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Dimensionamento de uma microcervejeira de 75 l

Dimensioning of a 75 l microbrewery

Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biotecnologia, ramo Industrial e Ambiental, realizada sob a orientação científica do Doutora Sílvia Maria da Rocha Simões Carriço, Professor Auxiliar com agregação do Departamento de Química da Universidade de Aveiro, e Engenheiro Rui Pedro Frias do Departamento da Manutenção da Super Bock Group.

à minha família

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palavras-chave Produção cervejeira, brassagem, ebuilição, fermentação, filtração, dimensionamento digital, microfábrica, processos industriais.

resumo A produção cervejeira compreende diversos processos biotecnológicos desde a brassagem até à fermentação do mosto. Para os processos cervejeiros é essencial que os equipamentos utilizados consigam um controlo total das condições do processo incluindo temperaturas, pH e oxigenação entre outros, permitindo brassagens e fermentações eficientes e sem risco de contaminações.

O estágio curricular de mestrado teve como objetivo principal o dimensionamento de uma microfábrica de 75 l eficiente e com todos os equipamentos essenciais à produção cervejeira. O dimensionamento foi feito digitalmente tendo por base pesquisa bibliográfica e comparação direta com cervejeiras da empresa do estágio e outras cervejeiras da região norte do país. Como objetivo secundário foi proposto a otimização no número de fabricos semanais da mini-fábrica através do acompanhamento das produções da mesma.

O dimensionamento resultou numa microfábrica divida em três áreas, com a produção de mosto contendo um moinho de dois rolos, duas cubas de empastagem, uma cuba-filtro e uma caldeira de empastagem que simultaneamente funciona como Whirlpool e arrefecedor de mosto. A adega com seis cubas cilindro-cónicas e a área de utilidades com quatro caldeiras cleaning-in-place (CIP) e um tanque de água quente, servido esta microfábrica como rampa de aprendizagem e formação de pessoal. A otimização no processo de mosto da mini-fábrica permitiu uma otimização teórica em 10 fabricos de mosto semanais.

keywords Brewing, mashing, boiling, fermentation, filtration, digital dimensioning, microbrewery, industrial processes.

abstract Brewing covers several biotechnology processes from mashing until fermentation. For the brewing processes it's essential that the equipment used allows for a total control of the process conditions including temperature, pH and oxygenation as others, allowing for an efficient mashing and fermentations and without contamination risk.

The master's curricular internship had as main goal the dimensioning of an efficient 75 l microbrewery with all essential equipment for beer production. The dimensioning was digitally made following bibliography research and direct comparison with the company breweries and other breweries in the northern region of the country. As secondary objective was proposed to increase the number in the weekly wort productions of the minibrewery.

The dimensioning resulted in a microbrewery divided in three areas, with the wort production containing a two-roll mill, two mash-tuns, one lauter-tun and one boiling kettle that works simultaneously as whirlpool and wort chiller. The cellar with six cylindroconical vessels and the utility area with four cleaning-in-place kettles and one hot water tank, allowing for this microbrewery to works as learning ramp and staff training. The weekly wort production optimization allowed for a theorical optimization of 10 extra batches per week.

Abbreviation list

ATP – Adenosine triphosphate

CCV – Cylindroconical vessel

CIP – Cleaning-in-Place

DMS – Dimethyl sulfide

FBT – Filtered beer tank

IPA – Indian pale ale

PET - Polyethylene terephthalate

PVPP – Polyvinylpolypyrrolidone

MD – Munich Dunkel

SiO_2 – Silica hydrogel

SiOH – Silanol

SMM – Methionine s-methyl

TPI – Teeth per inch

Wei – Weiss

Glossary

Adjunct – any other extra source of carbohydrate supplier ingredient to wort excluding the malt from barley.

Ale – beer brewed with a top-fermenting yeast with a relatively short and warm fermentation.

Attenuation – reduction of wort extract during fermentation.

Attenuation degree – the attenuation value at the end of the first fermentation.

Centrifugation – Used mainly to remove yeast and other undesired components in suspension at the end of the fermentation, can also be used for removal of precipitated material after boiling with hops.

Dextrin – a complex sugar molecule left by the diastatic enzymes activity in starch.

Dry Hopping – addition of hops in the fermenter vessel or trough circulation of beer in a hop-gun to incite intense flavour and scent of hops to the finished beer.

Enzymes – proteins that catalyse specific chemical reactions.

Extract – the concentration fermentable compounds in clarified wort which can be shown in percentage or Plato degrees.

Filter aids – Solutions with silica base usually added during primary fermentation to promote protein flocculation and therefore promoting secondary clarification processes.

Green beer – immature beer before the maturation.

High-gravity brewing – production of a concentrated extract wort in which is dilution is necessary, usually during boiling or after fermentation, to produce the final beer extract.

Hop-gun – equipment which is filled with hops in the form of pellets or paste in which the maturated beer is infused having the hops oils and properties transmitted.

Kieselguhr – Unicellular algae fossils from the shells of diatoms used in alimentary industry to aid in filtration derived to their high porosity.

Krausen – foamy head that builds on top of the beer during fermentation.

Lager – beer brewed with bottom-fermentation yeast with a long fermentation at low temperatures.

Limit attenuation – the maximum attenuation possible to achieve in wort during fermentation.

Lupulin glands – small yellow structures in wort at the base of the hop petal in which are contained the resins of interest to wort boiling.

Maturation – process where green beer is storage at very low temperatures in which the last flavours and stability are reached.

Peptidase – enzyme which degrades small endosperm malt proteins to form amino acids.

Perlite – volcanic origin glass which (SiO_2) which when heated form small spheres used as alternative to kieselguhr derived to their high fissure in structure and porosity.

Saccharification – conversion of insoluble sugars in starch to soluble and fermentable sugars in enzymatic activity.

Trub – the sediment at the bottom of the whirlpool consisting of hop bits and precipitated.

Whirlpool – tun used after wort boiling in which the wort enters tangentially inciting rotation to the wort in the interior of the tun leading to sedimentation of the precipitates in the centre of the tank.

Wort – malt extract and other components mashed in water, boiled and fermented to make beer.

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1 Objectives and dissertation contextualization

1.1 Introduction in beer production and interest in brewing equipment dimensioning

Beer production relies on a combination of essential raw materials and processes to brew a quality product (**figure 1**), first the malt has to be milled, then it's mixed in specific amounts of water, depending on the recipe, to create the wort, which is later heated in the mashing to solubilize the components in the wort as well for degradation of the starch molecules into simple sugar molecules increasing that way the fermentation speed and effectiveness. The wort then has to be filtered in the lautering process removing all the solid materials from wort, boiled with hops to get flavour, bitterness and aroma as well for achieve colloidal stability and sterilization. The boiled wort is then clarified to remove the remaining hops as for other particles in suspension and chilled to reach the optimal fermentation temperature. Yeasts are pitched in the chilled wort and begins the fermentation until all sugars in wort have been consumed ending the fermentation and getting the unfiltered beer. The beer at the end of fermentation has plenty of components in suspension such as yeast and other sub products of fermentation having the need for a filtration to clarify and remove all undesired beer components, the beer is then filled into bottles going to the consumer.

In brewing there's an infinite range of existing equipment used to produce beer differing in different approaches to processes and in brewery scale. The breweries system also differ in their heating sources, chilling options, brewery structure and equipment materials. The study of the raw-materials as well for the several different equipment and processes techniques used in breweries is essential to the dimensioning of an efficient microbrewery.

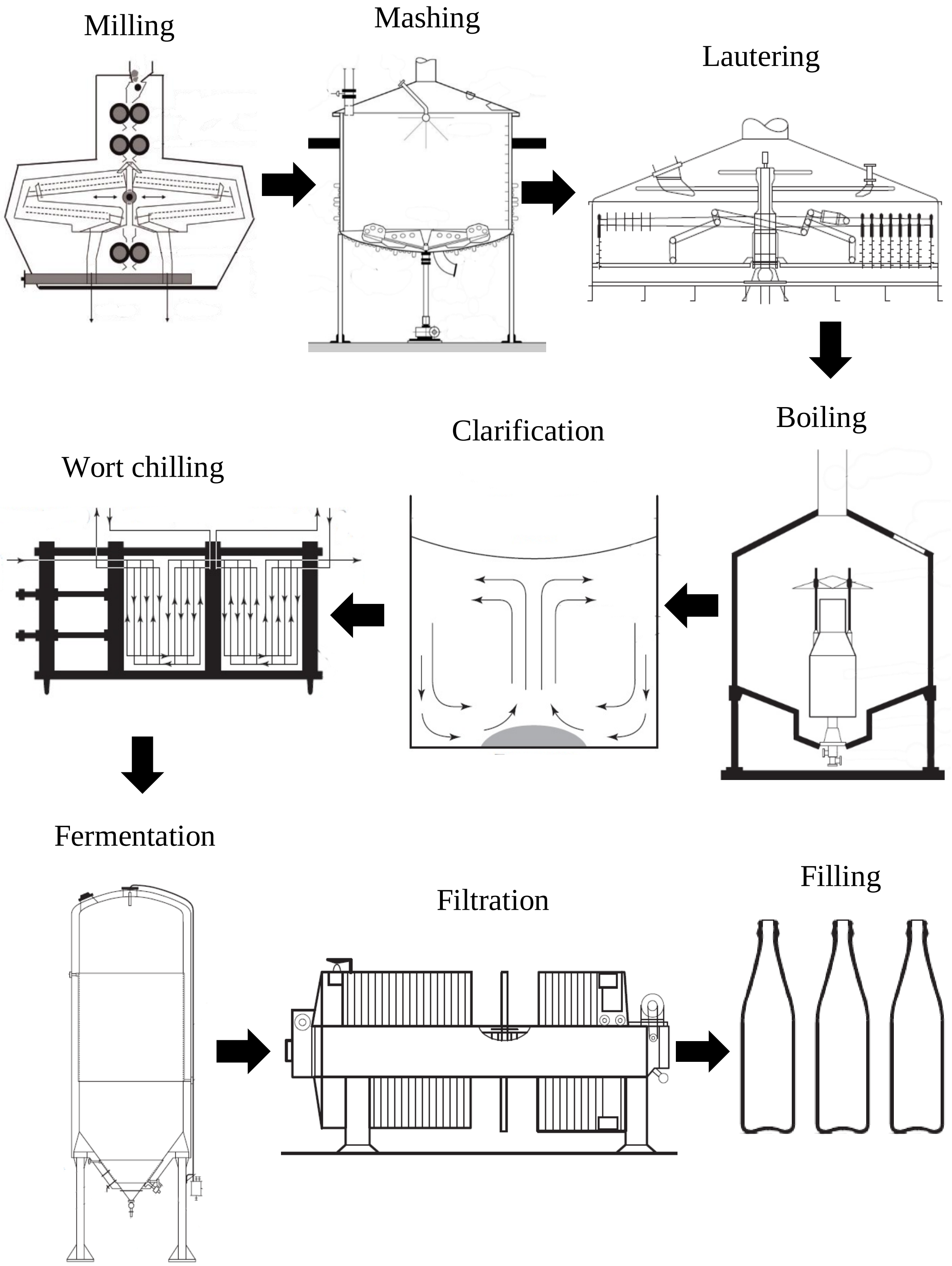

Figure 1 Illustration adapted from *Handbook of Brewing: Processes, Technology, Markets* (2009). Brewing stages, milling, mashing, lautering, boiling, clarification, wort chilling, fermentation, filtration and filling of beer

1.2 Aim of the work

The Super Bock Group factory possesses three breweries within it, the pilot brewery which produces 200 l batches used for experimentation and testing of new recipes, the minibrewery which is used to produce artisanal beer in 20 hl batches and the main brewery which produces the most commercial beers from the group in great batches of 600 hl. The factory employs a lot of workers and the need for staff training in some areas or introduction of new workers to the brewery environment, therefore the necessity of a microbrewery which works in smaller scale, batches from 75 l, with all the necessary equipment and utilities to completely able workers to progress and work in bigger breweries within the group. The objective is to scale digitally a microbrewery able to produce a quality artisanal beer from the milling of the grains to the filling of bottles or kegs where workers from the different areas can practice and better learn the brewing processes.

As secondary objective was proposed an optimization in wort production of the minibrewery of the group as this objective would also increase the knowledge in brewing systems and problems associated to breweries complementing with the main objective of the microbrewery dimensioning.

2. Beer production and associated equipment

2.1 Raw materials

The beer production is based in four raw-materials, water, malt, hops and yeast. Water is the raw-material with higher quantitative impact and its properties, such as acidity and hardness must be thoroughly controlled because they directly impact the character and quality of the final beer. In the industrial environment water has an increased importance since it's also associated to cooling and Cleaning-in-Place (CIP) processes. The malt used in beer production comes from barley grains that suffered the process of malting, which it's the main source of sugars and enzymes essential for degradation of large sugar molecules into simple sugars during mashing allowing for an efficient fermentation. Other cereals such as rice, wheat and corn can be used as alternative or complementary source of sugars although lack of enzymes in their constitution and therefore there's a need for malt or adding of enzymes. The hops are the flowers of the plant *Humulus lupulus* which oils during boiling will affect the beer properties such as aroma and bitterness while also helping in achieving clarification and colloidal stabilization of beer. The last raw-material is yeast, a unicellular fungus, responsible for the alcoholic fermentation of wort using the degraded sugars as substrate and releasing as main products ethanol and CO_2. It's required a full knowledge of these ingredients, their characteristics, effects on process and in the final product to accomplish a quality brew in an efficient and effective way.[1–6]

2.1.1 Malt

Malt is used in beer production derived to its high content in starch (50 to 63% of the total carbohydrate content) present in the cereal grains. The starch $(C_6H_{12}O_5)_n$ is formed in the slowly ripening barley grain by assimilation and sequent condensation of the glucose ($C_6H_{12}O_6$) to form an energetic reserve which is going to be metabolized by the seedling in its initial growth phase until its own energy production is switched on, after chlorophyll has been synthesized, and the commencement of assimilation is ensure. The starch is then deposited in the endosperm's cells for the barley germination, in the beer industry happens during the malting of barley. The starch grains are denominated amyloplast and are constituted by two biopolymers the amylose and the amylopectin, the average composition in a dry grain is shown in **table 1**.[1,4,5,7,8]

Table 1 Compounds in mass percentage of a barley grain[1]

Compound	Mass percentage (m/m %)
Total carbohydrate	70.0 – 85.0
Protein	10.5 – 11.5
Inorganic matter	2.0 – 4.0
Fat	1.5 – 2.0
Other substances	1.0 – 2.0

The malt is not only important for its starch content but also for its amylolytic enzymes specially the alpha-amylase and the beta-amylase, although they all show catalysis and hydrolysis of alpha-glucosidic bonds of starch and saccharification activity they differ on their structure and in their catalytic activation. The saccharification of these enzymes hydrolyse the complex carbohydrate into monosaccharides to serve as substrate for the yeast during the fermentation, but for that to happen the barley must be turned into malt in the malting process. To be a good quality malt it must have high ability to use its nutrients, high grain yield, high water uptake rate, low water sensitivity, low nitrogen content, high enzyme forming potential and high extract yield on malting.[1,3,4,9]

In malting (**figure 2**) the barley grains are harvested and cleared of any contaminants and impurities and begin the steeping process, barley grains are mixed with water in step vessels for the water uptake, this process usually occurs a 10^0C with oxygen induced and until the barley reaches a water content of 42-48% (V/V), the water mainly enter the embryo region of the barley kernel and then passes to the interior of the kernel (endosperm). At the start of the malting process, starch content are in a high stable molecular form, these compounds must be degraded into smaller molecules before they can be transported with the help of the water to the embryo in the centre of the barely. This degradation is performed by enzymes which are formed during germination, during this process, barley has a “controlled germination” where there’s enzymes and enzymes complexes activation within the barley grains. The most important enzymes for starch degradation are α and β amylase, cytolytic enzymes, β-glucanases and cytases. Germination process continues until the state of green malt is reached when the enzyme activation reaches its peak and the germination is stopped, water is removed from barley begging the kilning. In the kilning stage air-flows and heat is incited to malt grains drying them and applying characteristics such as colour, taste and aroma depending on the heating temperatures and duration, at the end of this process the malt is passed through a deculmer to remove the culm and small roots. [1,4,5,10]

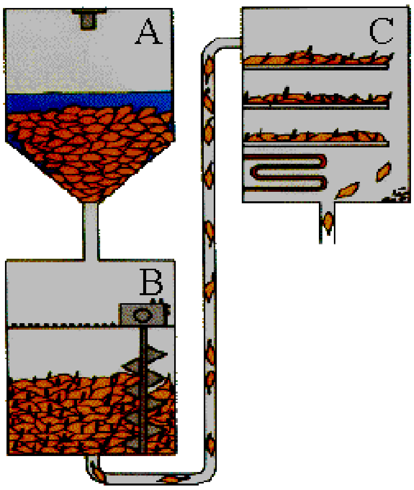

Figure 2 Malting processes: A) steeping of barley grains; B) controlled germination of barley grains; C) kilning of malt grains.[4]

2.1.2 Hops

Hops plants possess cones in which are located the lupulin glands responsible for conserving the bitter resins and ethereal oils which supply bittering and aroma components to beer, these bitter substances are composed of a mixture of several acids and resins being the most important ones the soft resins α- and β-acids (humulones and lupulones), the bitterness of the beer mainly depends on the conversion of these initial insoluble α-acids into soluble iso-α-acids though isomerization during the boiling of the wort for a long time or by treatment with a alkali. The bitter substances also have impact in preventing the growth of microorganism, such as bacteria in wort and beer prolonging the shelf time derived to their antiseptic properties. The bitter substances are very surface active and improve the stability of beer foam, better foam stability (head retention) should therefore be expected from a more strongly hopped beer. Polyphenols in hops have great importance to the brewer derived to their astringent taste, the ability to combine and precipitate with complex proteins, their oxidation to reddish-brown compounds, such as the phlobaphene, and their ability to combine with iron salts increasing naturally the shelf time and clarification of the beer. Of the polyphenols, the anthocyanogens are the most important both quantitatively and qualitatively, the average composition of a raw hop cone is shown in **table 2**. The utilization of hops in the beer industry is mainly through pellets, paste or extracts derived to loss of nutrients and properties on the conservation in harvested hop cones.[1,2,4,11]

Table 2 Average chemical composition in weight percentage of dry hop[1]

Component	%(w/w)
α-acids	2 – 18
β-acids	1 – 10
Oils	0.5 – 3.0
Polyphenols (Tannins)	2 – 5
Proteins	15
Cellulose	40 – 50
Water	6 – 10
Monosaccharides	2
Pectin	2
Minerals	10

2.1.3 Yeast

The yeast (*Saccharomyces cerevisiae*) it's a unicellular organism biologically identified as fungi, it obtains energy and carbon through organic compounds being this caption by anaerobic or aerobic form. Yeast cell are composed by 75% m/m water and when dry their chemical composition varies according to **table 3**. In both forms there's conversion of fermentable sugars as substrate to pyruvate from glucose where in the aerobic form the yeast will consume the pyruvate through respiration having as products CO_2, water and 38 adenosine triphosphate molecules (ATP) while in the anaerobic form the pyruvate is consumed in the fermentation forming products as ethanol, CO_2 and 2 ATP molecules. The brewing yeast can also be divided by Ale (top fermentation) or Lager (bottom fermentation) yeast. In ale beers the yeast does the fermentation at the surface of beer, this happens quickly between 3 – 5 days at 16º to 25º Celsius (C) while in lager beers the fermentation happens at the bottom of the tank, it also takes longer and at lower temperatures between 5 – 9 days at 7º to 15ºC. More differences exist between these yeasts such as their fermentable capacity, fermentation velocity, sugar conversion, temperatures tolerance, flocculation characteristics, volatile components and different sub products giving to beer specific tastes, scents and properties according to the used yeast and conditions applied during fermentation. The sugars used by brewing yeast are limited being them the glucose, saccharose, fructose, mannose, galactose and maltose, however the brewing yeast is not able to use as substrate long sugar molecules having the need to hydrolyse them which happens during wort production.[1,4,6,12,13]

Table 3 Average chemical composition in mass of dry yeast[1]

Chemical composition	Mass percentage (m/m%)
Carbon (C)	50
Oxygen (O)	20
Nitrogen (N)	14
Hydrogen (H)	8
Phosphor (P)	3
Sulphur (S)	1
Potassium (K^+)	1
Sodium (Na^+)	1
Calcio (Ca^{2+})	0,5
Magnesium (Mg^{2+})	0,5
Chlorine (Cl^-)	0,5
Iron (Fe^{2+} or Fe^{3+})	0,5
Manganese (Mn), Zinc (Zn^{2+}), Molybdenum (Mo^{2+}), Cobber (Cu^{2+}), Cobalt (Co^{2+})	~ 0,3

2.1.4 Adjuncts

The adjuncts are complementary ingredients added to wort production, they aren't essential to production but have direct impact in beer properties such as taste and scent, their main function is to reduce cost through the supplying of sugars to wort reducing the quantity of malt necessary to achieve the desired extract level to wort, also they present other advantages such as better head foam retention, control of nitrogen content and better nutritional values. Adjuncts usually are non-malted cereals like rice, wheat and corn being characterized for their high amount of starch content and lack of enzymes in their grains. The enzymatic potential from the malt enzymes it's enough to catabolize all the starch provided from malt and adjuncts but if there's a need to lower this process enzymes are added to speed the hydrolyzation of sugars. Nowadays many other types of adjuncts are begging to be used such as fruits, extracts and syrups in beer production largely because of the increasing of artisanal beers.[1–5,8]

2.2 Wort production

Wort production is divided in four major stages (**figure 3**), milling, mashing, lautering and boiling, in wort production is where the initial insoluble and complex compounds in wort are submitted to ideal conditions of temperature, acidity, oxidation to convert these compounds into soluble and fermentable ones for a quick and efficient fermentation. This conversion is possible derived to the malt enzymes hydrolyse the sugars in wort since the milling of grains until the boiling with hops where enzymes are denatured. During the wort production the equipment used are thoroughly chosen to reach perfect fermentation conditions with the less cost possible, less production time and with the desired properties of bitterness, colour, pH, extract and attenuation degree.

