieri 2015.)

For the check system to work, excellent documentation and communication is required. When troubleshooting, documentation of the PIMs and POMs for every process step, including process anomalies, and what procedures were done to correct them, are extremely valuable. The knowledge of the process, measurements, documentation for each step and reviewing the data for improvements needs to be mastered and managed. These are all part of process control and therefore also quality control. In order for a quality control system to evolve, the brewery needs to take the time to define its customer criteria and quality values, and give all the employees the responsibility of making a quality product. (Pellettieri 2015.)

5.4 The checklist

Checklists are used in many different fields to avoid easy errors to be made. For instance, checklists are used in fields such as medicine and aviation, where the professionals are excellent specialists, and are not expected to fail. An early example is from a U.S. Army test flight in 1935 in Dayton, Ohio. The U.S. Army was testing a new airplane, a Boeing aircraft Model 299, one that could fly faster and longer than the previous planes, and was called “the flying fortress”. The test ended in a disaster, the plane lifted and then suddenly turned on one wing and crashed in a fiery explosion. Two of the five crew members died, including the pilot, who was the chief of flight testing. (Gawande 2011.)

What the army decided to do was not to require the pilots to undergo longer training, instead they came up with a rather simple approach: they created a checklist for pilots. The test pilots made their checklist simple, to the point and concise, with step-by-step checks for take-off, flight, landing and taxiing. The checklist included steps that all pilots knew how to do, checking that brakes are released, the doors and windows are closed and that instruments are set, factors that are evident for the pilot. With the checklist in use, the pilots flew the Model 299 aircraft a total of 2,9 million km without one accident. (Gawande 2011.)

A great deal of the daily work in multiple fields have become too much of an airplane for one person to control. What to do when expertise is not enough and specialists fail, that something as simple as a checklist could be of significant help is far from evident. People believe that their jobs are too complicated to be reduced to one simple checklist. (Gawande 2011.)

In complex situations, experts are facing two main difficulties, which are the unreliability of human memory and attention and that people can allow themselves to skip steps, even if they remember them. When it comes to routine matters, they tend to be easily overlooked under more pressing events and a defective memory and distraction are a danger in so-called all-or-non processes; if one key thing is missed, you might as well not have made an effort at all. (Gawande 2011.)

Checklists are also used in the field of building construction. One example is a medical centre construction schedule, a day-by-day listing of all tasks that needed to be completed, when and in what order. The schedule was made with colour codes, red items highlighting the critical steps that needed to be done before it was possible to proceed with other steps. The whole schedule was one long checklist, and when a task was completed, it was marked with a checkmark on the schedule. (Gawande 2011.)

The company working in the medical centre also had another checklist, not for construction tasks, but for communication tasks. The idea of the communication checklist was to make sure the experts talked to one another. The checklist specified who had to speak to whom, about what aspect of the construction, and by which date. The builders trust in the capacity of communication and believe in the wisdom of the group, rather than in the wisdom of one single person. (Gawande 2011.)

The philosophy behind is that the power of decision making is pushed away from the centre and out in the periphery. People are given room to adapt based on their expertise and experience. What is asked for is that the people take responsibility and communicate with one another. Buildings that are difficult to design and construct are built in main cities, with thousands of people working on the site. Experts manage the complexities by putting their trust in checklists and not their individual abilities. (Gawande 2011.)

There are good and bad checklists. Bad checklists are imprecise and too long. Checklists that are too long are hard to work with and are unpractical. Good checklists on the other hand, are precise and practical. They are to the point, efficient and easy to use even in difficult situations. They provide reminders of the most important and critical steps, the steps that even the skilled professionals could miss. (Gawande 2011.)

In 2001, at Johns Hopkins Hospital, it was decided to give a doctor's checklist a try. On one sheet of paper there were 5 simple steps to take, in order to avoid infections when inserting a central line. First the doctors are supposed to wash their hands with soap, then clean the patient's skin with chlorhexidine antiseptic, place sterile drapes over the patient, wear a mask, gloves, hat and sterile gown, and place a sterile dressing over the insertion once the line is in. It might seem unnecessary to make a checklist for something so clear, since these steps have been known and taught for many years. The nurses at the hospitals were asked to observe the doctors for one month and record how each step was carried out. The result was that in more than one third of patients, the doctors skipped at least one step. (Gawande 2011.)