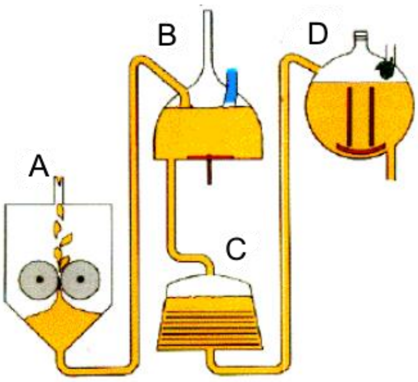

Figure 3 Stages of wort production: A)milling; B)mashing; C)Lautering; D)Boiling with hops[4]

2.2.1 Milling

The milling is the first step in brewing and already has great impact and has as primarily objective the milling of the malt grains for better solubilization of the fermentable compounds allowing for easier access of the amylolytic enzymes to hydrolyse the sugars condensed in the starch. There are four different types of milling, being them the hammer milling, the roller milling, the wet milling and the conditioned milling. In all the milling types the malt should be cleaned and all the metals, dust and other contaminants be removed not only to maintain a high-quality product but also to avoid the machinery worn.[1,4,8,14,15]

The roll mill, the most common one, uses two or more drill rolls to break the grains ideally into very small pieces while keeping much of the husk intact, the size of the grains is controlled by the gap between the rolls and it's a very cheap, effective and low maintenance equipment. The conditioned milling uses the same principle as the roll mill, only differing in an extra step needed previously to milling where the grains are pulverized with water for absorption (2 – 3% m/m) by the grain's husk, the celluloses in the husk will stay malleable not getting destroyed in the milling process and helping in the lautering working as a natural filter. The wet mill works in similarity to conditioned yet instead of pulverizing the malt with water, the malt its mixed in a tank with water (15 to 30 min at 30^o – 50^{o}C until 30% m/m of absorbed water), afterwards the non-absorbed water is removed and the malt is milled in a very narrow mill gap and directly entering the mash vessel and starting the mashing process. These two types of milling show advantages such as the lack of dust derived to the water introduction and higher yields of extract content and attenuation degree, also in wet mill you have the advantage of direct mashing of the grains reducing the wort oxidation.[1,4,14–16]

When there's a need of continuous milling and of large amounts of malt the most common equipment used is the hammer mill. In this mill, hammers are continuously rotating at high speed in a chamber and will mill the grains into flour, the size of the flour particles of malt is decided by the sieve sizes. This type of milling requires the usage of a different lautering system the plate or plaque filter, which uses polypropylene sheets since the malt is reduced into flour.[1,4,5,8,14,15,17]

2.2.2 Mashing

After the milling, it's in the mashing process where the sugars are going to be degraded and the fermentable compounds solubilize for an efficient fermentation. This stage of the brewing begins with the mashing-in where the milled malt it's mixed with water in a proportion determined by the amount of starch (%) in the mix per water to better solubilize the starch and other components which is called by wort gravity (OG). The beer's "original gravity" or starting gravity it's a measurement of the amount of the fermentable and unfermentable substances in the wort before the fermentation, this includes several sugars, nitrogen and other compounds extracted from malt which is classified in the Plato scale **equation 1**.[1–4,8,18]

Equation 1 Plato degree equation[4]

$$\text{Plato (oP) scale} - \text{ equivalent to its percent by weight of sucrose}$$
$$1\% \text{ sucrose solution} = 1 \text{ oP solution}$$
$$\text{OG } 1.050 \frac{\text{kg}}{\text{litre}} = 12 \text{ oP} = 12\%$$
$$= 12 \text{ g of dissolved extract per } 100\text{g of wort, pilsner beer's reference value}$$

The mashing-in of the malt usually happens at 35 – 38ºC (in small breweries and artisanal ones) to initiate the acidification process with the activation of the phosphatases, although when there's mechanisms to control the acidity and in-real-time properties (medium-industrial breweries) this temperature is skipped and the mashing-in begins at 45 – 50ºC the temperature of peptonisation. At this temperature the glucanases are at their optimal temperature and will start the degradation of the β-glucan which if not degraded will give undesired weight and viscosity to the beer. The peptonisation temperatures it's extremely important to achieve although high rest times at this temperature will have negative impact on the quality of the beer derived to the degradation of the proteins responsible for the foam stability and flavour.[1,2,4,5,9]

The saccharification or mashing is the most important stage of the wort production, the majority of the enzymatic activity and consequent degradation and solubilization of the sugars presents in the malt happen at this stage between 60 – 65ºC (low-saccharification) and 70 – 75ºC (high-saccharification) responsible by β- and α-amylases respectively, throughout this all process there's a need for extremely control of the temperatures to ensure the maximum enzyme activity, avoid denaturation of enzymes and the formation of starch hazes in the wort. In saccharification the initial long starch chains will be reduced to simple molecules, maltose, by the β-amylase in the end of the non-reducing chains, also forming other molecules such as glucose and maltotriose, however with only the activity of this enzyme the degradation of the molecules could take enormous amounts of time or even days because the β-amylase only acts on the extremity of the dextrin's. The big dextrin's are tasteless, add weight and viscosity to the beer and the fermentation of this type of sugars molecules is harder and longer having the need for simple sugars to ensure an efficient fermentation, the α-amylase will ensure the degradation of the longer chains of starch by acting in the middle of them creating several extremities to better complement and improves the activity from the β-amylase, the diverse types of sugars originated in this process are shown in **figure 4**.

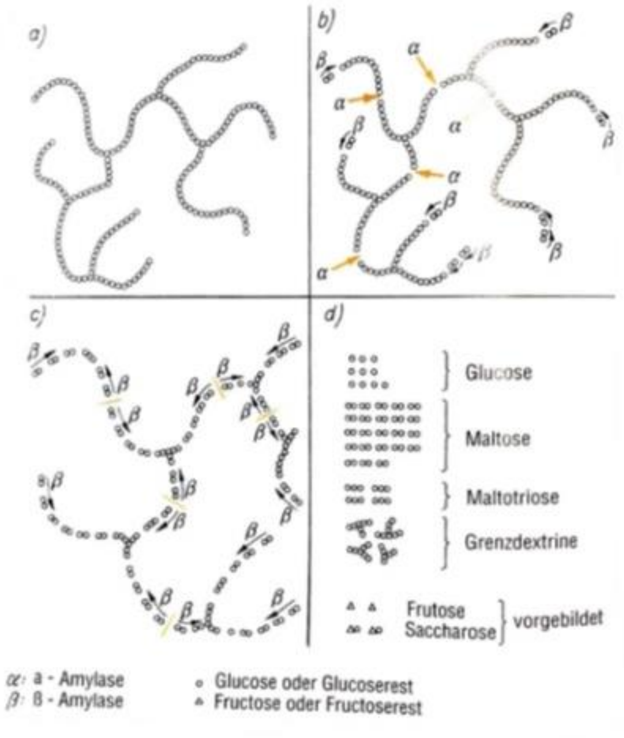

Figure 4 Dextrin degradation from α-amylase and β-amylase and sugar type originated by the enzymatic activity[1]

In breweries this stage is complemented with the addiction of coagulants to accelerate the filtration stage and enzymes to compensate the lack of them, in brewing types with large amount of non-malted cereals or simply to augment the enzymatic activity while decreasing the time of some wort production stages and digesting more complex molecules in the process and in some cases there is the addiction of acid to correct the pH of the wort for avoid losing of properties, product quality, saponification and keeping the optimal pH for the enzymes. During the wort production many other enzymes are activated besides the amylases having their optimal temperature and pH, products, substrates and inactivation temperature described in the **table 4**. [1–5,15,18]

Table 4 Activated enzymes in wort during mashing and their characteristics[1]

Enzyme	Optimal condition in wort		Inactivation temperature °C	Substrate	Product
	pH	temperature °C			
Peroxidase	6.2	40-50	65	Organic and inorganic substrates	Free radical
Lipase	6.8	35-40	60	Lipids and lipids peroxides	Glycerine, fat acids of long free chains and hydroperoxides
Phosphatases	5	50-53	70	Phosphates with chemical connection	Inorganic phosphate
α-amylase	5.6-5.8	70-75	80	Big and small β-glucan molecules	Melagasaccharides e oligosaccharides
β-amylase	5.4-5.6	60-65	70	α-glucans	Maltose
endo-β-(1-4)-glucanases	4.7-5.0	40-45	55	Big β-glucan molecules	Cellobiose, lamminaribiose and small β-glucan molecules
Exo-β-glucanases	4.5	<40	60	Cellobiose, lamminaribiose	Glucose
Limit dextranase	5.1	55-60	65	Limit dextrin	Dextrin
Polyphenoloxidase	6.5-7.0	60-65	80	Polyphenols	Oxidized polyphenols

Posterior to the mashing-in it begins the mashing process where the saccharification takes place, this process conducts the temperatures used, the duration of each heating ramp and each saccharification stage duration an which of the two methodologies is used in the process being them the infusion and the decoction. In the infusion methodology, the whole body of the mash stays in the same mash-tun which means during the all mashing process there's no transference of the wort to other mash-tun or vessel decreasing the risk of oxygen uptake and consequently lesser oxidation of the unsaturated fat acids. This methodology shows other advantages such as the lower equipment cost, operational costs and duration of the all process, when comparing to the decoction methodology, an example of infusion mash **figure 5 A** where a continuous heating of the mash is shown as well for its temperature ramps and stages duration. [1–4,7,9,10]

The decoction methodology has the whole body of the mash begging the mashing in one mash-tun and then be partially transferred to another one tun where the transferred wort will be quickly summited to all stages of the saccharification and then boiled to stop all the enzymatic activity in this part of the mash before being retrieved to the main mash tun where the main mash remained at the step saccharification of which the partial wort was removed, as the boiled wort is being added the main will have its temperature increased to the next saccharification step, reducing energy costs and heating time as shown in the **figure 5 B**. The main reason for the utilization of this methodology is derived to the higher extract and quantity of simple sugars obtained when comparing to the infusion one, also with the decoction is possible to achieve lighter wort, better colloidal stability, better control in enzymatic activity and better removal of dimethyl sulfide (DMS), which in values over 150 ppb will affect the beer flavour giving it a cabbage flavour.[1–5,17–19]

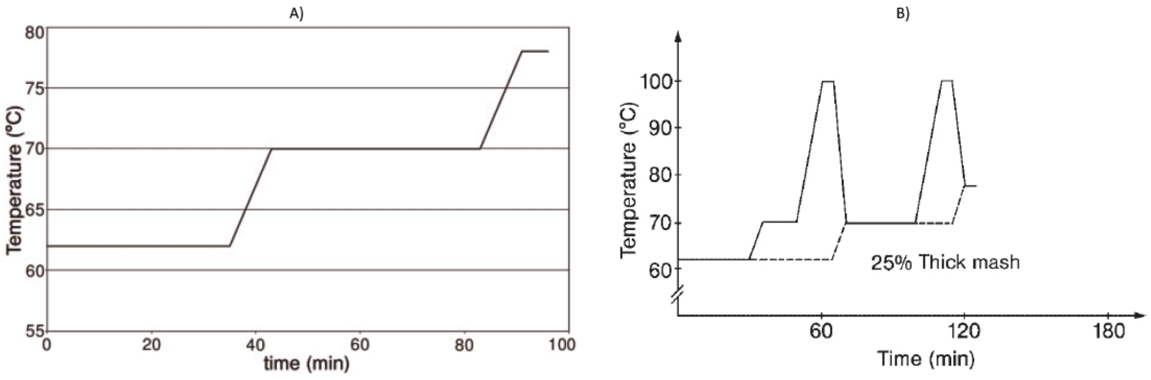

Figure 5 mashing heating graphs: A) infusion method[9]; B) decoction method[9]

The adjuncts as main function is to complement the properties in the mash, add sugars for costs reduction, flavour or make up for an easier fermentation and clarification. The adjuncts are non-malted cereals that also go through mashing like malt however with different temperature and time steps specific for each cereal. They usually start the mashing-in at higher temperatures between 55^o – 65^{o}C in some cases even higher and do both of the saccharification steps going straight to boiling to stop all enzymatic activity before being added to the main mash at the end of peptonisation raising the temperature of the main mash to the low-saccharification temperature reducing the heat costs. The non-malted cereals although they show some enzymatic activity, they lack enzymes to do a proper saccharification so there’s the need for enzymes adding during the mashing of these cereals.[1–4,18,20]

The equipment used for mashing is a mash-tun, this is a circular tank in stainless steel or bronze, closed with isolation at the bottom and the sides to avoid losing of heat to the outside increasing the energy costs during the process. Ideally the mash-tun should have good heat transference to the wort and heat it evenly, be able to mix evenly the mash without inciting oxidation or shear stress which will deteriorate the quality of the wort and may increase the wort viscosity slowing the lautering, an example of a modern mash-tun is shown in **figure 6**. In cases of wort production with non-malted cereals as adjuncts, or wort production which uses a decoction methodology for the mashing, there’s a need for a second tun occupation, which can have a smaller size when used for small batches or the same size of the main mash-tun if used as a complementary tun in breweries where simultaneal mashing’s are happening. There are many different types of mash-tun and accessories used depending on the size of the brewery, it’s utilities and objective in production. Mash-tuns can be heated by steam, heating plates or electrical resistances like in small breweries, the transference between tuns can be drive by pumps or gravity, also the stirrers in a mash-tun are very important to maintain an evenly mix having multiple format and types. In the end, the mash-tun should be able to mix evenly, allow for a good temperature and other properties control without any contamination while being easy to clean for consequent productions, per example at home brewing the mash-tun can be simple as a large pan heated in a stove, mixed with a wooden spoon, a kitchen thermometer and the miller be a hand blender.[1–3,5,18,21]

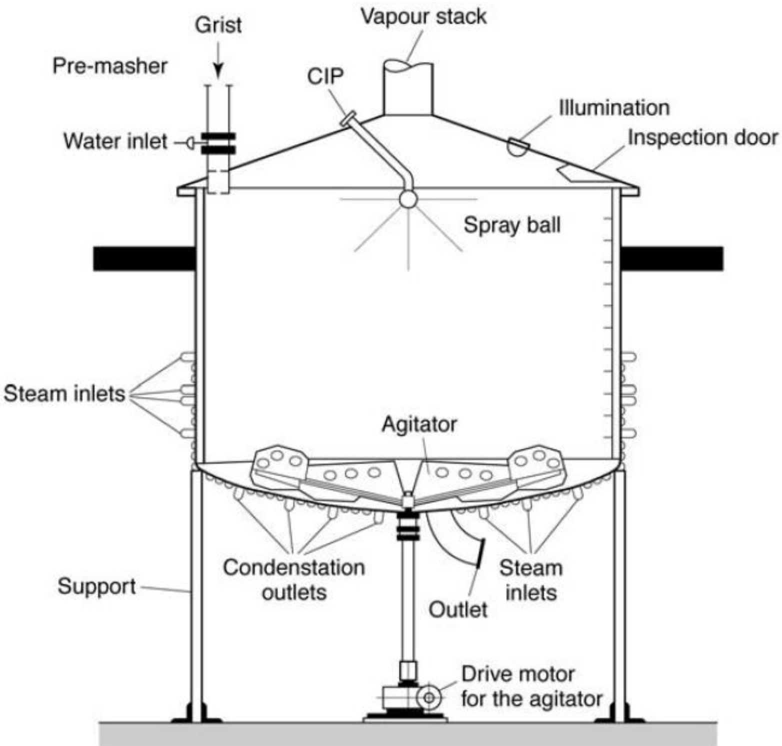

Figure 6 Mash-tun and all the accessories characterized[41]

2.2.3 Lautering

After the mashing the wort is an aqueous mix with dissolved and undissolved substances, so the aim of the filtration is to separate the liquid wort from the husk in order to obtain the maximum of dissolved extract, remove undesirable substances like heavy metals, tannins and lipids and achieve the maximum dissolved while preserving the quality of the final beer. The wort filtration, lautering, is divided in 3 steps, the recirculation, the mash-out and the sparging. In the first in mash will leave the tun and enter it again in to help form a filtration cake, the second the filtered wort has more extract than the beer to be produced, it can have 4 – 6% more extract than intended, per example a beer with the 12ºP after the first filtration should have 16 – 18ºP. The first filtration is not enough to remove all the extract present in the spent grains, so there's a need to do a second filtration in which the spent grains will be sparged to dissolve the remaining extract, the sparging initial will remove a lot of extract still but decreasing quantity in which sparge, the sparging of the spent grains will continue until no significantly extract is present in the grains and we achieve the desired Plato in wort, by addiction the lowered concentrated water from the sparge of the grains.[1,4,8,15,18,22,23]

The filtration can be made by 2 types of equipment, by lauter-tun or mash-filter, the milling type will rule the type of filtration made in cases where the dry, conditioned and wet mill roll is used the type of filtration uses a lauter-tun, when the milling is made by a hammer-mill is used a mash filter instead. The lauter-tun **figure 7** is a tun characteristic for having a false bottom with slots from 0.7 to 0.9 mm which retain the spent grains from the wort while allowing for the passage of filtered wort, the retained spent grains is then sparged and filtered again with the help of the lauter knives. The lauter knives are other important element in this filtration type, they are metallic curved blades which will incite frenzy to the system, break and lift from the bottom the grain clumps derived to the "shoe" at the extremity of the blade which runs tangential to the false bottom, accelerating the filtration process and allowing for a good extract extraction, this filtration works better with a good milling in which the husks from the grains remain intact allowing for the formation of a good filtration cake during the recirculation of wort in lautering increasing the efficiency and efficacy of this process.[1–4,8,18]

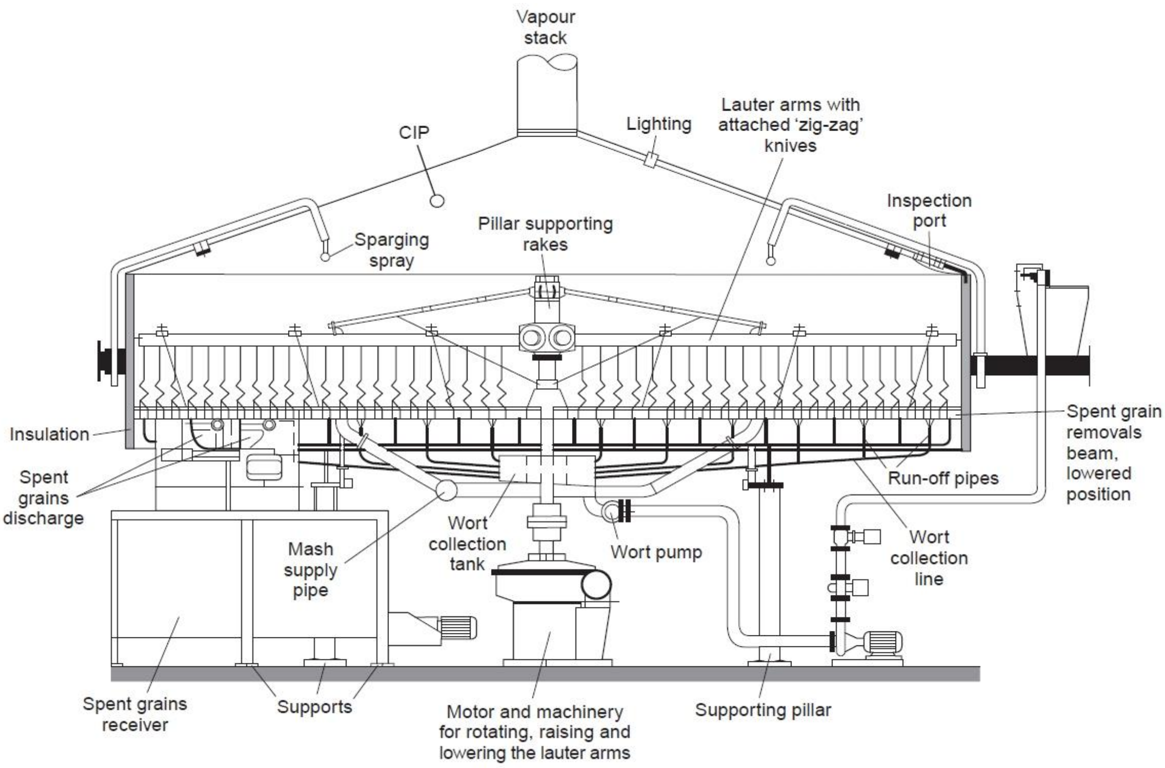

Figure 7 Lauter-tun with all accessories equipped[9]

The mash-filter **figure 8**, instead of having the wort filtered by false bottoms, the wort is filtered in polypropylene sheets with very small gaps from 0.152 to 1.27 mm in multiple sequenced plates where primarily the non-filtered wort crosses **figure 9 A**, which will stock the plate gap, named filtration chamber, with the husks and other undesirable particles forming a filtration cake **figure 9 B**. After the wort passed through all plates, and the filtration cake created in all the filtration chamber the compression begins **figure 9 C**, between plates which will force the extraction of the wort remaining in the grains. Afterwards as happens in the filtration with the lauter-tun, the sparging stage begins where water is made through the plates to take the remaining extract **figure 9 D**, another compression happens to remove the water from the sparge **figure 9 E** and at last the decompression of plates happens to remove the spent grains from the filtration chamber **figure 9 F**. In both filtration types the spent grains are dried and resell for animal feedstock.[1,2,4,8]

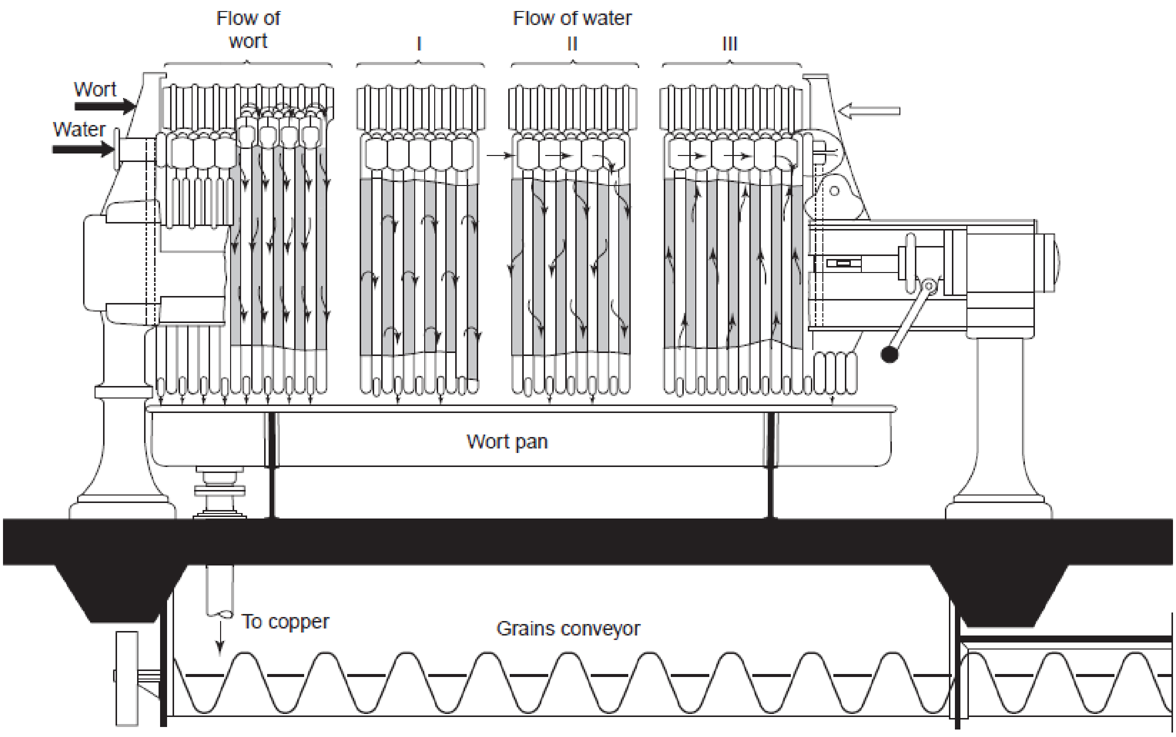

Figure 8 Mash filter with wort and water flows[9]

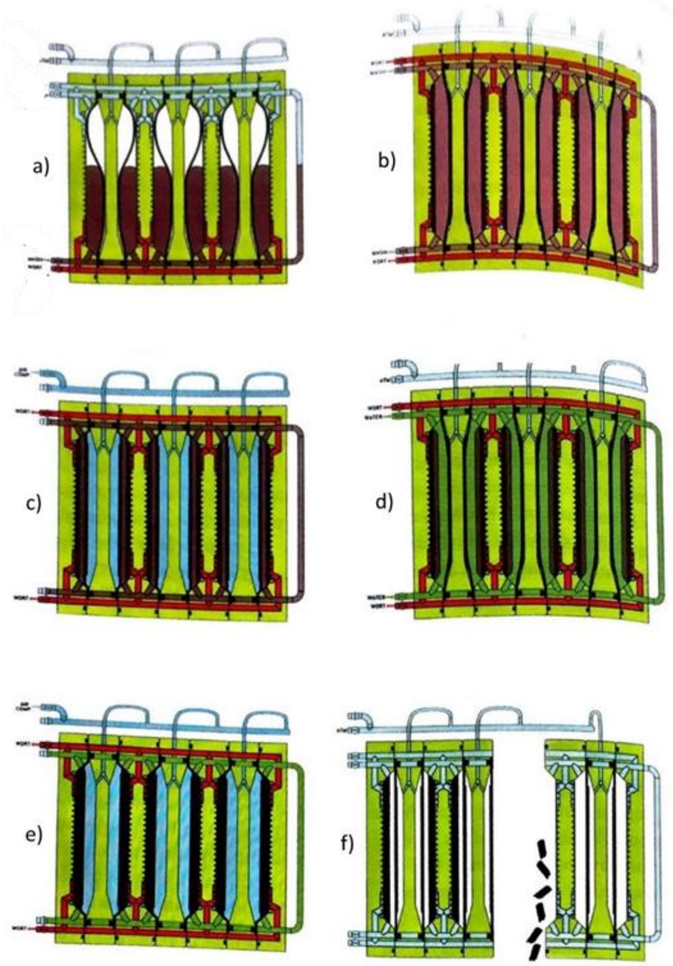

Figure 9 Mash filter operation flow: A) filling the filter; B) running off the first wort; C) first compression; D) sparging; E) final compression; F) spent grain discharge[1]

2.2.4 Wort boiling

The hops are responsible for suppling the bitterness to the beer through the isomerization of the α-acids into iso-α-acids during the wort boiling. So, after the lautering the wort is transferred to the brew kettle in which the wort is heated evenly to boiling temperature and where it remains from 1 to 2 hours depending on the values of volatile compounds and amount of evaporation of wort needed to remove the undesired components as shown in **figure 10**. The hops help in clarification reducing the beer haze derived to the polyphenols content which react with the proteins forming insoluble precipitates, promoting the coagulation of other proteins and evaporation of other detrimental compounds to the beer such as the main volatile compound the DMS which produces bad aroma and taste. The DMS derives from its inactive precursor the methionine s-methyl (SMM) formed in malting during the malt germination, the SMM it's a thermolabile compound which when heated during the malt kilning divides into the active precursor DMS-P which when reaches the mashing temperatures forms the DMS. Other main goals of the wort boiling are the denaturation of enzymes ending the enzymatic activity, wort sterilization, increase in wort colour, reduction of wort pH, reduction of wort nitrogen level and production of reducing compounds.[1–4,10,19]

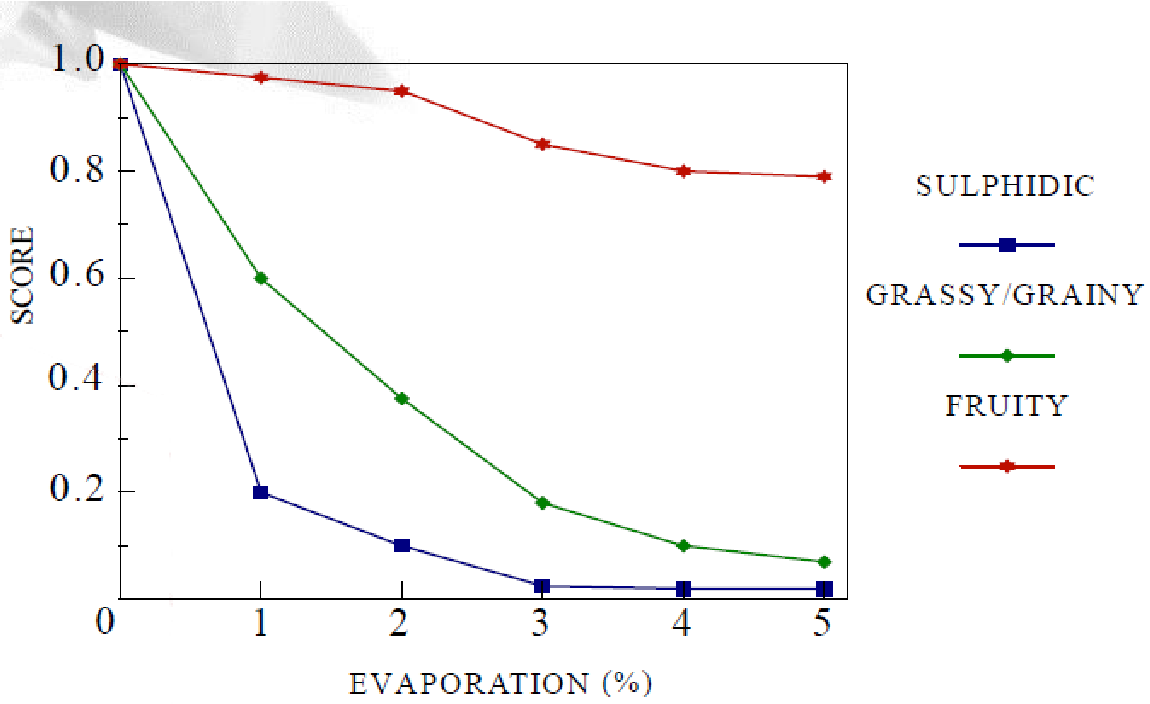

Figure 10 Graph showing the percentage of wort evaporation needed to remove the volatile compounds responsible for sulphidic, grassy/grainy and fruity flavours in wort[9]

Boiling kettles are similar to the mash-tuns in their base format, they need to heat up the wort evenly, have a good isolation and heat transference throughout the all boiling, however there are many different boiling kettles structures and systems, changing in the way they force the heating flow in the wort, in the way they can be heated being internal with heating steam pipes or volcanic flows in an internal heater **figure 11** or external heater with a closed circuit to ensure the maintenance of the boiling temperature while avoiding oxidation. The kettle must have a chimney and be able to support continuous boiling temperatures while controlling the overflow of foam made from excessive boiling, which can cause increase in equipment pressure leading to equipment deterioration or even accidents in the brewery. [1–4,18,19]

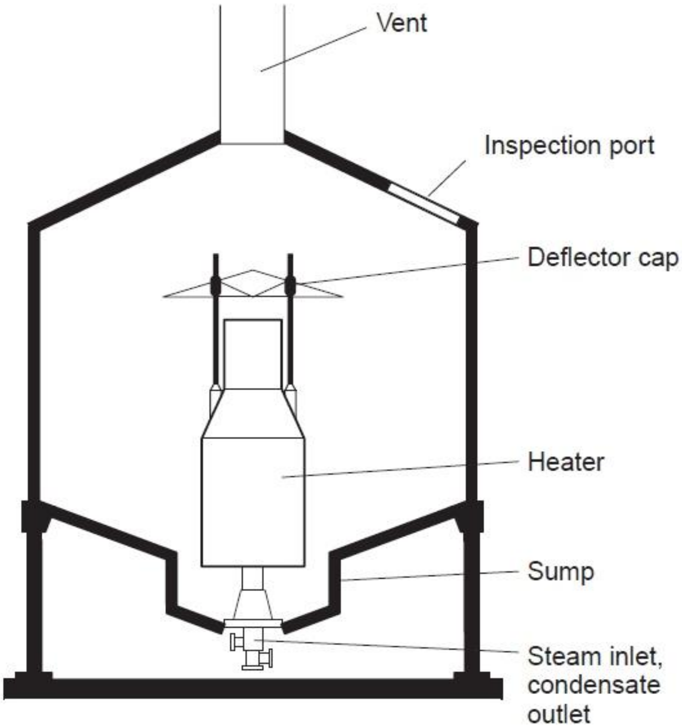

Figure 11 Kettle with internal boiler and equipped acessories[9]

In small breweries the kettle resembles to mash-tuns with a few extra accessories to support the operation conditions while in medium to big breweries the utilities equipment have great impact derived to the steam and cooling water usage. In order to avoid odour emissions, save energy and costs of boiling operations the breweries add utility areas with condenser which retrieve the steam from boiling, condense them and by thermal or mechanical compression retrieve great quantities of water in amounts similar to the ones from evaporation which are used for wort production, however this water doesn't possess minerals only having the organic substances from the hops and malt so there's a need for a previously filtration by activated carbon or inverse osmosis for condensed purification.

2.2.5 Wort clarification

At the end of boiling with hops, the wort has trub flakes and hop pieces in suspension and show high turbidity, so there's the need for a particle separation, not only for wort clarification but also for removal of contaminants or harmful components to beer quality. There are several equipment types and formats for this process yet all of them use one of three basic principles, the tangential flow, sedimentation and centrifugal action. The tangential flow uses equipment like the whirlpool, which is a cylindrical vessel in stainless steel without any interior accessories and having an almost plain base with an inclination of 1 – 5° to the interior of the whirlpool. The operation of this equipment works as the given name (**figure 12**), the wort enters in the whirlpool tangential in two locations, primarily close to the bottom of the whirlpool to avoid the oxygen assimilation from wort and when the wort reaches certain whirlpool height in the inferior third to incite rotation to the mix. The rotation will cause the sedimentation and accumulation in a inversed cone shape at the whirlpool centre while the cleared wort is retrieve in the whirlpool edge. The sedimentation principle works in huge decanters with a conical bottom where the wort rests for 20 to 40 minutes and the clarified wort sited on top of the trub is retrieved or the trub is retrieved from the bottom of the conical bottom. At last the wort clarification can be made using a centrifuge, which is the most efficient and effective equipment working in aseptic environments and having almost no wort loses (<0.3%) however centrifuges are not able to work with great volumes of wort, are very expensive and have high maintenance costs, working the majority of the times as complement to the other clarification processes removing the remaining wort from the removed trub.[1,2,5,8,24]

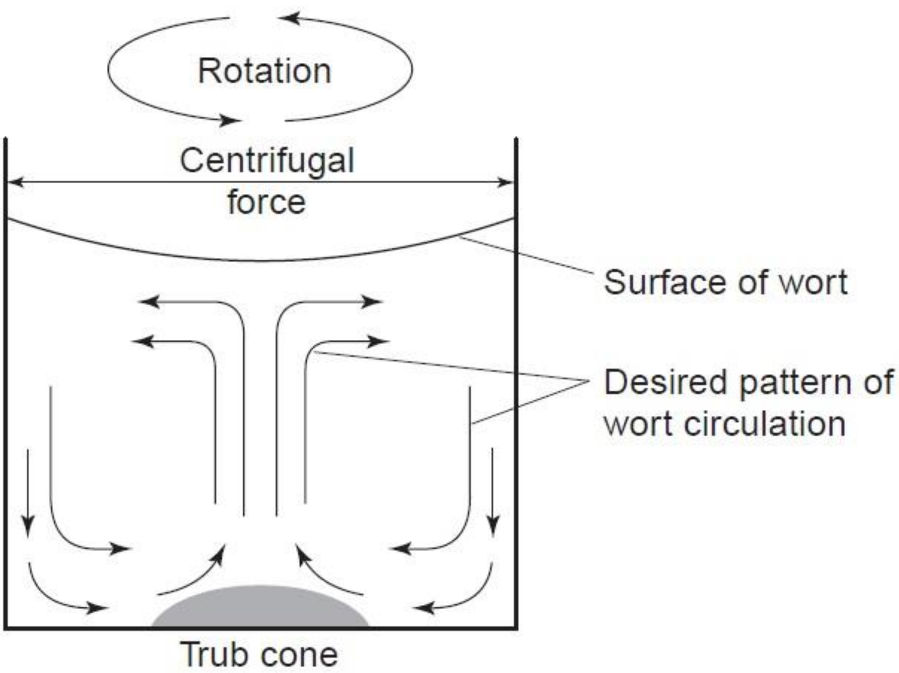

Figure 12 Whirlpool tangential and rotation flows and formation of trub cone[9]

2.2.6 Wort chilling

Before the pitching of yeast to begin fermentation, the wort needs to be chilled because yeast can't support high temperatures, so the wort must be chilled to 15 – 22ºC for fermentation of ale beers and 6 – 12ºC for lagers. The wort chilling must be quick to avoid the growth of microorganisms which can multiple and generate metabolic products which have negative impact in beer taste and characteristics. The most common equipment used for wort chilling is the plate exchanger, which consists in a series of metallic plates, connected to each other, which divide the running chilled water or glycol and the warm wort in alternated plates to increase the superficial area for temperature transference without any contaminations and pressure loses during the process. The advantages of using this equipment rely on few equipment occupation space, easy to clean and sterilize having the possibility of being connected to CIP equipment.[1,2,5,6]

2.3 Fermentation processes

The fermentation is the stage of the production where wort is turned into beer through the conversion of the sugars present in the wort with the release of CO_2 and alcohol as well for other sub-products which will have great impact in aroma and beer characteristics. There are two fermentation types, the top and bottom fermentation that brew ale and lager beers respectively. The focus of the microbrewery dimensioning is for main lager beers so the fermentation processes studied are for bottom fermentations. For lager fermentation there's a need to fulfil certain factors to ensure the yeast culture growth such as the good wort aeration, optimal temperatures and nutrient content allowing for an optimal fermentation. The yeast used in pitching comes from the yeast propagation tanks in which it's cultivated or is stored from previous brews until a maximum of 6 – 8 before negatively affecting the beer, then it's pitched with part of the wort in a small vessel of 1/20 of the main wort volume for yeast accommodation and afterwards introduced in the cylindroconical vessel (CCV) with the rest of the wort to begin the fermentation.[1–3,6,25,26]

After the pitching of yeast begins the fermentation which can be divided in three phase, the adaptation phase, the attenuation or first fermentation and the maturation or conditioning (**figure 13**). The adaptation phase can last up to 12 hours in which the yeast consumes the nutrients added to the mix and the ones already in wort to multiply, initially from aerobic metabolic processes due to the energetic efficiency against the anaerobic, therefore there's the need to ensure an initial aeration of wort to shorten this phase and assuring a quick multiplication of yeast, when the oxygen is no longer present in wort begins the anaerobic processes. The attenuation phase gets the name from the vigorous fermentation in the first 6 to 7 days where 2/3 to 3/4 of the wort extract is consumed by the yeast releasing the alcohol and the CO_2, the simple sugars are the first to be consumed and as the amount of this sugars gets lower, yeast changes to the consumption of the polysaccharides molecules and some early products of yeast. Also, during this phase it's noticed the formation of *Krausen* at the top of the wort, a foam consisting of wort proteins, hop resins and dead yeast. At the ending of attenuation phase, the lack of extract leads to a reduction of yeast activity and coagulation of yeast at the bottom of the CCV, lager beer, forming the fermentation cake and the green or immature beer which can later be centrifuged to recover beer from the yeast. In end of this process the green beer without the fermentation cake is transferred to a maturation vessel or the fermentation cake is removed, and the maturation is made in the fermentation vessel. [1–4,6,9,12]

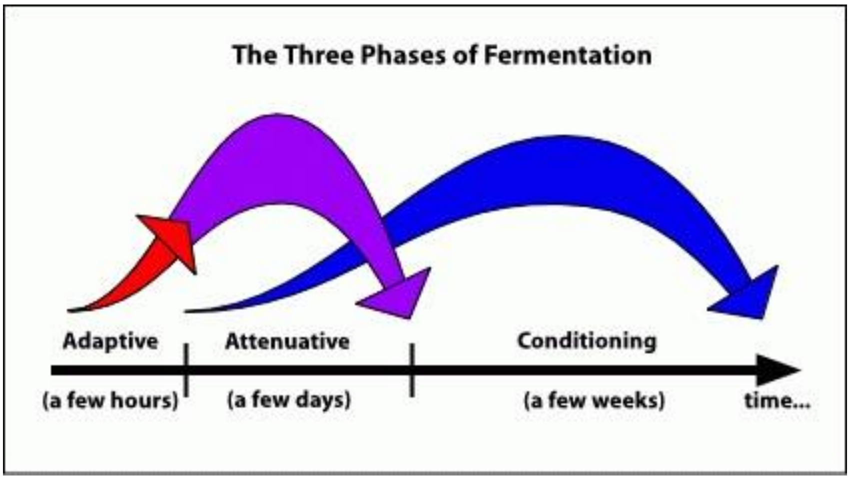

Figure 13 The three phases of fermentation[10]