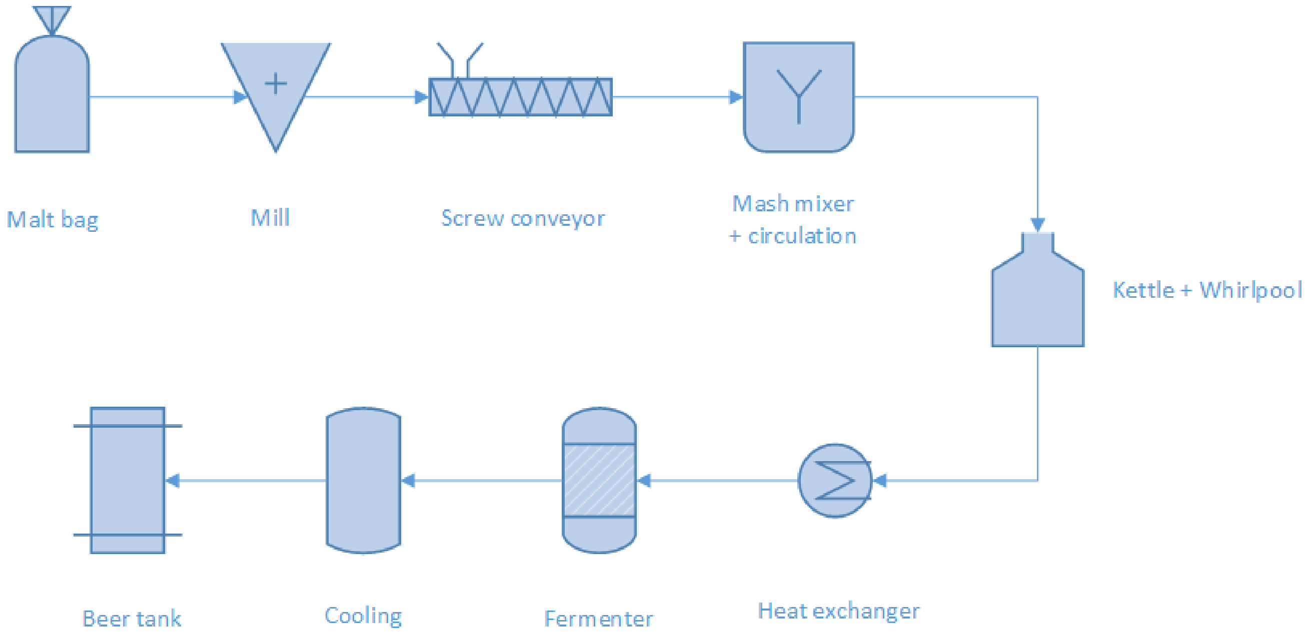
The following month, nurses were given authority to stop doctors if they noticed them skipping a step on the checklist. For a year, the checklist testing was monitored, and the results were dramatic. The ten-day line infection rate decreased from 11 to 0 %, so it was decided to follow patients for 15 more months. During the entire period, only two line infections occurred. It was calculated that in this hospital, the checklist had prevented 8 deaths, 43 infections and saved the hospital 8 million dollars in costs. The checklist had helped with memory recall and set out the minimum steps necessary in a process. It seemed checklists established a higher standard of basic performance. (Gawande 2011.)

The checklist project was extended to eight hospitals, during a time period of three months. During these three months significant results were made. The final results revealed that after introducing the checklist, the major complications rate for surgical patients in all eight hospitals fell by 38 % and deaths fell by 47 %. The infections rate fell by almost 50 %, and the number of patients having to return to surgery because of complications in their original operations fell by 25 %. The results were more significant than what was expected. In this group of approximately 4000 patients, based on earlier observed data, 435 patients would have been anticipated to develop serious complications, instead only 277 did. The use of checklists had spared over 150 people from harm, and 27 of them from death. (Gawande 2011.)

The most revealing information was what the staff said about the checklist experiment. Over 250 staff members filled out an anonymous survey after the three months test period of using checklists. Most of the staff members had been sceptical in the beginning, but by the end, 80 % reported that the checklist was easy to use and had improved the safety of care. 78 % of the people had observed the checklist to have prevented an error from being made in the operating room. Scepticism towards the checklist still occurred, since 20 % did not find it easy to use and felt that it had not improved the safety of care. Then the staff was asked one more question, if they were to have an operation, would they like the checklist to be used? To this question a complete 93 % of the staff answered yes. (Gawande 2011.)

6 THE KAHAKKA BREWERY PROCESS

The Kahakka Brewery's process looks somewhat different from the brewing process explained in Chapter 2. The process has fewer steps than in the general brewing process, but includes the same processes. The flowchart of the process is presented in Graph 3. (Kavilo 2018.)