During conditioning phase there's a slow reduction of the fermentable compounds remaining, it's made close to 0ºC allowing for a refining of flavours and removal of diacetyl, aldehyde and hydrogen sulphide which harsh the flavours and haze the beer. This stage starts middle of the attenuation phase, is made under high CO_2 pressure released by the yeast and can endure from 1 to 3 month depending on the beer type. The aging of beer has high influence on the final taste of beer, this aging is also used in wines, beer filtered or pasteurized will not have these aging benefits.[6,13,25,27]

The fermentation equipment has to endure internal pressure and be able to control the internal temperature derived to the saccharification reactions which release energy and CO_2 while managing to have sample valves and retrieve without any issue or contamination the beer in the interior. The most common equipment used is the CCV which present several advantages when comparing with other equipment types because it's able to support all the fermentation phases having the lower total equipment and operational costs, great durability and resistance while allowing for excess CO_2 removal, temperature control and easy yeast removal derived to the conical bottom. The CCV are vertical vessels can many of them can be arranged in a small area and manage them, there are many other fermentation vessels, such as open and closed fermentation tanks, maturation and lagering vessels although they use of more pipeline, require more operational control as well for equipment costs when compared to a full cellar are equipped only with CCV.[1,2,6,13,27,28]

2.4 Beer filtration

At the end of the fermentation stages, the beer ideally didn't suffer oxidation and has all sugars converted, however at the end of this process beer possesses greats amounts of yeast and hazer substances in suspension so there's a need for removal of these compounds with filtration ensuring colloidal and properties stability throughout the storage and shelf time. The filtration is a very minacious process in which there's not the need for phase separation without any oxygen uptake from the beer but also to recover beer and yeast which will be later recycled for use in another brew or to use as animal feedstock. The most common and old used method is the decantation or centrifugation of the beer, although this methods take much time in the process for big volumes of beer as well for increasing nucleic acids concentration, proteins and pH, being not that effective as primary filtration methods but very used nowadays as a complementary method.[1,2,4,5,8]

The need for a complete removal of yeast and material in suspension in beer is made using filter aids, kieselguhr and perlite, they are small particles with huge porosity and when dosed according to their porosity and size to a filter support in the 3 phases, the first precoat **figure 14 A**, second precoat **figure 14 B** and then the body feed **figure 14 C**. The support can be a fabric, a plaque or a plate, cake which the filter aid will complement largely increase the efficacy. There are several filter types being the most common ones the plate filter, the disk filter and the candle filter. [1,4,5,9,29]

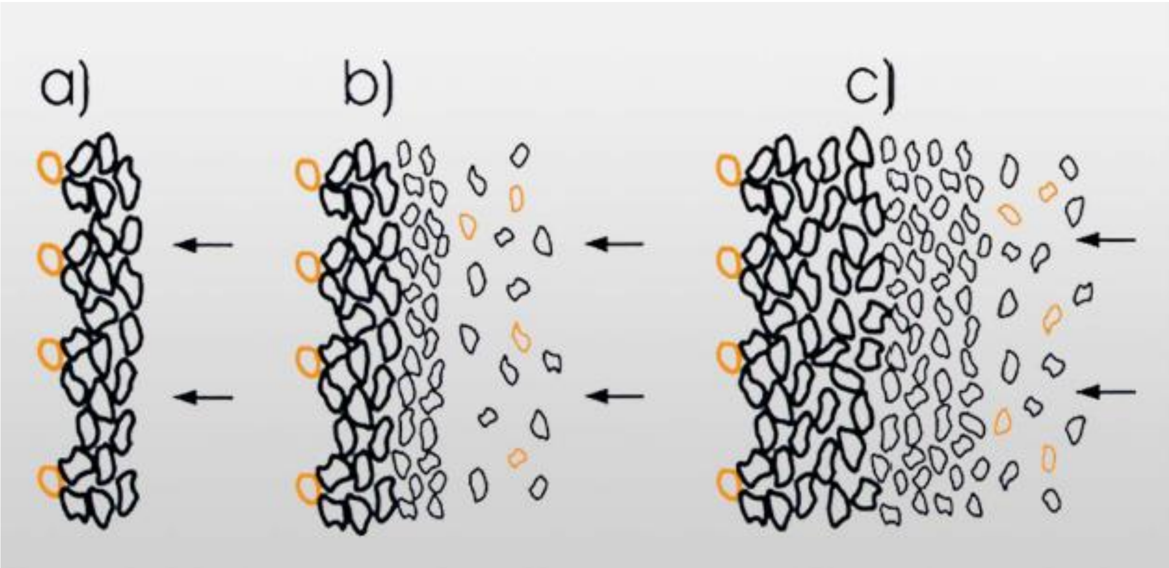

Figure 14 The three phases of kieselguhr precoat: A) first precoat; B) second precoat; C) continuous dosing[27]

The plate filter (**figure 15**) consists in many sequenced plates covered with cellulose plaque in which the filter aid settles, the unfiltered beer is then forced through the filter and retrieved the cleared beer from the other side of the plate, similar to the mash filter operation. The plate filter can be accoupled to CIP equipment making it easy to clean and sterilize the cellulose plaques turning this filter into a rentable and practicable beer filter. [1,2,4,5,8,29]

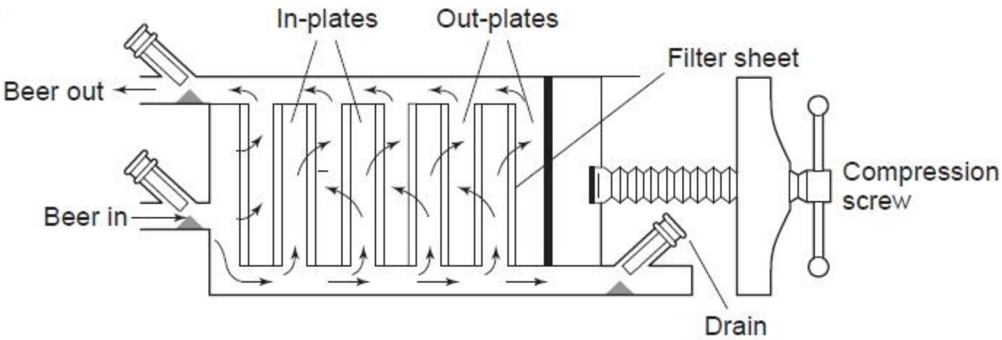

Figure 15 Plate filter entries, accessories and flows[9]

The disk filter (**figure 16**) is a cylindrical vessel with many horizontal disks of a metallic mesh in a chain where each disk works as a separated filter. All the disks are covered with filter aids and the beer forced through the filtration cake set upon the disks being the filtered beer retrieved from the interior of the disks to an internal channel which leads to the filling lines. At end of filtration, a residual filter aid is deposited at the bottom part of the disks so is incited rotation to the disks which forces the filter aid to be pushed to the walls of the vessel and retrieved at the end of the conical end. Exists a version of this filter with vertical disks although the operation costs are higher, and the conditions of work require more time and effort to set the filtration system. [1,2,8,16,29]

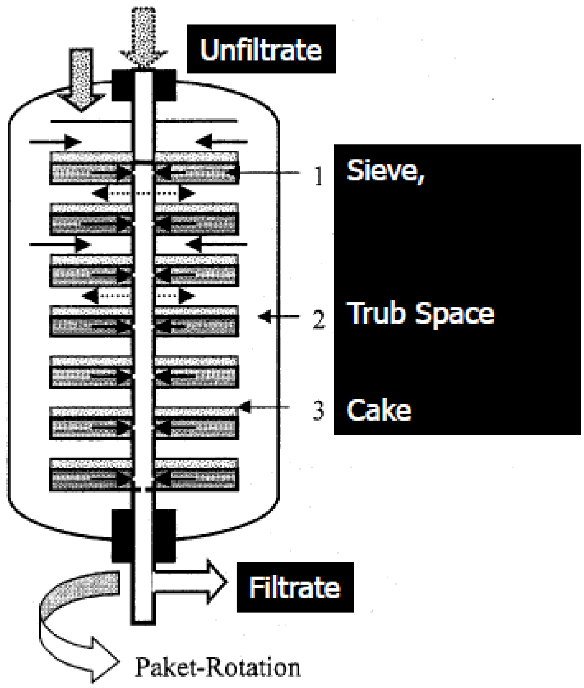

Figure 16 Disks filter flows and acessories[9]

The candle filter (**figure 17 A**) is a pressurized cylindrical vessel with a conical bottom and a lid in the top part with several holes in which the candles will be suspended as shown, the candles (**figure 17 B**) are perforated cylinders with low diameter but with heights reaching 2 meters, the candles are covered with overlapping rings to increase the efficiency of this filter. The candles will be covered with the filter aid in the same procedure as the disks in the disk filter and the filtered beer will be retrieved from the interior of them. A candle filter can have up to 700 candles which lead to an enormous superficial area for filtration granting a great filter flow rate at low operation costs, although with high equipment cost.[1,4,5,8,29]

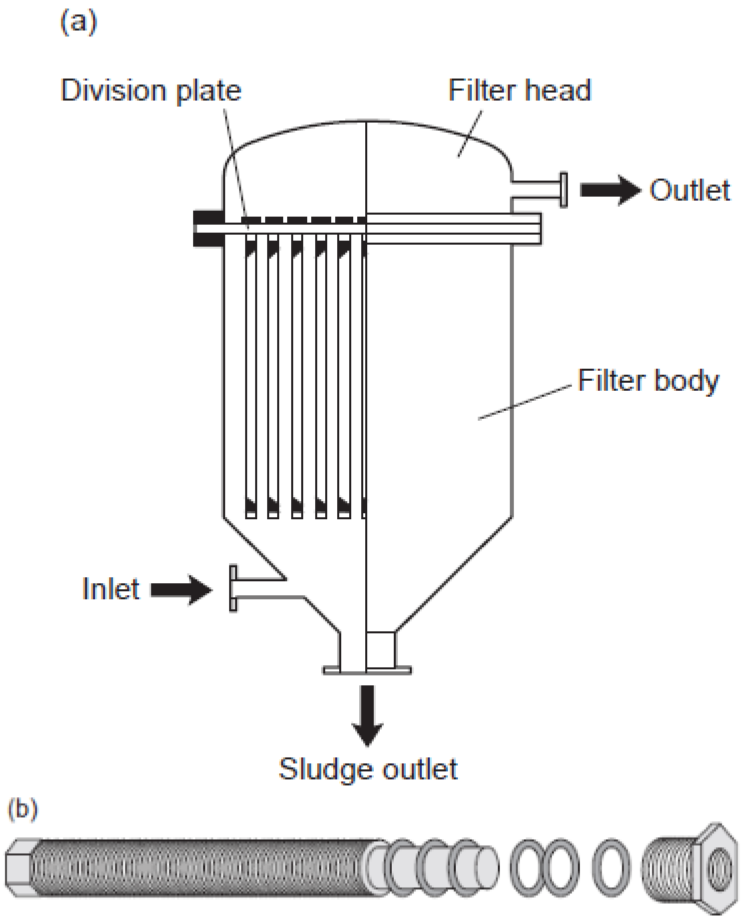

Figure 17 a) candle filter flows and acessories;[9] b) candle of filter with the internal structure exposed[9]

2.5 Beer stabilization

After beer filtration there's some residual turbidity as well for possible contaminations and incorrect beer properties, one of the treatments to correct this properties is made using silica hydrogel (SiO_2) which is a structure with high porosity and superficial area, the SiO_2 is covered in silanol (SiOH) and possesses great ionic affinity to some polypeptides and proteins mainly the ones affecting the turbidity of beer and foam stability. The silanol has great affinity to proline present in the polypeptides and through that affinity the polypeptides are adsorbed in the hydrogel surface. This adsorption is made in the maturation tanks which flocculate and sediment at the tank bottom with the adsorbed proteins for later removal and centrifugation of the complex silica-gel.[1–4,8,22,29]

For beer colloidal stability is added to the beer polyvinylpolypyrrolidone (PVPP) in the form of dust which selectively removes all phenol substances in suspension, the removal happens by the formation of hydrogen bonds between phenol and PVPP content which later is broke in an alkaline solution to remove the phenol content retrieved from the beer for recycling of the PVPP. The adding of PVPP can be made by three distinctive ways, by direct adding the lagering tanks at the end of maturation, in a recirculation system with sequential adding of PVPP and in filtration with the filter aids. To avoid PVPP leftovers in beer, the filtered beer is made through a trap filter to remove PVPP and other finals impurities that were not remove previously.[1,2,4,22,24,29]

The last beer treatment is the removal of the oxygen made which entered beer during all the filtration and treatment processes, oxygen has negative impact in shelf beer time and taste, therefore is made an adding of sulphur dioxide (SO_2) which is added under the form of sulphites significantly increasing shelf time. At last with the beer completely removed of all undesired contents and stability reached is made an extract and CO_2 adjust to the beer before being transferred to the filtered beer tanks (FBT) where it's storage until the filling.[1,2,4,22,29,30]

2.5.1 Pasteurization

The microorganisms are present in both air and water, so is impossible to prevent their entry in beer and to eliminate these contaminations the process used is the pasteurization. In pasteurization beer is heated to temperatures between 60^o to 62^{o}C during 10 to 20 minutes eliminating all microorganisms, nevertheless this temperature speeds some chemical reactions leading to loss of flavour therefore the pasteurization has to be controlled to avoid loses with pasteurization units (PU) where 1 PU is equal to 1 min at 60^{o}C using the following **equation 2**.[1,2,4]

Equation 2 pasteurization unit formula[4]

$$\text{PU} = tempo \times 1.393^{(Temperatura\ de\ aquecimento^oC\ -60^oC)}$$

Beer needs 14/15 PU treatment in beer to ensure complete pasteurization and there are many types of pasteurization methods used nowadays like flash pasteurization, hot filling of beer (8 to 10 bar overpressures to keep the CO2), tunnel pasteurizer, cold sterile filling of beer (recent technology, soft, slow and expensive). The most used method is the flash pasteurization, beer and other beverages are controlled in a continuous flow and submitted to a temperature around 71.5ºC to 74ºC, for the duration of 15 to 30 seconds. Flash pasteurization of beer uses from two to three phases of heated plates with hot water to exchange heat.

2.6 Filling and packaging

Filtered and treated beer is storage in filtered beer tanks (FBT) before going to the filling lines to fill either cans, bottles or kegs. All these compartments have to be sterilized and washed before the filling with beer and it's imperative this process is made in aseptic conditions or with CO_2 counter pressure to avoid any contamination enters the compartments. Breweries with large beer productions have entire filling lines with automated machines to entirely control the process from the compartment pick-up send from the supplier to the packaging of cans in pallets. Small to artisanal breweries do the filling directly from the beer CCV or FBT and without the pasteurization system build into the filling lines the pasteurization is made with the deposition of the beer compartments in water tanks at 65ºC posterior to the filling.

3. Methodologies and microbrewery dimensioning

For better understanding of beer production, systems used and how they operate, primarily was made a daily follow-up during two months of the beer productions in all of three breweries within the Super Bock Group factory having that way the incite on the procedures during wort productions, fermentations, filtrations and fillings in three different brewing scales. During this time was observed at the smallest detail all the operations made and all the equipments used, why they were choose and installed in those breweries and which advantages and disadvantages they had. Since only one of the breweries within the factory had production volumes close to the microbrewery to be dimensioned, the pilot brewery with 200 l batches, several other breweries in the northern area of Portugal were visited and their equipment and production choices were taken in consideration and their advantages and disadvantages studied. All the information retrieved was then compared with bibliography and companies which sell brewing equipments from different scales.

The result was a microbrewery of 75 l batches digitally dimensioned that works in semi-automatic mode, having all key equipment to brew in efficient mode artisanal beer from milling to filling. Therefore, the microbrewery was divided in three areas (**figure 18**) the wort production area, the cellar and the utility area. In wort production (**figure 18**) area was chosen for milling a two-roller mill, for the mashing two mash-tuns, with one of the mash-tuns able to work in simultaneous as the other to mash adjuncts. The filtration of the mash is made using a lauter-tun and the boiling is made in a kettle dimensioned to work as simultaneously as a whirlpool and wort chiller having a cooling coil set in the interior of the kettle, this three equipment in one allows for cost saving in equipment and operational costs while maintaining the efficacy and efficiency of many equipment. To make the wort transferences more efficient and have less pumps transferring wort, the tuns are settled in an optimized brew stand allowing for the transference of wort using gravity. The tuns and kettle are heated with steam and the coil chills the wort using cold water.

The cellar area (**figure 18**) possesses six cylindroconical vessels with 210 l total volume possessing all essential accessories for a good and automatic control of fermentation, not having the need for a continuous supervision, the CCV are refrigerated with glycol water controlled by pneumatic valves and have sample valves allowing for analyses and control of the beer during fermentation. The cellar area has a well-structured pipeline narrowing the number of pumps on that area to one and was dimensioned to allow for a future expansion of a filling line and filtration area. At last the utility area possesses the equipment for CIP, a hot liquor tank to reduce heating costs of the mash, the condensate and steam equipment which retrieve all condensate gases and sends all heating steam to the production area, this area supplies all the microbrewery in an efficient and organized way.

For better understanding of the microbrewery structure and equipment disposition was made a P&D showing all the equipment equipped with all valves, probes and accessories, divided in the three different areas and connected by the different pipelines which connect all the brewery systems (**figure 18**). The digitally dimensioned equipments were disposed as well in the 3D system divided in the three areas (**figure 19**).

All the digitally dimensioned equipment for this microbrewery wasn't built, although the project and the digitally dimensioned equipment as for the dimensions and materials was given to the Super Bock Group to future construction.

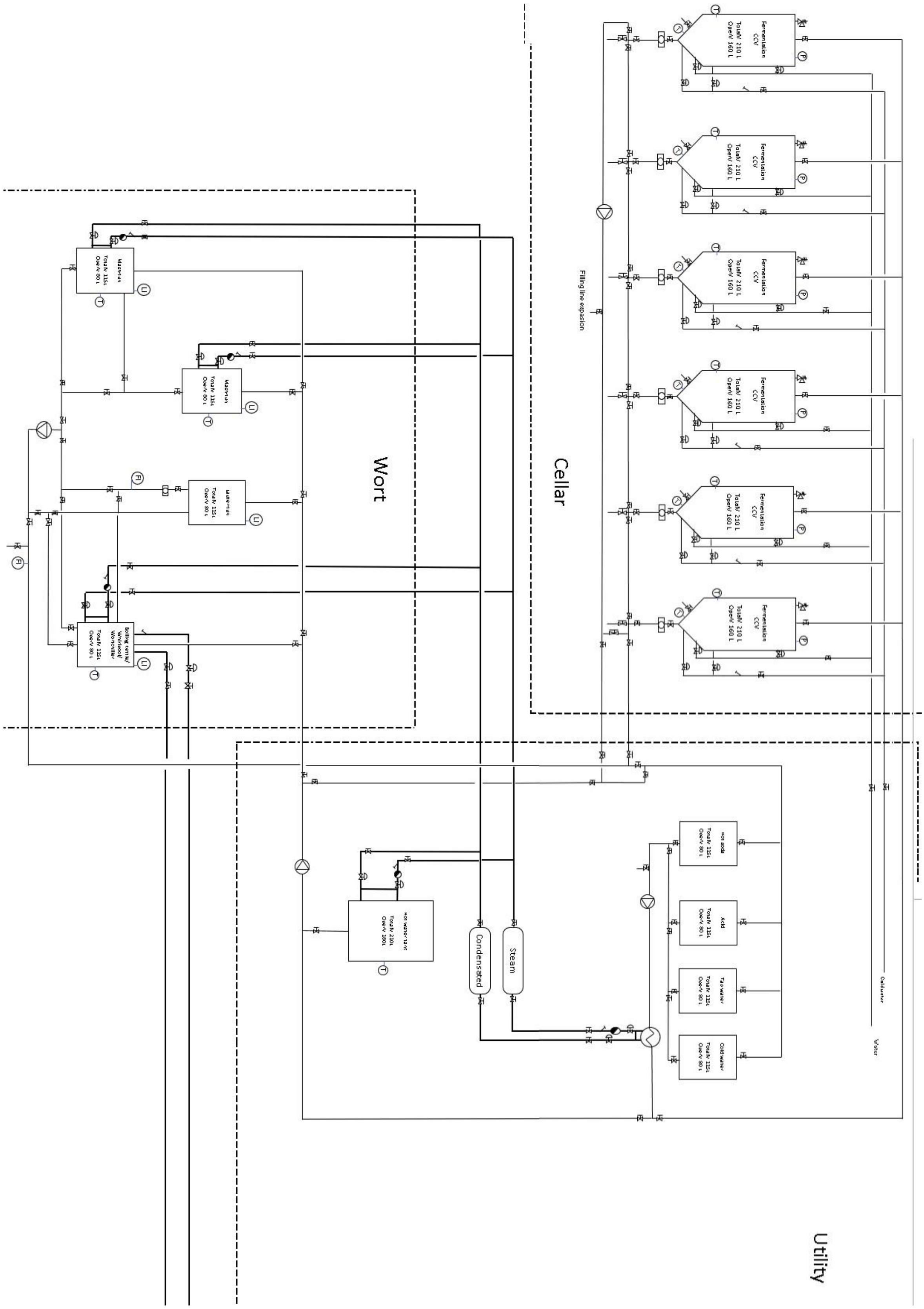

Figure 18 Microbrewery P&D with all equipment, accessories, valves, pumps and connecting pipelines between the different areas

Figure 19 Microbrewery equipments all 3D dimensioned and divided in the three different areas.

3.1 Equipment description

3.1.1 Production area

3.1.1.1 milling

The milling of the microbrewery (**figure 20 A**) is a dry or conditioned milling using a two-roller mill equipped with a hopper and a stand, the reason of choice for this milling took in consideration the production volumes, the dimension of the microbrewery and derived to be a simple and efficient equipment with low equipment cost, simple operation and low maintenance. It can be manually operated or automatically while having the possibility for future expansion to a wet milling.

This milling possesses 2 rolls, one main roll (**figure 20 B:1**) and one warrant roll (**figure 20 B:2**), both made of tempered steel, to possess greater wear resistance, they have 50 mm Ø by 150 mm length equipped with 12 teeth per inch (TPI) and a milling capacity of 3 – 4 kg/min. The rolls can be manually operated of have a motorization incited on the main mill which has a shaft for that effect (**figure 20 B:3**).

The rolls are set in a support formed by 4 aluminium plaques in which the rolls dovetail in the oil impregnated cooper bush within the lateral plaques (**figure 20 C:1**), the lateral plaques are identical with the exception of the Ø of the shaft main roll fitting (**figure 20 C:2**), this plaques also contain frontal punctures to unite with the frontal and back plaque (**figure 20 C:3**) and lateral punctures (**figure 20 C:4**) to tune the gap between rolls through the tightening against the warrant roll bush. The frontal and back plaque are identical (**figure 20 D**), they have superior punctures (**figure 20 D:1**) for fitting of the hopper with the mill support, lateral punctures (**figure 20 D:2**) for fitting of lateral plaques and bottom punctures for fitting of the mill support.

The hopper (**figure 20 E**) is made of welded stainless steel plate, being a low-cost and light material, in conical shape with lateral flaps (**figure 20 E:1**) for fitting of the hopper with the roll support, the hopper can hold up to 8 – 9 kg of malt, depending on the density of the malt, the mill also possesses two interior flaps to force the malt grains to the gap between rolls increasing the efficiency. The mill base (**figure 20 F**) is circular made of plywood to support both mill and a small electromotive for automatic milling, the Ø of the base is equivalent to the mash-tun Ø so it’s possible to make a direct milling into the mash-tun not having the need to transport milled malt around, the rolls support will fit in the punctures on top of the base (**figure 20 F:1**) and has a hole in the middle with area equivalent to the gap from the mill (**figure 20 F:2**).

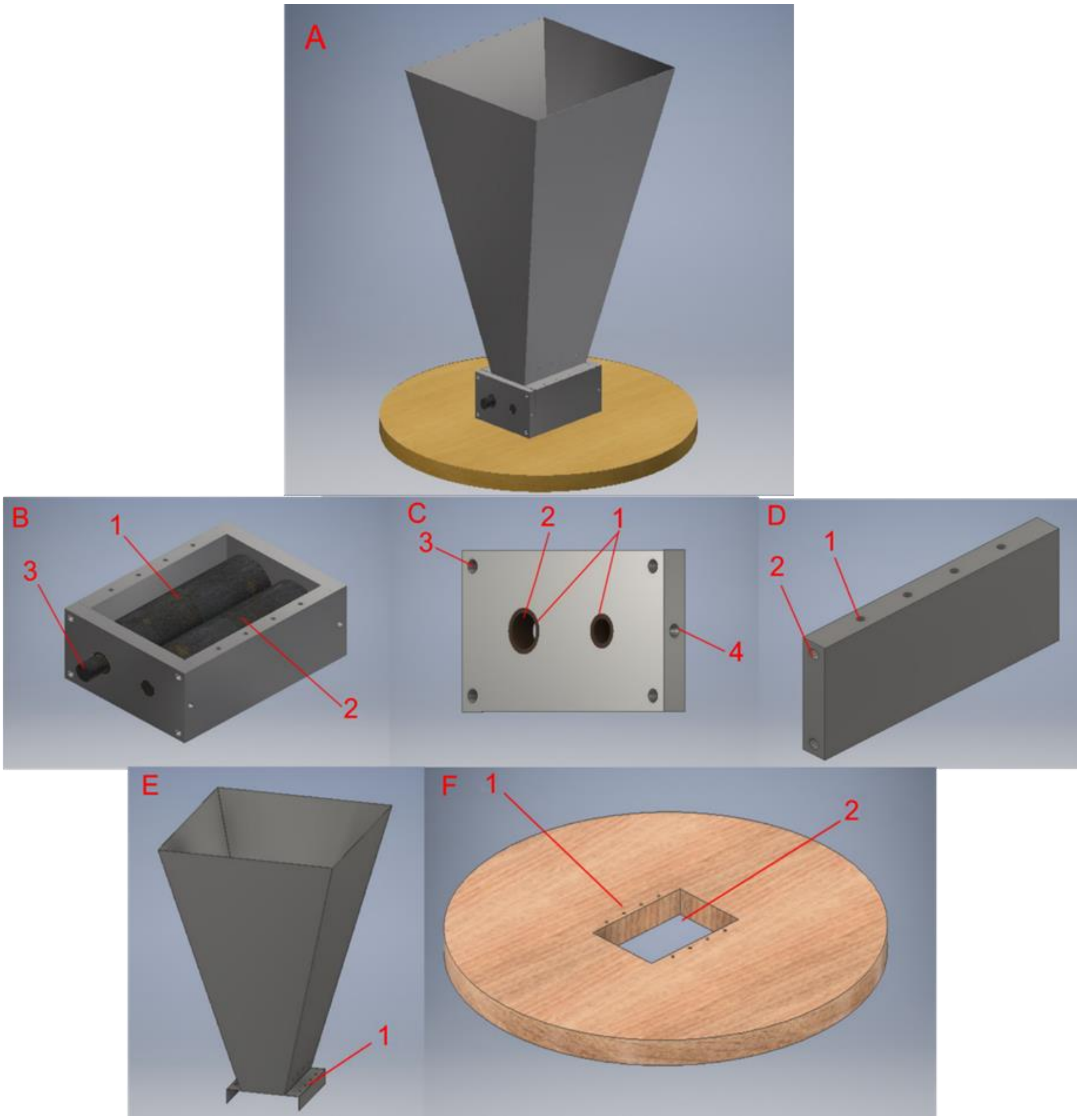

Figure 20 Two-roll mill: A) assembled mill | B) rolls assembled in their support: 1) main roll; 2) warrant roll; 3) main roll shaft; | C) right lateral support plaque: 1) cooper bushes; 2) main roll shaft fitting; 3) frontal punctures; 4) lateral punctures; | D) frontal roll support plaque: 1) superior punctures; 2) lateral punctures; | E) mill hopper: 1) lateral punctured flaps; | F) mill base: 1) top punctures; 2) mill gap;

3.1.1.2 Mash-tun

The mash-tun (**figure 21 A**) was dimensioned to be an optimized mashing equipment with all the essential accessories, it possesses a volume of 115 l so it can support the volume of the malt plus the water, having an operational value of 75 l in stainless steel, which has good heat transference, high wear resistance and doesn't oxide with the mash, resisting as well to CIP products. The tun contains two entries both of 50 mm Ø in the walls, one in the right lateral of the tun (**figure 21 B:1**) and other in the back of the tun (**figure 21 B:2**). The right lateral is relative to the pipe from the other mash tun while the entry in the back of the tun is relative to the rotating spray ball responsible to supply the process water for the mashing-in as well for supply the CIP cleaning to all the tun, having the spray ball entering the tun from this entry to the centre of the tun allowing for a pressurized water supplying to remove all residual content of previous mashes, this entry has the flow controlled with an automatic valve allowing for automation of the process. For better control of the temperature and to avoid heat loses reducing energy costs the tun is equipped with 30 mm of mineral wool (**figure 21 C:1**) within an external and an internal wall of 1.5 mm thickness (**figure 21 C:2**). The heating is made with a heating jacket (**figure 21 C:3**) of 1.5 mm thickness and a superficial area of 4554 cm^2 transferring heat to all the wort height inside the tun, the steam enters and the condensate steam leaves through small entries of 9.6 mm (**figure 21 C:4**) this characteristics allows for a uniform and controlled heating of all the mash from the begging of mashing-in to the last step of saccharification before lautering.

The tun has a curved bottom towards the centre of the tun (**figure 21 D:1**) to facilitate the transference of wort out of the bottom exit with 50 mm Ø (**figure 21 D:2**) leading or to the other tun if was an adjust mash or decoction or leading to the lauter tun and an entry (**figure 21 D:3**) with 40 mm Ø for the mash-tun agitator arm. At last, the tun is also equipped with a temperature probe directly connected to the actuators and pneumatic valves which will regulate the steam entry and leaving making for a reliable control of all heating temperatures. For a uniform mash and good mix of all contents the mash-tun is equipped with an agitator (**figure 21 E**) with optimized shape to better mix the mash with the impulse made by a small motor drive on the bottom of the tun equipped with a specific valve to the process reducing leaks while allowing for rotation of the agitator. Both mash-tuns are identical with the exception of the superior tun not having the lateral entry since there's no transferences of mash into the tun from decoction or adjuncts in the superior tun only transferences from the bottom out of it.

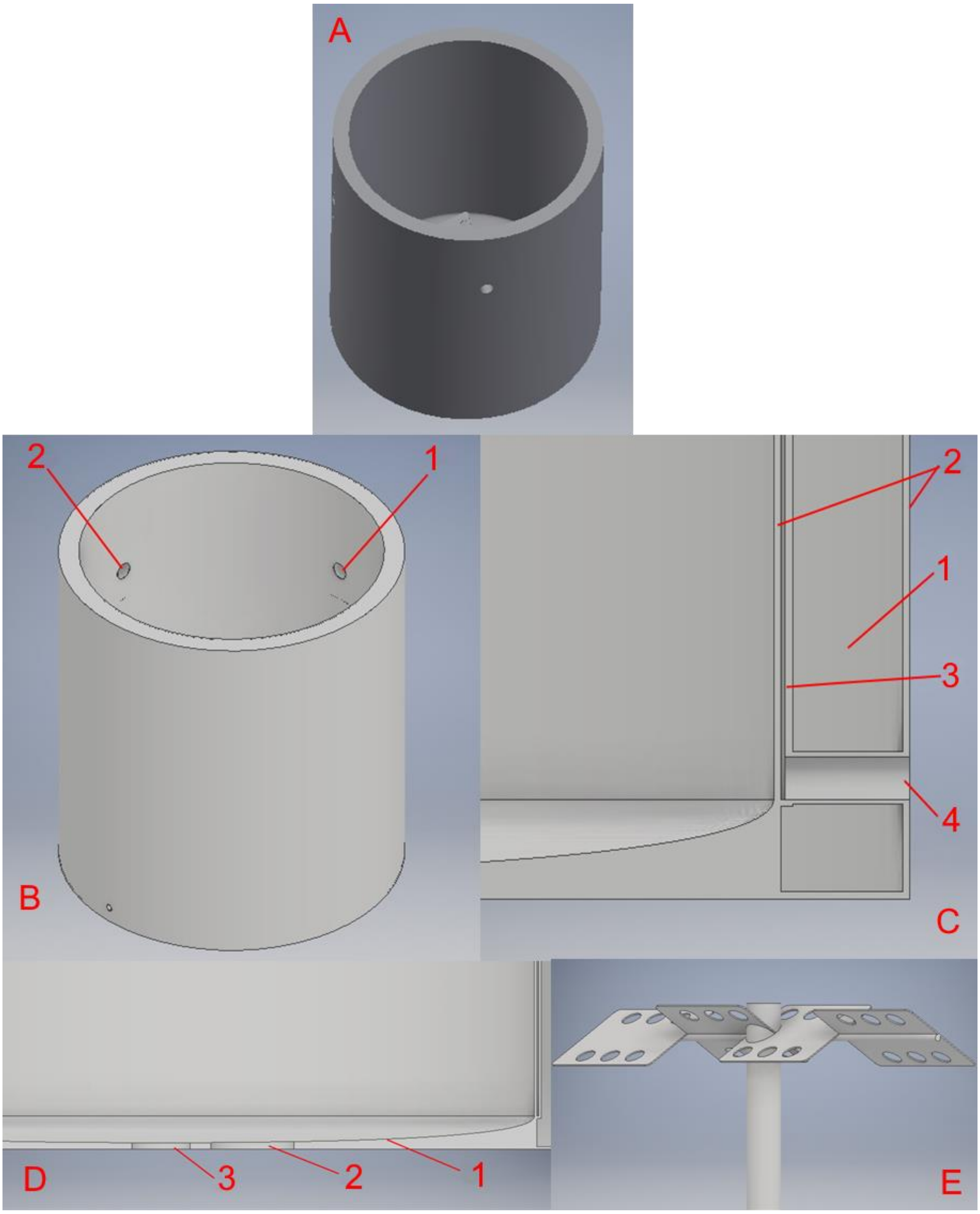

Figure 21 Mash-tun: A) mash-tun assembled; | B) outside view from mash-tun and respective entries: 1) mash entry; 2) entry for water and CIP; | C) side wall cut view of the mash tun: 1) mineral wool insulation; 2) internal and external walls; 3) heating jacket; 4) steam entry; | D) bottom cut view from mash-tun: 1) curved bottom to the centre; 2) wort exit; 3) entry of agitator arm; | E) mash-tun agitator

3.1.1.3 Lauter tun

The wort filtration in the microbrewery is made using a lauter tun in stainless steel with a total volume of 115 l and operational volume of 75 l. The lauter-tun has two entries, one frontal (**figure 22 A:1**) and one posterior (**figure 22 A:2**) both with 50 mm Ø as the frontal entry serves as entrance of the wort transferred from the mash-tuns or from recirculation of the mash from the lauter-tun and the posterior entry has the spray ball from which entries the process water for the sparging of the grains during the lautering process and in simultaneous working for the CIP having the same operation as the mash-tuns staying above the lauter knives ensuring a good cleaning of the all tun. To filtrate the mash the tun has a false bottom (**figure 22 A:3**) which covers the entirety of the tun bottom this is divided in half having in one of the sides a handle allowing for the easy removal of the false bottom in case of maintenance without compromising the filtration speed. The man-hole (**figure 22 A:4**) is at the exact same height as the false bottom which allows for an easy manual removal of spent grains from lautering without leaking wort during the process, the last accessory of this tun are a set of four lauter knives (**figure 22 A:5**) set in support motorized at the bottom of the tun allowing for a good mix of wort to retrieve the maximum extract possible before the boiling of wort. At the lauter-tun is equipped with handles to work as support when handling this tun since there's no insulation (**figure 22 A:6**).

The tun has a wall thickness of 2 mm (**figure 22 B:1**) with a conical bottom to an exit with 50 mm Ø (**figure 22 B:2**) from where the wort is filtrated to the boiling kettle and for circulation of mash to better form the filtration cake and lastly an entry with 40 mm Ø (**figure 22 B:3**) for the lauter-tun knives arm.

The lauter knives have an optimized shape for the lautering of the grains allowing for a good frenzy of the system, breaking the clumps of grains and lift them from the bottom for accelerating the filtration process. They are made of stainless steel to endure multiple brews having each knife bolted into the support (**figure 22 C:1**) for easy removal in case of maintenance, they also have curved blades (**figure 22 C:2**) to increase the superficial area and increase the lautering yield and are equipped with a shoe (**figure 22 C:3**) at the extremity of the blade which runs tangential to the false bottom, accelerating the filtration process while allowing for a good extract removal.

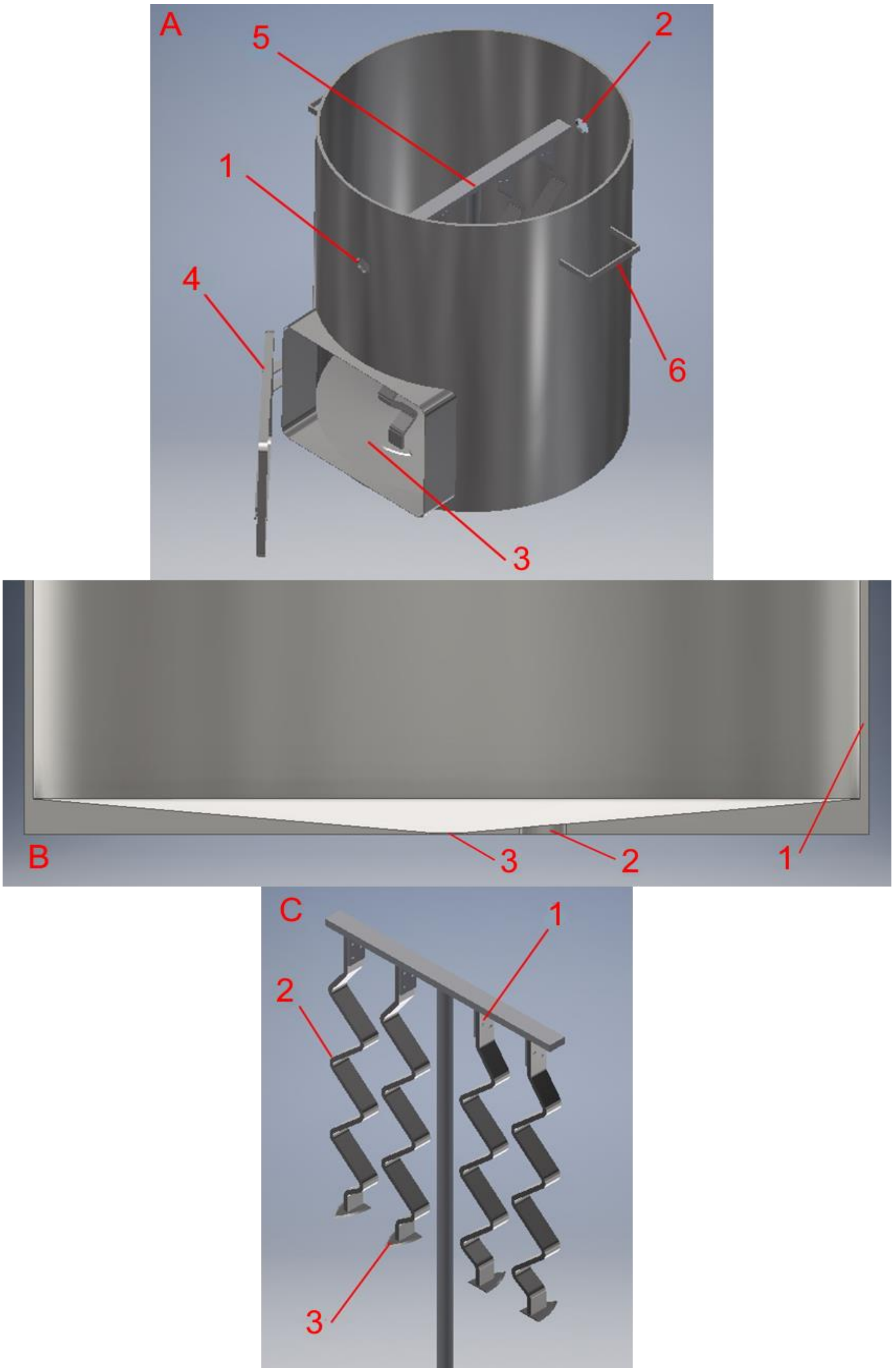

Figure 22 Lauter-tun: A) lauter-tun assembled: 1) mash entry; 2) water and CIP entry; 3) false-bottom; 4) man-hole; 5) lauter-knives; 6) lauter-tun handles; | B) bottom and wall cut view from lauter-tun: 1) lauter-tun wall; 2) wort exit; 3) lauter-knives arm entry; | C) lauter-tun knives: 1) connection of knives and support; 2) curved blades; 3) knives shoe

3.1.1.4 Boiling kettle, whirlpool and wort chiller

The kettle is able to recreate three equipment in a single one working as boiling kettle, whirlpool and wort chiller, the kettle is made of stainless steel, possesses a total volume of 115 l and operation volume of 75 l. The kettle contains three entries of 50 mm Ø, the left entry (**figure 23 A:1**) serves as entrance of the filtrated wort coming from the lauter-tun, the posterior (**figure 23 A:2**) is used for the spray ball from which comes the water process and the CIP with same operation as the other tuns. The last entry (**figure 23 A:3**) of the kettle is responsible to the whirlpool effect, after the boiling, the wort will leave the bottom exit and enter the kettle tangentially through this entrance inciting the whirlpool effect to the wort. The wort chill happens using a coil in which cold water is circulated refrigerating all the mash within the kettle having the entry (**figure 23 A:4**) and exiting of water in the posterior wall of the kettle.