GRAPH 3. The Kahakka Brewery process

6.1 Milling and mashing

Milling of the malt starts by setting the jaw gap of the mill to 1,35 mm, in order to get the right grist size. When the milling has started, the milled grist will transfer to the grist case with the help of a screw conveyor. The mash tun (FIGURE 8) is filled with hot water until the water level is approximately 5 cm above the false bottom, before the grist is admitted in the mash tun. When the grist case is starting to fill up, the grist is transferred to the mash tun through the grist hydrator (FIGURE 7), where the hot water is added. (Kavilo 2018.)

When the mash in is complete, the mash pH and mash temperature are checked. The target temperature of the mash is 63 °C, and the pH should be 5,50 ± 0,05. When 30 minutes has passed since the start of mash in, the temperature is raised to 65 °C. When the temperature has settled at 65 °C, the mash is allowed to rest, without mixing, for 30 minutes in order for the malt bed to form. When the malt bed is formed, the circulation of the turbid wort is stared. The aim of the circulation is to get a clear wort. The circulation is continued for approximately 10 minutes at a temperature of 80 °C, which is the end of the mashing process. (Kavilo 2018.)

FIGURE 7. Grist hydrator at Kahakka Brewery

FIGURE 8. Mash tun at Kahakka Brewery

7 STANDARD OPERATING PROCEDURE

A Standard Operating procedure (SOP) is a detailed instructions manual set by an organization to assist employees perform routine operations. SOPs are frequently written for operations that are performed regularly, and by more than one operator. The aim of an SOP is to standardize the performance of a specific operation and to minimize the interpretation of the instructions. In a process, there will be SOPs covering all steps of the process. (Prichard 2007.)

SOPs explain in detail how an activity is to be performed in a quality promoting way, regarding quality system requirements. In order for an organization to maintain quality control and quality assurance, SOPs need to be written specifically for the organization whose activities are described. SOPs are of limited value, if they are not written correctly. Additionally, if SOPs are not followed, they will fail to fulfil their purpose. Copies of SOPs need to be accessible in the work areas, either in hard copy or in electronic format, for the employees using them. If the SOPs are not easily accessible for the person needing them, they serve little purpose. (United States Environmental Protection Agency 2007.)

The use and development of SOPs are an essential part of a successful quality system. SOPs minimize variation, and promote quality throughout the process, even with personnel changes. A valid SOP promotes consistency in manufacturing quality products or results, and also reduces work effort. (United States Environmental Protection Agency 2007.)

SOPs should be written in an easy-to-understand, step-by-step format. The information should be presented in a simple and short way, and leave no room for interpretation or doubt to what is required. Preferably, the present verb tense should be used, but the term "you" should not be used. (United States Environmental Protection Agency 2007.)

8 CONCLUSIONS

This thesis will work as a guideline for further developing of SOPs in a brewery. The breweries that do not use SOPs can get an idea of how a SOP can look like, and maybe consider applying them in their own process to ensure the process is operated in a standardized way. The use of SOPs will help the brewery to work in a standardized manner, which will result in constant quality of the products.

The SOPs made in this thesis includes the first steps of the brewing process and are presented in the appendices. For further developing the SOPs, the next step would be to check if changes need to be made to the structure of the SOPs. A SOP needs to give the user all the necessary information to perform a task correctly, but should be simple enough and not to leave room for interpretation. The SOPs prepared in this thesis will be sent to Kahakka Brewery and tested as part of a brew through a validation test. It is on the field where it will be detected if changes are necessary.

When the SOPs are assessed and working, the next step would be to digitalize the SOPs and to have a program in which parameters can be adjusted. If parameters are changed, the program will update the SOP according to the new information. The digitalized SOP could include a checklist, where the brewer has to mark if the check is performed in order to continue to the next step of the process. If a measurement needs to be performed, the result could be inserted into the checklist. This way the test results for each brew can be documented in the SOP itself.

The SOPs could be used on a tablet, and not require the brewer to constantly access a computer to check the next steps of the SOP. The SOPs could also have hyperlinks attached if further information about brewing is needed. For instance, if the brewer wants to know more about the mashing conditions, he or she could access a web page through a hyperlink that will lead directly to information specific to mashing.

Every brewery has their own specific process, and it is important that the SOPs used in the breweries are made with regard to their individual processes. Kahakka Brewery can further develop the SOPs created in this thesis in the way they see fit, and in a way that the SOPs meet their process requirements.