For the boiling effect the kettle is isolated with 30 mm of mineral wool (**figure 23 B:1**), an internal and exterior wall thickness of 1.5 mm (**figure 23 B:2**) having the same heating system with steam as the mash-tun (**figure 23 B:3**) the same heating jacket size and heat transference area, the same steam entries and condensate steam exits as well for the valves, probes and actuators, for the whirlpool effect the kettle has a tab (**figure 23 B:4**) which grows vertically blocking the trub for entering the exit of wort and internal slope of 3 % (**figure 23 B:5**).

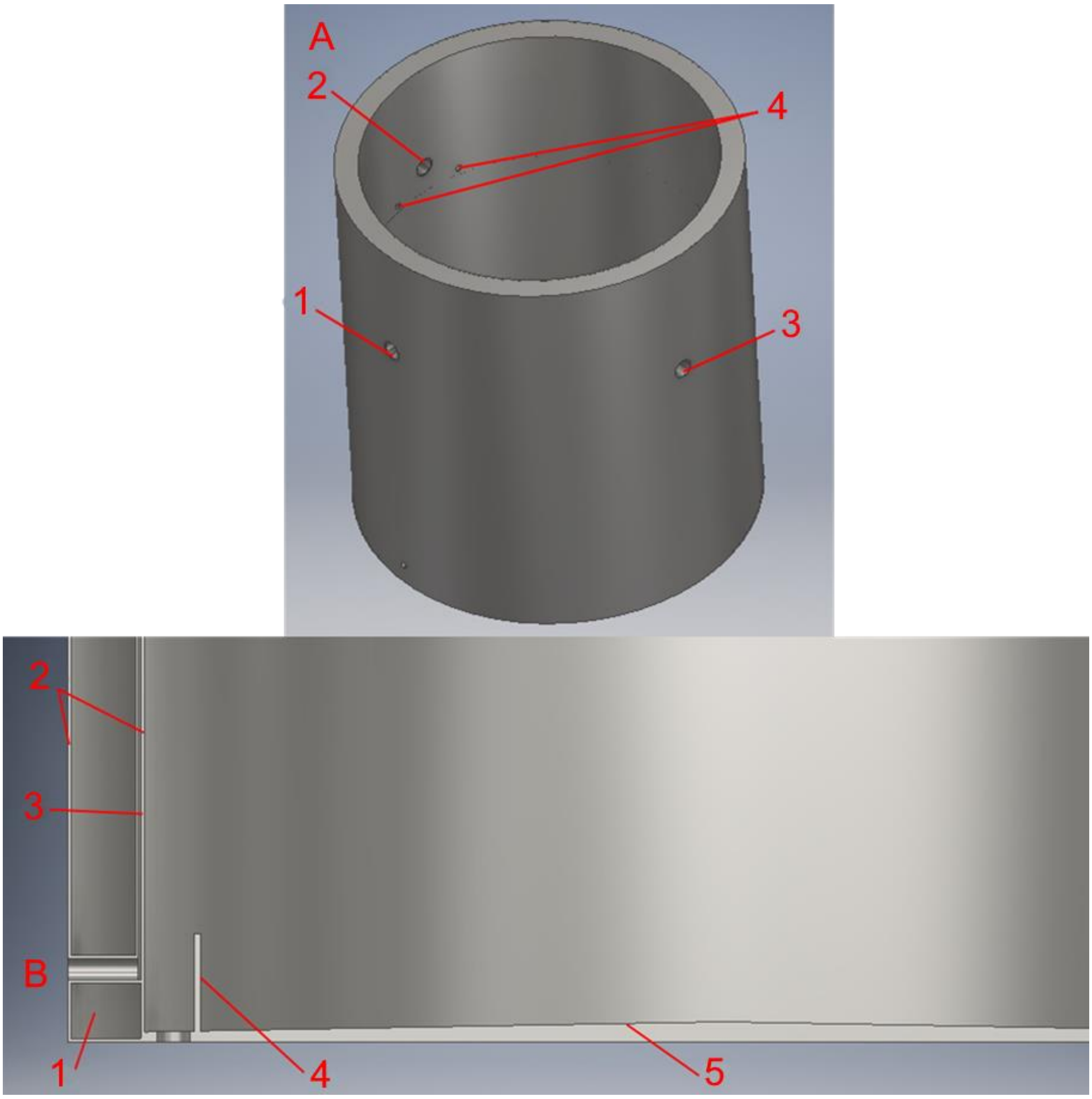

Figure 23 Boiling kettle: A) boiling kettle outside view: 1) wort entry from lauter-tun; 2) CIP and water entry; 3) wort entry from circulation; 4) glycol water entries to chilling coil; | B) bottom and side wall cut view: 1) mineral wool insulation; 2) external and internal kettle walls; 3) heating jacket; 4) whirlpool effect tab; 5) kettle bottom slope

3.1.1.5 Brew stand

The brew stand (**figure 24**) is a structure made of steel to organize and help reducing the equipment and operational costs, the stand has 2600 mm length and 850 mm height, it has two lower zones with 280 mm height were are placed the mash-tun and the boiling kettle and two higher zones with 850 mm height were are placed the other mash-tun and the lauter-tun. The reducing of operational costs using this stand is derived to the disposition of the tuns which makes possible for the entire production area to work using only one pump, this system uses the gravity for transferences of wort between some of the kettles and this disposition also reduces the need of extra pipeline length.

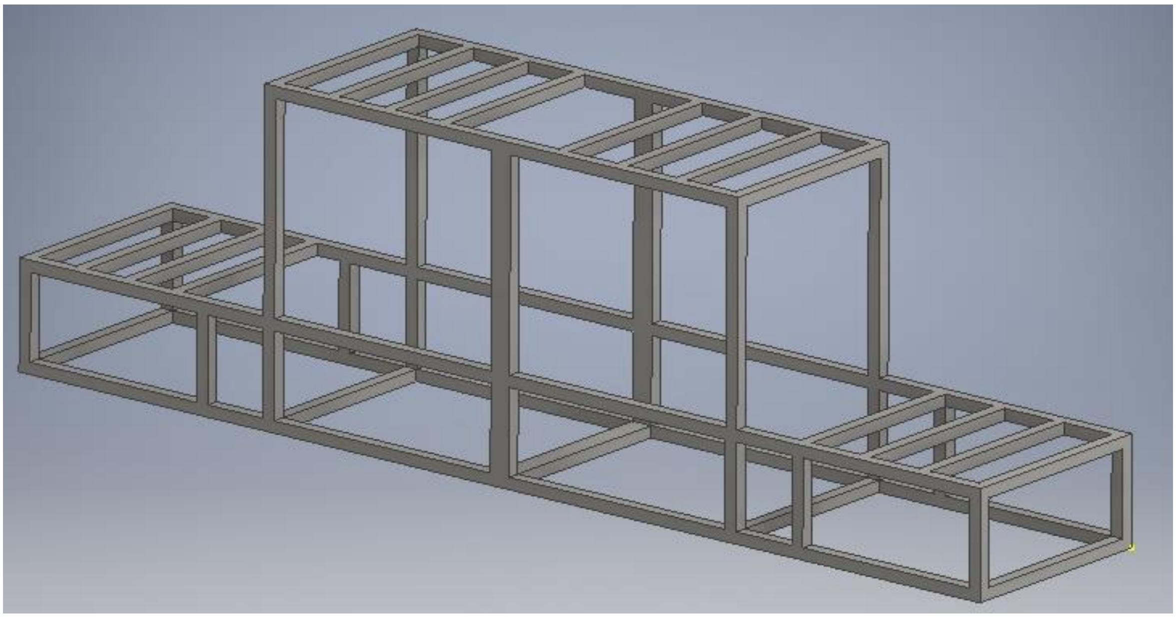

Figure 24 Brew stand with optimized structure for the wort production process

3.1.2 Cellar area

In the cellar area the only existing equipment are the cylindroconical vessels for the fermentation of wort and their associated pipeline, the CCV are made of stainless steel, have a total volume of 210 l and an operational volume of 160 l with a conical bottom with 65º (**figure 25 A:1**) with a puncture of 50 mm Ø at the bottom of the CCV which work simultaneous as entry and exit of wort and beer followed by a sight-glass and a discharge valve. The CCV has one posterior entry for the spray ball supplying the CIP (**figure 25 A:2**) with 50 mm Ø, three superior punctures one relative to the pressure discharge valve (**figure 25 A:3**), in case of excessive pressure in the CCV preventing damage to the equipment, other to the pressure probe (**figure 25 A:4**) and the last puncture for the level probe (**figure 25 A:5**). The CCV also has a superior lid with 150 mm Ø (**figure 25 A:6**) allowing for hop adding during maturation or filter aid adding and one entry for forced carbonatation with 12.3 mm Ø (**figure 25 A:7**).The CCV are isolated with 30 mm of polyethylene (**figure 25 B:1**) with a thickness of 2 mm in the exterior wall and 3 mm thickness wall supporting fermentations which create large gas pressure and having the volume to support the formation of krauzen. The temperature probes, one at the middle of the cone other at the middle of the cylinder will coordinate the actuators and valves controlling the flow of glycol water to the cooling jacket of the CCV which contains 2 cooling jackets, the cylinder (**figure 25 B:2**) and the conical jacket (**figure 25 B:3**) having 9280 cm^2 and 3030 cm^2 respectively and both having 2 mm thickness with a wall of 1.5 mm thickness equipped with exit and entrances of 9.6 mm Ø (**figure 25 B:4**).

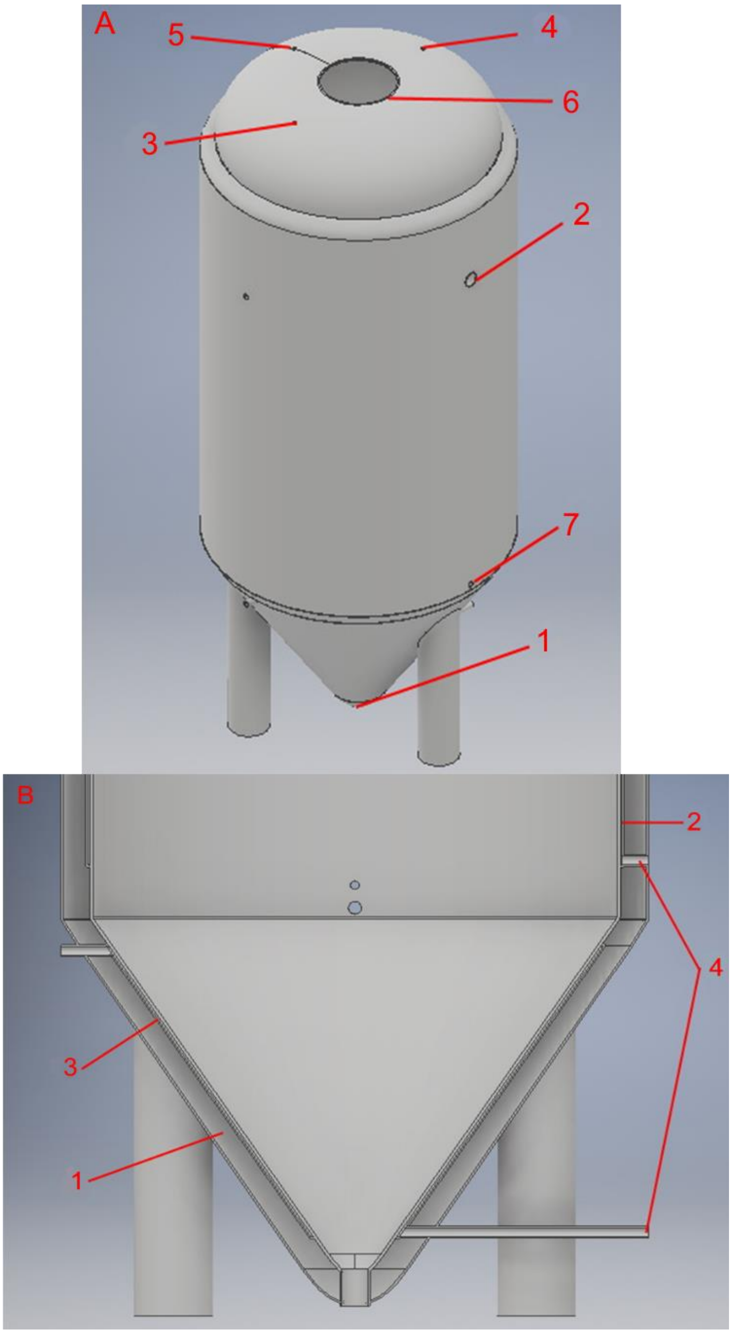

Figure 25 CCV: A) outside view from CCV and respective entries: 1) bottom beer entry and exit; 2) water and CIP entry; 3) pressure discharge valve; 4) pressure probe; 5) level probe; 6) CCV top entry; 7) carbonation stone entry; | B) wall and bottom CCV cut view: 1) mineral wool insulation; 2) cylinder cooling jacket; 3) bottom cooling jacket; 4) glycol water entries

The cellar area has six cylindroconical vessels in series using a common pipeline which come from the production and utility area with the flow controlled by automated valve matrix, the cellar was dimensioned to work with a single pump and not having filtration equipment using the chemical, physical and lagering techniques for beer clarification.

3.1.3 Utility area

The utility area has four stainless steel tuns with a total volume of 115 l and operational volume of 80 l regarding the CIP equipment. They have wall thickness of 1.5 mm, a bottom exit as well for a posterior entry both with 50 mm Ø both using the circulation of water and CIP, the heating of the tuns is made by steam and have the same dimensions and insulation as the mash-tuns used in the wort production area. The tuns are identical between each other only having different functions, one of the tuns is used for hot soda, other for acid, one for tap water and other for the cold soda. The tuns are disposed in series (**figure 26**) supported by an optimized steel stand using only one pump to supply all microbrewery with CIP, all the CIP products pass through a heat exchanger products before leaving the area, with the exception of the glycol water.

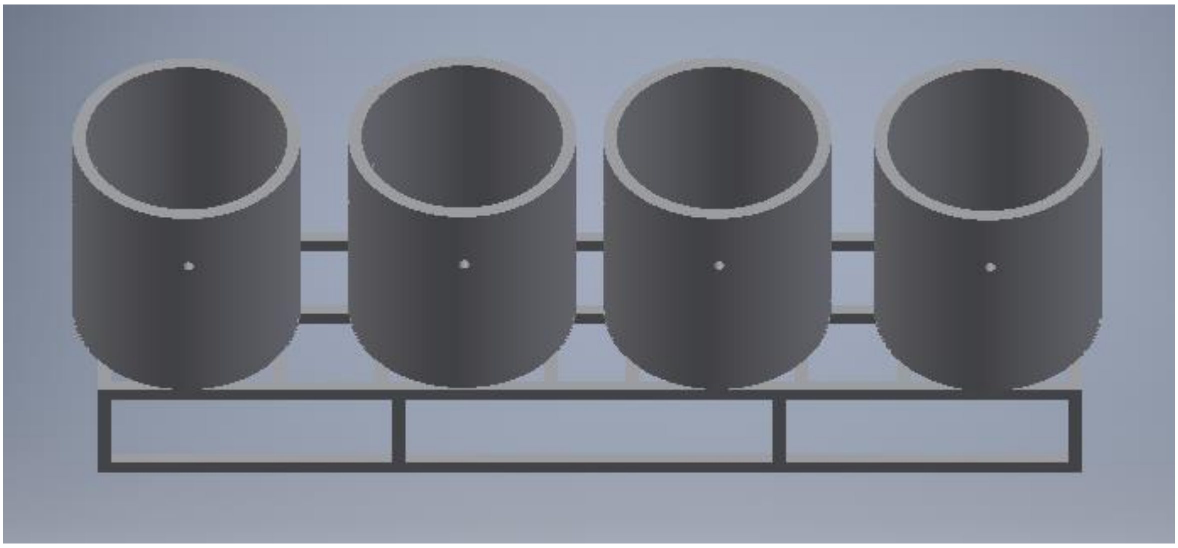

Figure 26 Outside view from the CIP kettles with respective posterior entries disposed in series and supported by an optimized steel stand

The utility area also includes a plaque exchanger for cooling of water to both CCV and wort chiller, a condensate steam collector and steam for control of heating in the microbrewery and the hot water tun (**figure 27**), which is a closed tun in stainless steel with a 210 l total volume and 180 l operational volume, it has a 30 mm mineral wool isolation between the 1.5 mm thickness internal and external walls and one bottom exit and top entry both with 50 mm Ø as well for a temperature probe controlling the actuators and valves of the heating jacket with 2 mm thickness and 1.5 mm wall having the same superficial area as the cylinder heating jacket from the CCV. The hot water tun is responsible for suppling the process water to the production area, including the water for the mashing-in and the sparging as well for the other areas of the microbrewery reducing the heating energy costs derived to the continuous control of water temperature in this tun.

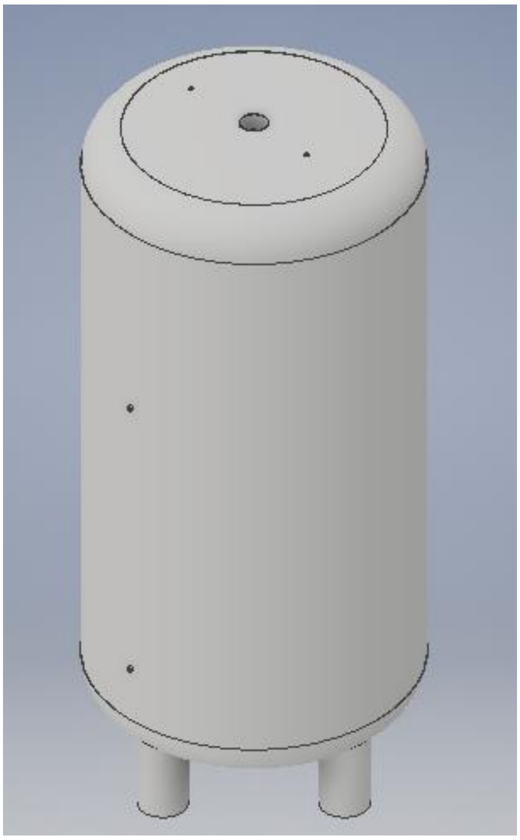

Figure 27 Hot water tank outside view with respective top entry, level and temperature probes entries at the top and lateral entries for steam

The volumes of 80 l used for the CIP tanks took in consideration the length of the pipes from the cellar area to the wort production and cellar area plus the size and number of vessels and their volumes. The hot water tank also took in consideration the length of the pipes to all areas and was dimensioned with a 180 l to support two wort productions starting next to another and still have hot water to supply the sparging during the lautering as well for the washing of the mash-tuns to remove the remaining malt from mashing.

3.2 Operational methods

The microbrewery was dimensioned to operate having two daily wort productions twice a week which are sent to a single CCV that's able to support two wort batches, the production of the two wort batches is made within a normal day of labour (8 hours) and therefore the microbrewery as an annual production of 86.5 hl, the production volume can be easily increase simply by adding more CCV and increasing the weakly production of wort. In the brewery to avoid shear forces the travel speed between tuns and vessels in the pipeline cannot go higher than 4 m/s, therefore to avoid those negative impacts and taking in consideration the diameter of the pipes, the pumps are set to incite a maximum flow rate of 0.0075 m^3/s which in litres is translated to 7.5 l/s.

3.2.1 Wort production

The wort production uses a total of 4 vessels (**figure 28 A**), being two mash-tuns, one lauter-tun and a boiling kettle, they are placed in specific places of the brew stand to increase efficiency and reduce operational and equipment costs. In the begging of operations (**figure 28 B**), the wort is introduced in the hopper of the mill and milled for a container or directly into the mash-tun then the process water enters the tun from the spray ball to begin the mashing-in. In case of using adjuncts, the milling is operated in the same way made in the superior mash-tun and after the adjuncts saccharification is made the wort is transferred by gravity to the other mash-tun continuing the mashing process of the main mash. This system allows for a decoction saccharification (**figure 28 C**), while using this method the mashing-in is made in the superior mash-tun and the small mash parts which are going to suffer the decoction are transferred to the bottom tun by gravity, in the transition of saccharification stages, end of the decoction mash, the main mash is transferred by gravity to the bottom mash-tun continuing the rest of the mashing before going to filtration. In cases of large need of wort production both tuns can work in simultaneous begging the mashing-in of one vessel while the other is finishing the mashing steps.