REFERENCES

Bamforth, C. 2003. Beer: Tap into the Art and Science of Brewing, Second Edition, Oxford University Press.

Bamforth, C. 2000. Food, Fermentation and Micro-Organisms, John Wiley & Sons, Incorporated.

Bamforth, C. 2002. Standards of brewing, Brewers publications.

Barth, R. 2013. Chemistry of Beer: The Science in the Suds, Wiley.

Boulton, C. 2013. Encyclopedia of Brewing, John Wiley & Sons, Incorporated.

Deming, W.E. 1953. Management's responsibility for the use of statistical techniques in industry, Society for Advancement of Management Inc.

Gawande, A. 2011. The Checklist Manifesto, How to Get Things Right, Profile Books Ltd.

Goldammer, T. 2008. The Brewer's Handbook, Second Edition, Apex Publishers.

Hieronymus, S. 2012. For the love of hops: the practical guide to aroma bitterness, and the culture of hops, Brewers Publications.

International Organization for Standardization. 2015. Quality management principles.

Kavilo, N. 2018. Kahakka Brewery, interview.

Mallet, J. 2014. Malt: a practical guide from field to Brewhouse, Brewers Publications.

Palmer, J; Kaminski, C. 2013. Water: a comprehensive guide for brewers, Brewers Publications.

Pellettieri, M. 2015. Quality management, Brewers Publications.

Prichard, E. 2007. Analytical Measurement Terminology: Handbook of Terms used in Quality Assurance of Analytical Measurement, Royal Society of Chemistry.

United States Environmental Protection Agency. 2007. Guidance for Preparing Standard Operation Procedures (SOPs), Office of Environmental Information.

White, C; Zainasheff, J. 2010. Yeast: the practical guide to beer fermentation, Brewers Publications.

Würzl, S. 2017. Quality and Environmental management, lecture handout.

KAHAKKA HELLES – MILLING SOP

Version 1.0

Malt

Viking Pilsner malt
Viking Light Munich
Viking Caramel Pale

Procedure:

Step 1 Weigh 200 kg of Viking Pilsner malt

Step 2 Weigh 25 kg of Viking Light Munich malt
Weigh 25 kg of Viking Caramel Pale malt

Step 3 Set the jaw gap of the mill to 1,35 mm

Step 4 Check the mill for foreign objects

- If foreign objects are found, remove them before proceeding

Step 5 Empty 50 kg of the Pilsner malt in the mill

Step 6 Start the screw conveyor

Step 7 Empty 25 kg of Viking light Munich malt in the mill
Empty 25 kg of Viking Caramel Pale malt in the mill

Step 8 Empty the rest of the Pilsner malt in the mill

Step 9 Check that all malt bags are empty

Step 10 Vacuum clean the mill

KAHAKKA HELLES – MASH IN SOP

Version 1.0

Pre-phase: Heating of brewing liqueur

Procedure:

Step 1 Check the temperature in the hot liqueur tank. Target temperature is 80 °C ± 2 °C

- If the temperature is too low, heat up the liqueur. Check SOP for brewing liqueur

Step 2 Start the mill

- Check SOP for milling

Step 3 Preheat the mash tun by opening the inlet valve for water to the grist hydrator
Fill the mash tun with hot water until the water level is 2 cm over the false bottom

Step 4 Open the grain hatch to the grist case
Start the mixing rake
Check the consistence of the grain/water mix. It should be an even mix of grain and water

Step 5 Measure the mash temperature by using the sampling scoop and the handheld thermometer
Measure the temperature every two minutes. Target temperature is 63 °C

Step 6 Grist case is empty (Just water entering the mashing tun)
Check the water level in the hot liqueur tank
The water level should go down by 680 litres

Step 7 Turn off the water inlet to the mash tun

KAHAKKA HELLES – MASHING SOP

Version 1.0

Step 1 Measure the mash temperature by using the sampling scoop and the handheld thermometer. Target temperature is 63 °C ± 0, 5 °C
Measure the mash pH. Target pH is 5, 50 ± 0, 05

- Check pH sampling SOP
- If the temperature is too high/ too low, check SOP for adjustment of mash temperature
- If the pH is too high/ too low, check SOP for mash pH adjustment

Step 2 25 minutes after the start of mash in heat the mash to 65 °C, with the help of steam

Step 3 Measure the temperature until it has reached 65 °C
Close the steam valve when the temperature has reached 64,5 °C

Step 4 Stop the rake
Mash rest for 30 minutes

Step 5 Perform SOP – Circulation of turbid wort