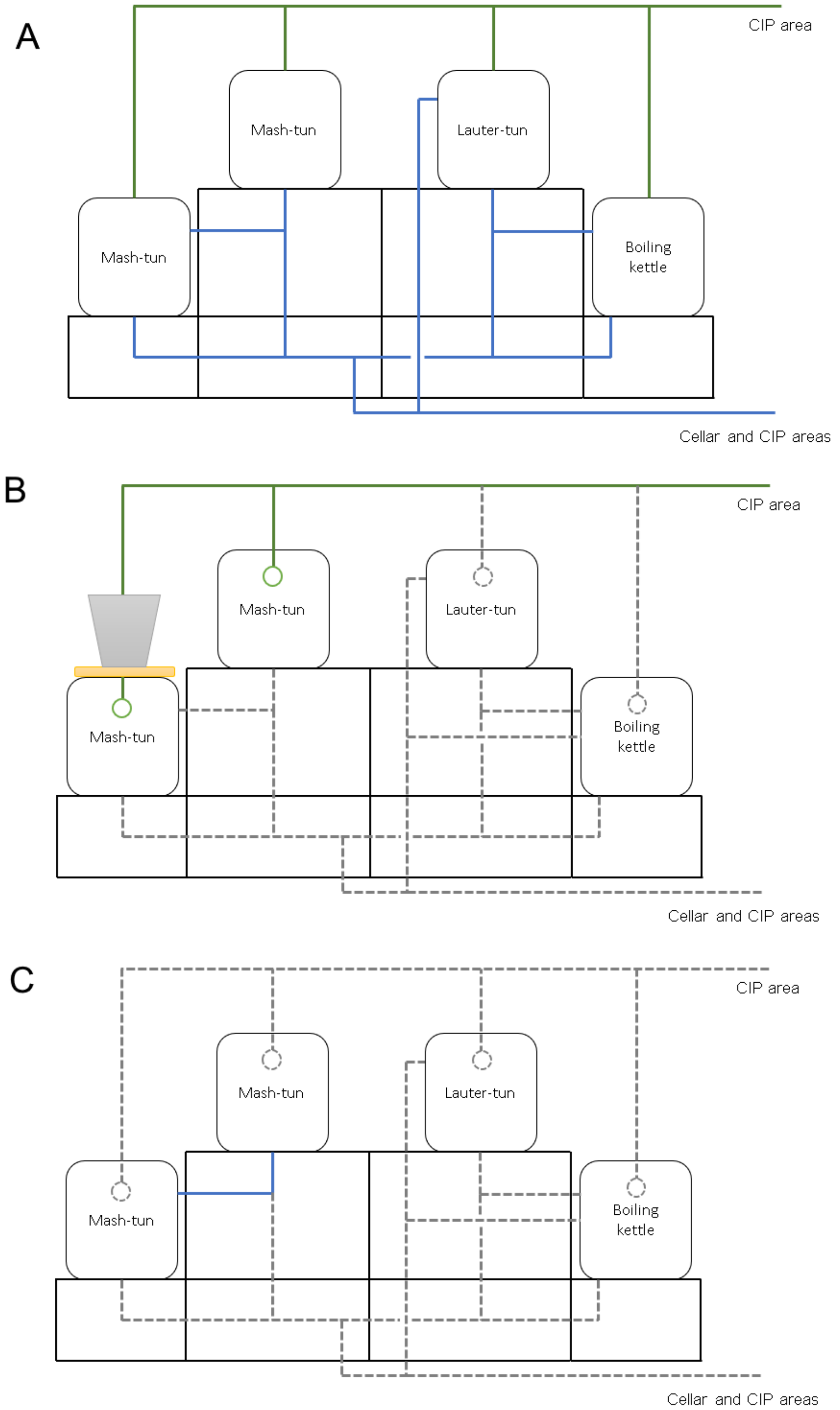

Figure 28 wort production flow chart: A) all equipment and pipes enlighten of the wort production in green the ones coming from CIP area in blue the transference pipes between tuns and to cellar and CIP areas; | B) water entrance pipes enlighten in both mash-tuns to begin mashing-in and milling of grains to the main mash-tun; | C) enlighten pipes used to transfer the mash from the secondary tun to the main tun during decoction or adjunct usage

For lautering (**figure 29**), the wort leaves the main mash-tun (**figure 29 A**) or the secondary mash-tun (**figure 29 B**) from the bottom and its transferred to the lauter tun with the help of a pump entering in the frontal entry of the lauter-tun. The wort then exits (**figure 29 C**) from the bottom for circulation of the mash back again to the lauter tun to form the filtration cake. With the circulation of wort made, the lauter-knives start to rotate and begins the lautering phase where the filtrated wort is transferred to the lateral entry of the boiling kettle (**figure 29 D**) by gravity passing through the false bottom at the bottom of the lauter-tun. In the end of the lautering the water will sparge water (**figure 29 E**) from the spray ball for removal of the remaining extract in the spent grains before the spent grains are removed manually from the man-hole for usage as feedstock or use as sub-product.

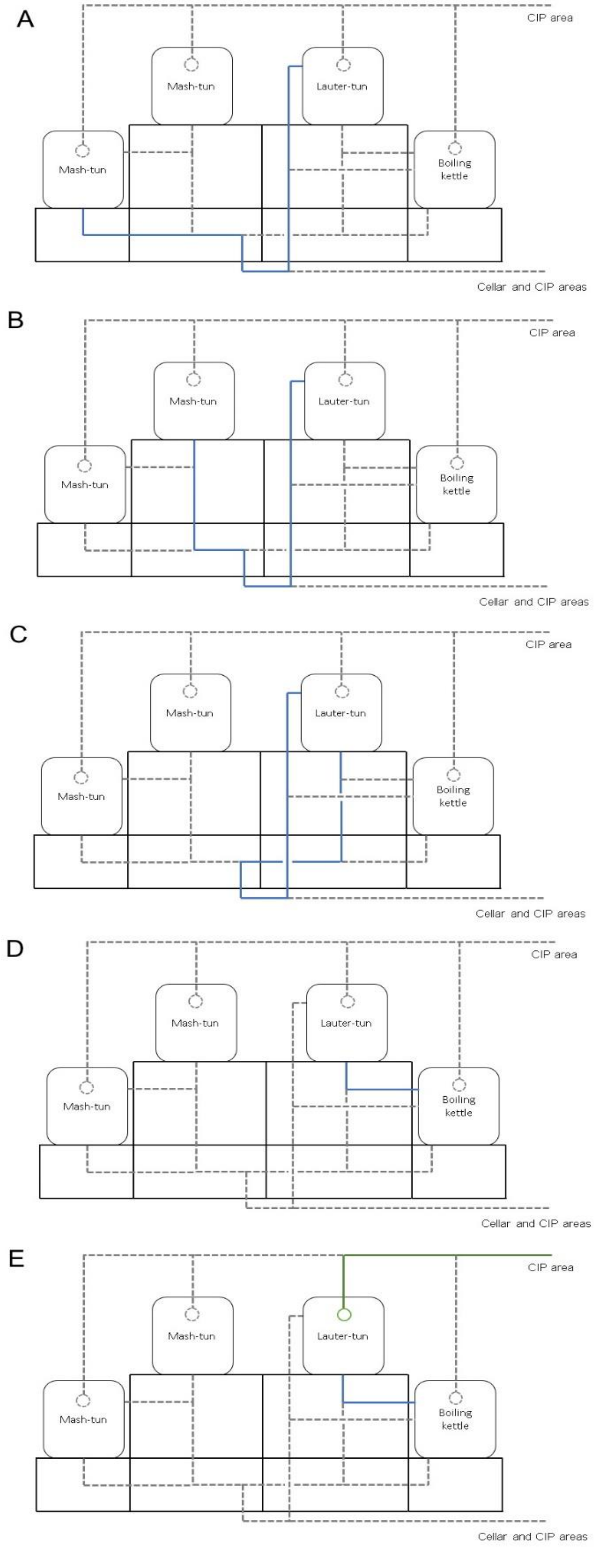

Figure 29 Lautering flow chart: A) enlighten pipes from wort transference from the main mash-tun to lauter-tun; | B) enlighten pipes from wort transference from the secondary mash-tun to lauter-tun; | C) enlighten pipes from recirculation of wort to form the filtration cake; | D) enlighten pipes from filtrated wort transference from lauter-tun to boiling kettle; | E) sparging of grains and transference to boiling kettle

The boiling kettle in this system as said before replicates three equipment. After the wort filtration into the kettle begins the controlled boiling (**figure 30 A**) using the steam as heating source, then the hops are added manually to the mix and by the end of the boiling stage the wort is made circulate (**figure 30 B**) leaving the bottom exit of the kettle and with the help of the pump is transferred to the frontal entry of the kettle, entering tangentially and inciting rotation to the wort simulating the whirlpool effect. With the clearing of wort made by the whirlpool effect, begins the circulation of cold water through the coil inside of the kettle begging the wort chilling stage until it reaches the desired fermentation temperature, then it's removed part of the mash for pitching of yeast and transferred (**figure 30 C**) the remaining wort to the CCV. The choice of using the coil over the most common equipment, the heat-exchanger plate, took hardly in consideration the production volumes, if was used a heat-exchanger plate the operational, equipment and maintenance would harshly increase and therefore was choose the coil refrigeration system which is already used in many microbreweries and home breweries which work in the same volumes as the one dimensioned in this project.

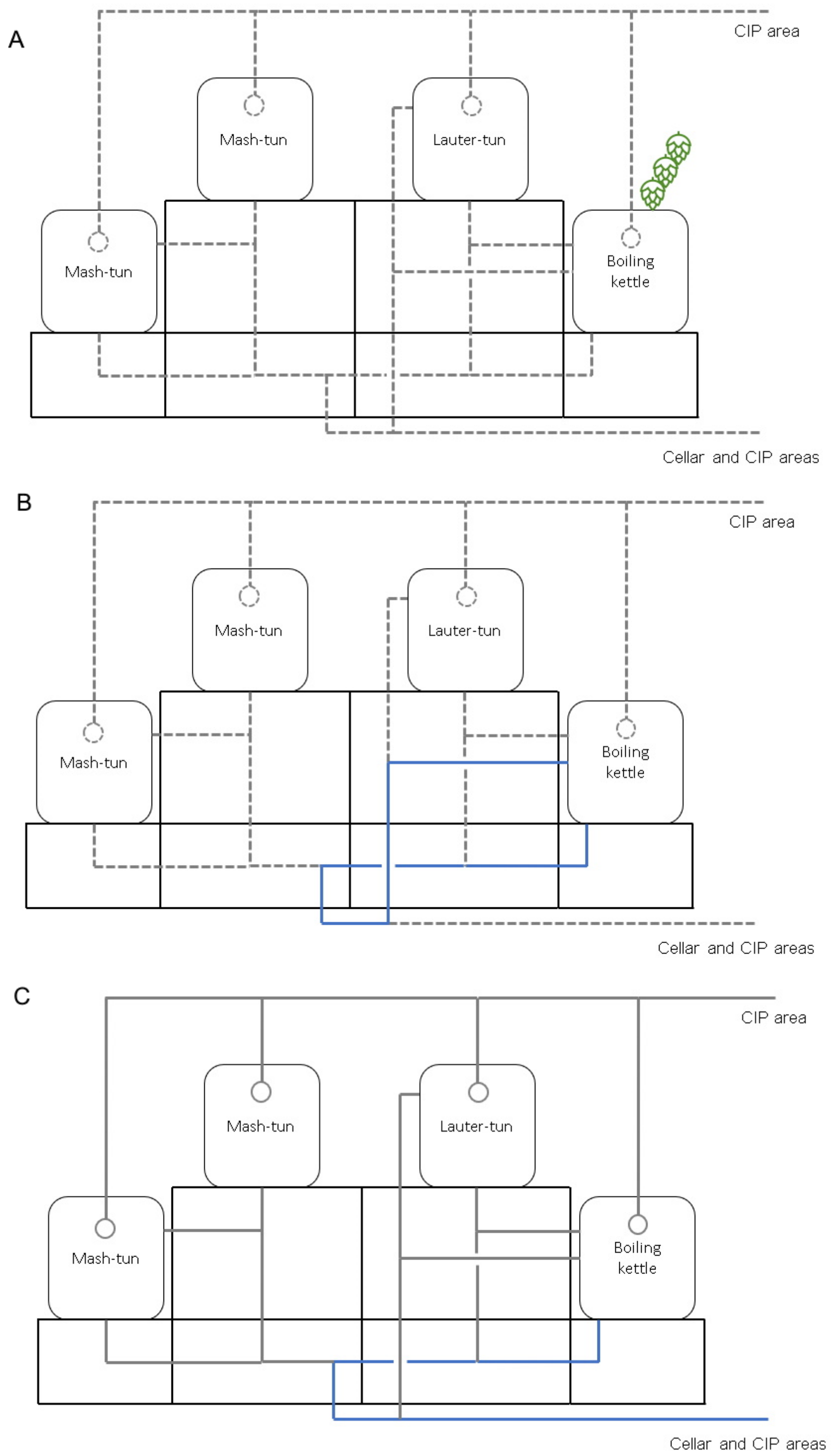

Figure 30 Boiling with hops flow chart: A) adding of hops during the boiling from the top of the kettle; | B) circulation of wort from the bottom of the kettle to the front entry to force the whirlpool effect in wort; | C) transference of chilled wort from the boiling kettle to one of the CCV in the cellar area

3.2.2 Fermentation

The fermentation begins after the direct adding of the pitched yeast previously through the superior CCV lid, the temperature during the process is controlled by automated valves and actuators and after the attenuation phase is completed, the yeast is removed by opening the bottom valve letting the sedimented yeast leave the CCV which is visible through the sight-glass at the end of the vessel, after all the yeast is removed the bottom valve is closed and it begins the maturation phase where adjuncts and hops can be added by the superior lid. Regarding the fermentation there are no extra equipment for this operation because the production volumes don't justify the equipment cost, instead filtration methods conjugating adding of innovated filter aids such as gelatine or isinglass with beer temperature manipulation incite coagulation and sedimentation of the remaining yeast as for other undesired sub-products of fermentation at the bottom of the CCV for later removal like it was made for the first fermentation. At the end of beer clarification, the desired levels of carbonatation are incited trough the carbonation stone present in the posterior part of the CCV and the filtered carbonated beer is sent to the filling line, with the help of the pump in the cellar area, for filling of the bottles manually.

4. Minibrewery theorical wort production optimization

During the master's curricular internship, the minibrewery from the Super Bock Group needed an optimization in the wort production volumes, so that optimization was proposed as secondary objective. To do it, initially was made a follow up of all the operations, occupation time of all tuns, kettles and filters, from the milling of the grains until the wort chilling for the multiple beer types produced in this brewery. Multiples findings were encountered having a negative impact in the mini brewery wort production performance, delaying the heating wort times, chilling wort times and equipment occupation periods. This findings were analysed, simulations were made, using the Excel program from Microsoft, and was suggested alterations to the process or equipment that would improved the number of weekly wort productions.

4.1 Wort chilling duration

One of the findings made was the increasing time in wort chilling when multiple brews of an Indian pale ale (IPA) were made in a row when directly comparing to other beer types such as Weiss reaching almost three times the duration to wort chilling (**figure 31 A**), this beer type uses large quantities of hops when comparing with all the other beer types produced in this brewery which would clog the wort chiller plaques reducing the heat transference rate and therefore increasing the chilling time. The increasing the wort chilling time would delay all the other brews in the system since a second wort could not be transferred the wort chiller since this was taking to much time to reach pitching temperature. To solve this problem was normalized a CIP of the wort chiller every three brews or if the chilling time was superior to 1 hour, when prior to this only was made a CIP to the chiller by the subjectivity of the technicians every 48 hours. The normalization was made and applied (**figure 31 B**) in this operation didn't add costs or needed extra equipment and had no negative impact in wort production time.

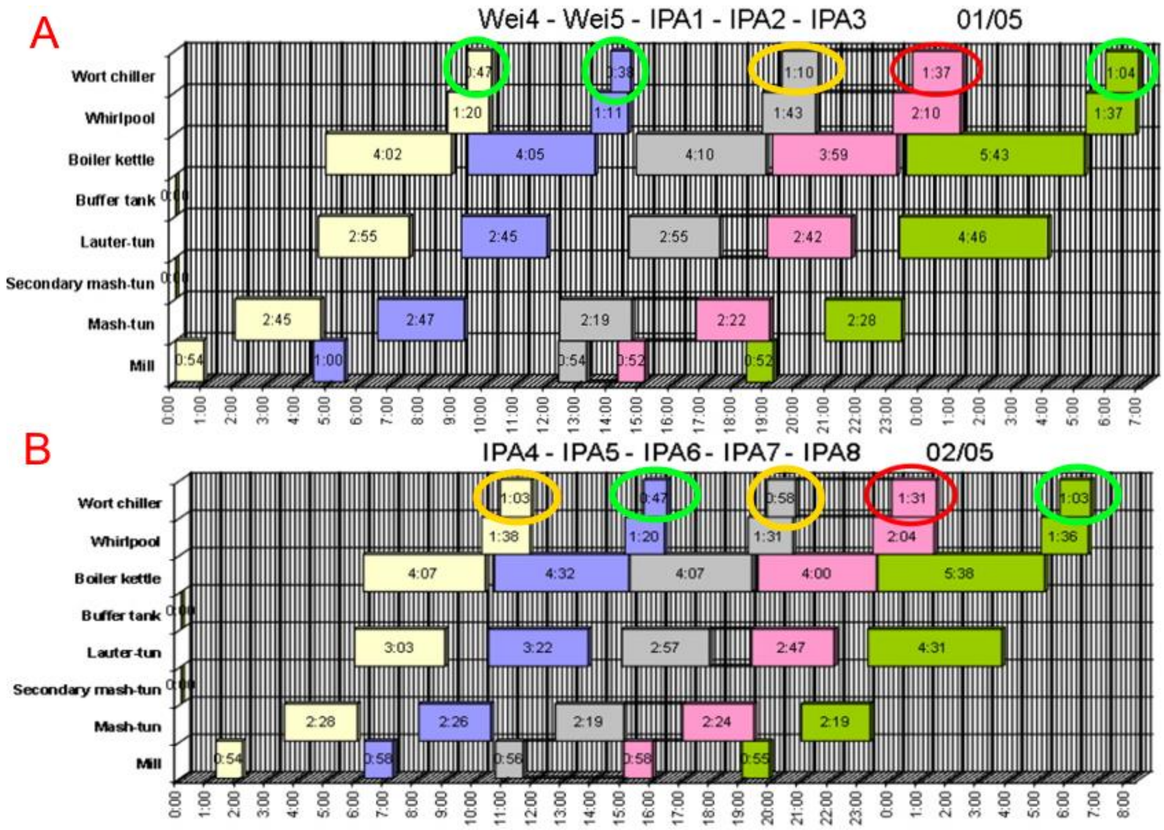

Figure 31 Wort chiller operation times during IPA and Weiss beers type: A) the first two chilling times are from Weiss beers and show way lower chilling times (green circle) with the introduction of the IPA wort the chilling time starts to increase (yellow circle) reaching almost three times the duration of a Weiss chilling time (red circle), a CIP was applied to the wort chiller as a experimental test resulting in an decrease of more than 30 min; B) shows the effects of the wort chiller CIP normalization every time the wort chill surpassed 1h

4.2 boiling kettle performance

Some weeks have more brews programmed than others depending on the orders from the sells department, in the weeks with high number of brews scheduled was noticed a decrease in the boiling kettle heating transference throughout the week leading to an increase of the boiling time duration having impact in all the beer types without having any specific type like in the wort chiller finding (**figure 32**).

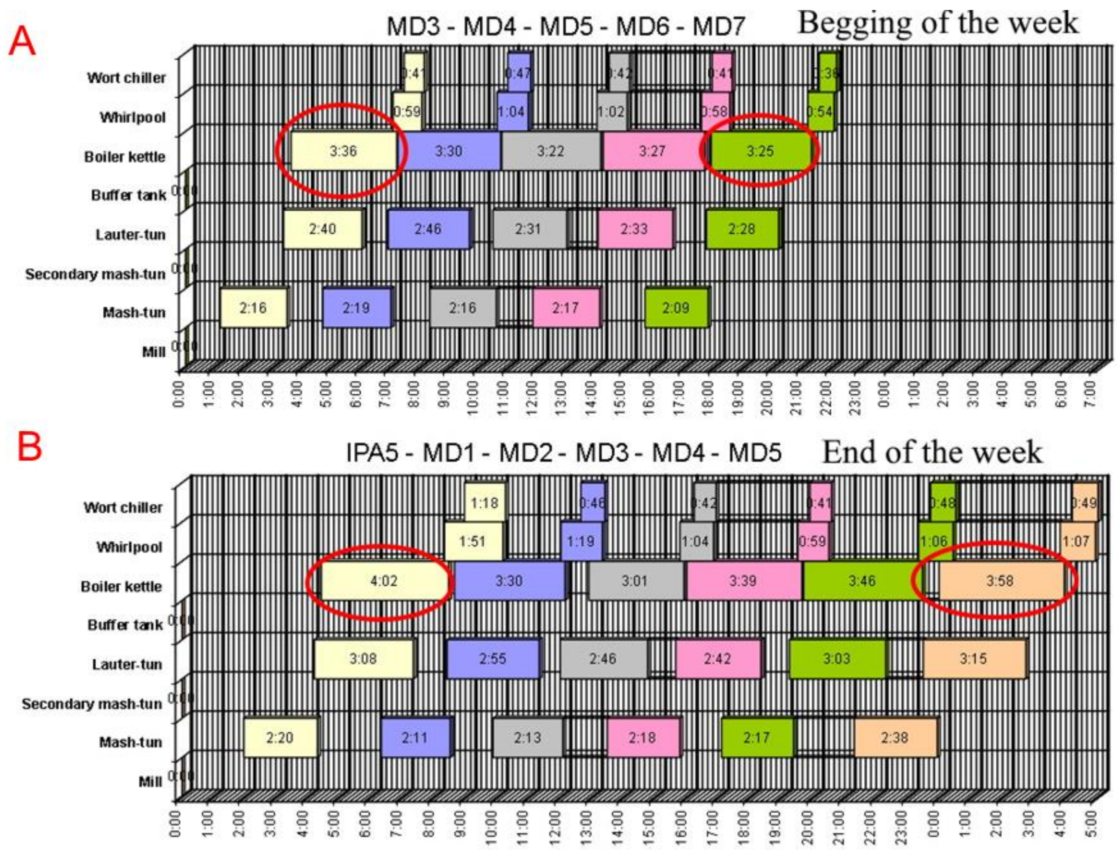

Figure 32 Boiler kettle increasing occupation times at the begging and at the end of the week for IPA and Munich Dunkel (MD): A) boiling kettle occupation times in the begging of the week doesn't surpasses 3h and 36 min; B) by the end of the week two different types of beer have their boiling times close to 4 h while other brews also take longer when comparing to the begging of the week

The problem for this heating loss was the coagulation of hops residues in the heat transference areas of the boiling kettle internal boiler, which at the begging of the week were close to none (**figure 33 A**) but by the end of the week would get worse and for each wort boiling made (**figure 33 B**). To reduce the coagulation of the hop resin in the boiler the agitator of the kettle was turn on at 5 – 10 % of agitation power, when before was turned off during boiling operation, and not higher because if it was it would incite the overboiling of wort creating the risk of overflowing the kettle. This optimization was applied and resulted in a significantly decrease of hop resin coagulation in heat transference zones as well for less coagulation of wort in the kettle bottom exit (**figure 33 C**).

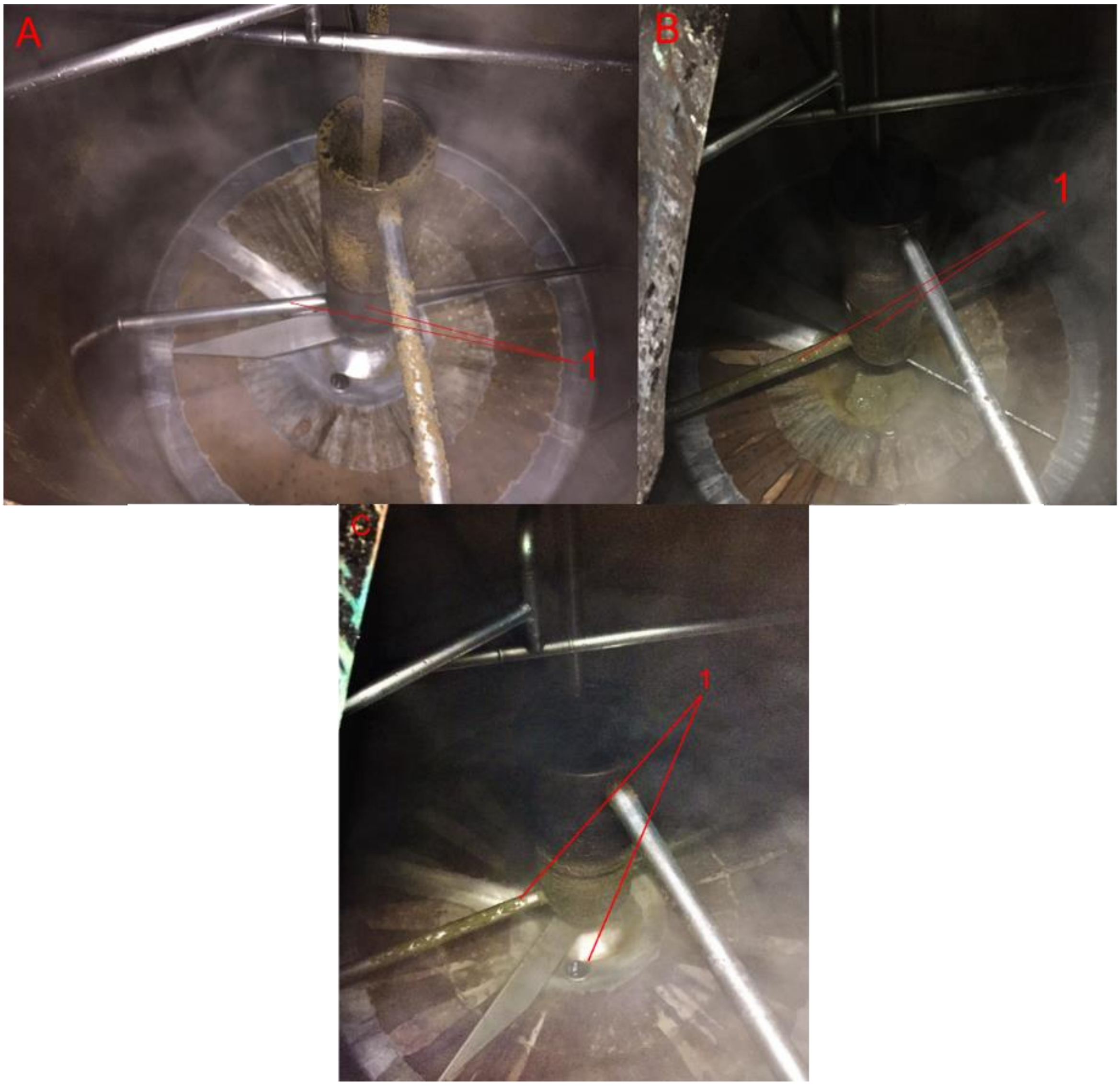

Figure 33 heat transference areas from boiler kettle: A) in the begging of the week before optimization: 1) clear heat transference zones cleared of hop resins; | B) end of the week before optimization: 1) heat transference zones covered in hop resin reducing heat transferences to wort; | C) boiler kettle heat transferences zones after the agitator optimization was installed: 1) significantly lesser hop resins coagulated to heat transferences zones

The other suggestion made to reduce the coagulation of hop resin was the CIP to the boiling kettle during the week, when it was only made Saturday, day in which the weekly wort production would end and therefore made a CIP to all wort production equipment. The CIP however had a problem with the pipeline adjacent to it because of the U pipe (**figure 34**). The U pipe is a pipe that works as valve, in this specific case, allowing either for process water to entry the wort productions equipment, for mashing-in, sparging, etc, or allowing the CIP products to enter the wort production equipment, this means it was only possible to transfer process water to the wort production area or CIP products not being possible to supply both at the same time and specifically to the boiling kettle having the need to stop the wort production in order to clear the kettle and having the risk of contaminating the batches with chemicals from the CIP products. To solve this problem was dimensioned an alteration of the pipeline and adding of several valves which would enable the transference of the CIP to the boiling kettle without the risk of introducing toxic chemicals in the other tuns which would be operating during this process. The enabling of this finding come with equipment costs but is able to save up to 20 minutes per brew which would translate to less 6 and half hours per week of operation of the kettle largely saving energy cost and time, the dimensioning however is not shown here derived to having the Super Bock Group pipeline and systems described and saved by copyrights and was to be built in the near future.

Figure 34 U pipe and adjacent valves showing the connection between the process water pipe to the wort production area and the close connection from CIP products

4.3 Buffer tank

The boiling kettle is the equipment which has the larger occupation time from all the wort production equipment and for every beer type produced (**figure 35**), this duration is derived to time wort takes to filtrate directly from the lauter-tun to the boiling kettle plus the time the wort takes during boiling before being transferred to the whirlpool and make the boiling kettle available again. All the equipment and their disposition was took in consideration when looking for alternatives.

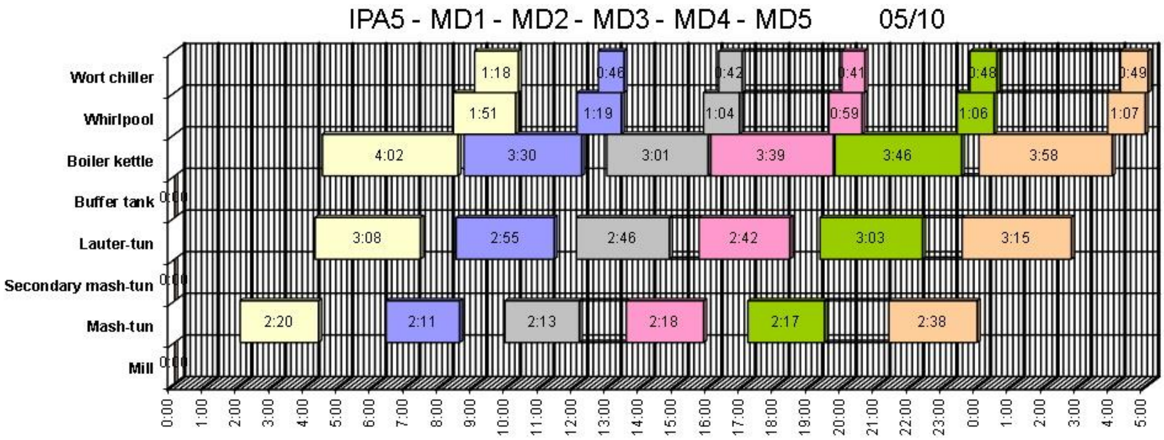

Figure 35 Image showing the occupation time between all wort production equipments and showing the boiler kettle as the equipment with larger occupation time in all the beer types

The minibrewery system only allowed for two brews in simultaneous (**figure 36 A**), wasn't possible to start the mashing-in of a brew until the previous brew reached the sparging during the lautering which, meanwhile, was being transferred to the boiling kettle. To solve the problem was suggested the utilization of a buffer tank in the brewery (**figure 36 B**). The tank was inactivated and if used allowed to have three brews occurring in simultaneous, per example when a brew was ending the boiling, another brew was being filtered from the lauter tun to the buffer tank and the third brew was begging the mashing-in. The only costs relative to this upgrade was an isolation of the buffer tank which before couldn't keep the wort hot leading to an increase in heating type during wort boiling.

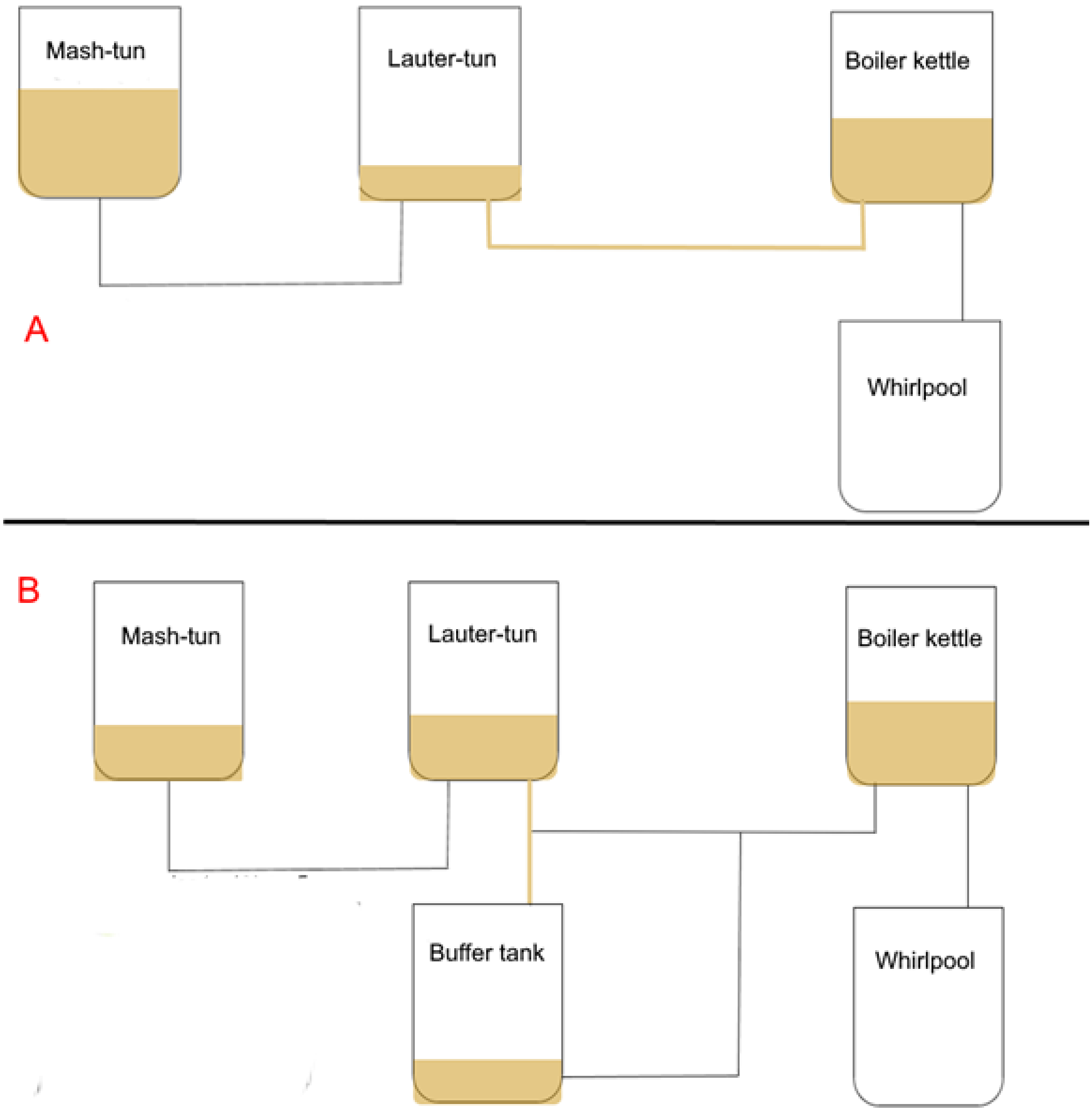

Figure 36 Wort production flow chart of the minibrewery: A) without the buffer tank only two batches occurring in simultaneous, while one brew was in mashing step the previously was ending sparging to the boiler kettle; | B) with the buffer tank three batches occur in simultaneous, while one brew is begging mashing-in, a second brew is being filtered to the buffer tank and a third brew is ending boiling

The result of this theorical optimization allowed for an increase the number of brews per week by 10 and per month by 40 (**figure 37**). This theorical optimization will be installed in the near future synergizing with the boiling kettle performance and allowing for a CIP of the boiling kettle without stopping the wort production since the lautering is now made to the buffer tank.

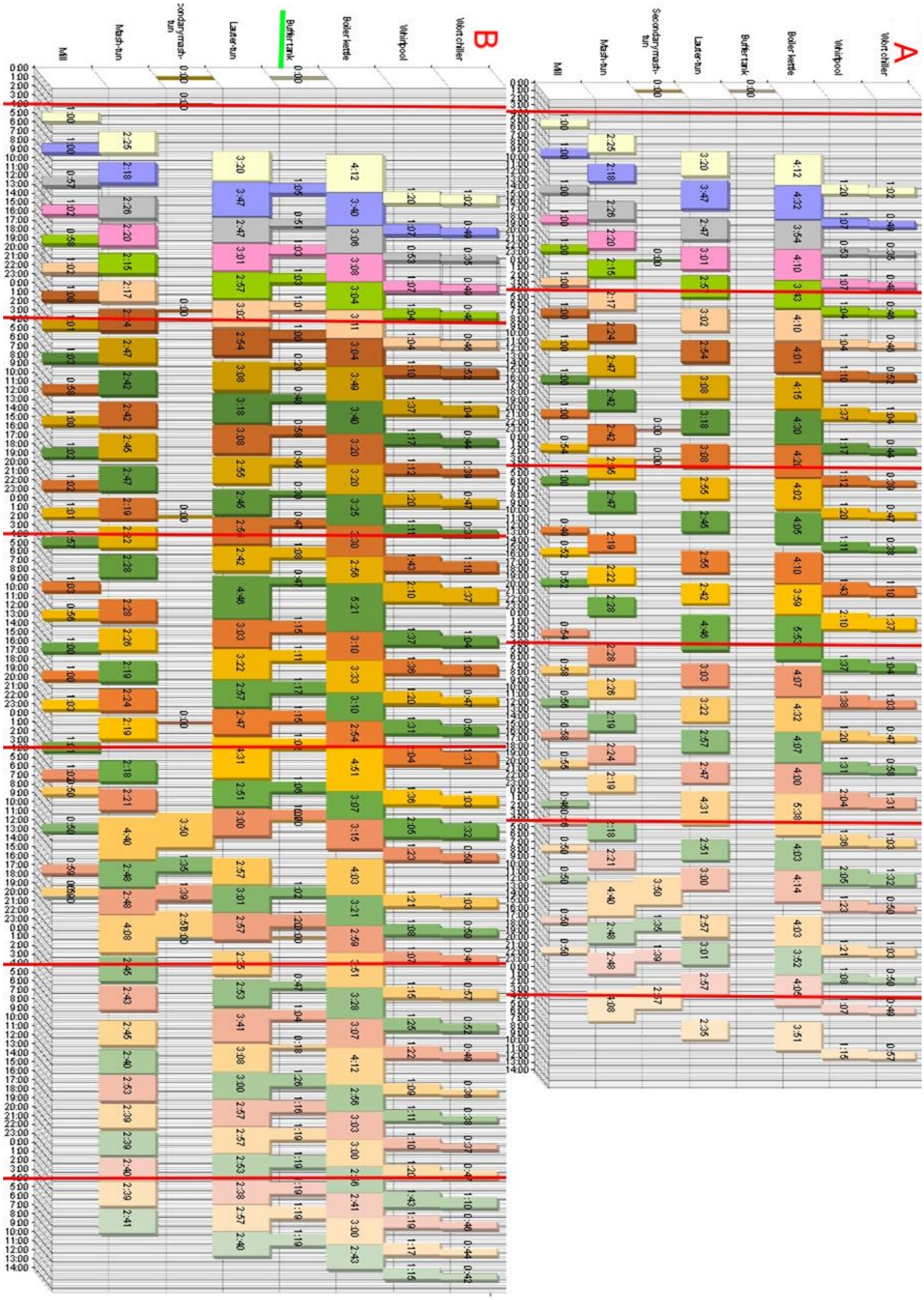

Figure 37 Wort equipment occupation time during a week with the red line responding to 24h work shift: A) Normal week of production without the optimizations having 26 brews per week; | B) week production simulation using buffer tank (underlined in green) and all other theorical and already made optimizations having 36 brews per week

Conclusion

The microbrewery was digitally dimensioned with all the essential equipment for the production of artisanal beer having one two-roll mill, two mash-tuns, one lauter-tun, one boiling kettle which works in simultaneous as whirlpool and wort chiller, a brew stand optimizing the wort production, six cylindroconical vessels for fermentation and a utility area with four CIP kettles, hot water tank, steam and condensate systems. The equipment dimensioned for the microbrewery was compared in terms of materials, dimensions and processes with several other breweries, commercialized equipments and bibliography taking in consideration the advantages and disadvantages from all the others assuring all the characteristic from the microbrewery were the best and didn't show any flaws to the beer and without risk of contamination or labouring risks with the higher efficiency possible at the lower operational and equipment cost, the dimensioning of the equipment made using 3D tools from the Autodesk® program.

The optimization of the minibrewery allowed for a better and deeper understanding of all problems associated to a brewery as well for the causes of loss production and efficiency and provided knowledge for the optimization of the microbrewery to be dimensioned. The optimization was able to achieve a theorical increase in production from 26 brews to 36 brews per week brews only limited by the size of the cellar area which doesn't have enough CCV to support more brews and wasn't taken in consideration during the optimizations.

The microbrewery, digitally dimensioned, wasn't built during the master's curricular internship yet the company kept the project for future construction. The microbrewery was made to be expanded in the future from the wort production area, to the filtration equipment and introduction of a filling line, therefore the microbrewery will be used as a ramp for internships, personal formation and training from all areas, from beer production control, to shopping and sales of products, as well for process optimizations, mechanical and electrician technicians training acquiring experience in a microbrewery before starting to work in large dimension tuns and kettles.

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