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Improvement of the microbiological quality of a beer filtration system

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Abstract

This work addresses the improvement of the microbiologic quality of beer in the BBT (Bright Beer Tanks), after the filtration of green beer, which is the final step of beer production before packaging. The objective was to improve the KPI to achieve a 91.00% Micro BBT FTR indicator in the end of the team's work, starting from 85.42% in the beginning of the work.

A multidisciplinary improvement team inside the brewery was formed to study and implement changes that would improve the FTR (First-Time Right) Microbiology Indicator for the BBT. The designed team was routed in the TPM (Total Productive Management) structure of the brewery, using the 5S's philosophy, and following a microbiological defect reduction route.

The team improved the indicator up to 87.05% by the conclusion of its work, thus falling short of its goal. Despite this, several improvements were made, such as the removal of dead legs on the CIP Circuit and the creation of an integrated Cleaning, Inspection, Lubrication and Tightening plan. Besides this, important studies regarding BBT usage and beer recovery alternatives in filtration were also carried out, and these could have a very significant impact in the overall Micro BBT FTR in the future.

Keywords

Beer, Beer Filtration, Microbiological Quality of Beer, Total Productive Management

Resumo

O foco deste trabalho recai sobre a melhoria da qualidade microbiológica de uma cerveja em tanques de cerveja filtrada (BBT), após a filtração da cerveja, sendo que este é o último passo antes do enchimento da cerveja. O objectivo deste trabalho foi a melhoria do indicador de performance Micro BBT FTR para o valor de 91% até à data da sua conclusão, começando com um valor de 85.42%.

Para tal foi designada uma equipa multidisciplinar dentro da fábrica de cerveja para estudar e implementar melhorias que levassem a um aumento deste indicador. A equipa inseriu-se no âmbito da estrutura do Total Productive Management da fábrica, seguindo a filosofia dos 5s e uma rota de redução de defeitos microbiológicos.

A equipa melhorou o indicador para 87.05% até à sua data de conclusão, não atingindo assim o objectivo proposto. Apesar disso, foram implementadas várias melhorias, como a remoção de troços mortos e a criação de um plano de Limpeza, Inspecção, Lubrificação e Aperto para a área de filtração. Para além disso, foram ainda conduzidos estudos relevantes sobre a gestão dos tanques de cerveja filtrada e sistemas alternativos para a recuperação de cerveja filtrada, que poderão ter impacto significativo no valor do indicador no futuro.

Keywords

Cerveja, Filtração de Cerveja, Controlo de Qualidade Microbiológico em cerveja, Total Productive Management

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Acronyms

BBT – Bright Beer Tank

FTR – First-Time Right

TPM – Total Productive Management

KPI – Key Performance Indicator

SCC – Sociedade Central de Cervejas

CIP – Cleaning in Place

COP – Cleaning Off Place

LAB – Lactic Acid Bacteria

HMRA – Heinken's Microbiological Ring Analysis

LUP – Lição de Um Ponto

CFU – Colony Forming Units

1 - Introduction – Motivation and a brief history of beer and the brewing process

This work was developed in the Vialonga Brewery of SCC (Sociedade Central de Cervejas), and its main goal was to reduce the microbiological contamination in the beer filtration stage, increasing the Micro BBT FTR indicator to 91%. This is important due to the fact that the beer filtration section is one of the sections of the brewery that is the final step in the beer production process and in SCC it is the less modernized stage and is sometimes reporting inconsistent results at times. To achieve this goal a team was made within the company to study problems and implement changes.

The team's work follows the work of another team on the same subject in 2013[1]. This team successfully detected several problems and was able to reduce the level of contamination to the target that was set at the time. However, not all of the problems found by the 2013 team were solved, and this left room for the creation of a new team to tackle these issues.

Beer is currently the second most consumed alcoholic beverage in the world. In very simplistic terms, it is made of fermented cereal starches, water and other components to enhance its flavor. A wide array of cereals and other components is used to brew different kinds of beer.

The origin of beer is related to the fermentation of sweet starches that were by-products of the first farming societies. While it is possibly older, the oldest artifacts known used for brewing date from around 4000 B.C., and were used by the Mesopotamians. In the same way, there are writings descripting the ancient brewing process by the Sumerians, Egyptians and Chinese from around the same time. The brewing process has been evolving ever since its origin, from the discovery of malting, which helps in the fermentation process to the addition of hops, which are responsible for the bitterness.

Throughout time, scientific advancements become of major importance in the brewing process, from the discovery of microbiology to the advancements in industrial and food process engineering.

Nowadays, beer is a commodity globally, and in 2014 the production of beer was of 189.06 million kiloliters worldwide. Asia is the region of the globe with a higher consumption of beer, followed by Europe and Central and South America, North America, Africa, Oceania and the Middle East. The respective share of the global consumption and its evolution over the past years is presented in the figures 1.1 and 1.2.

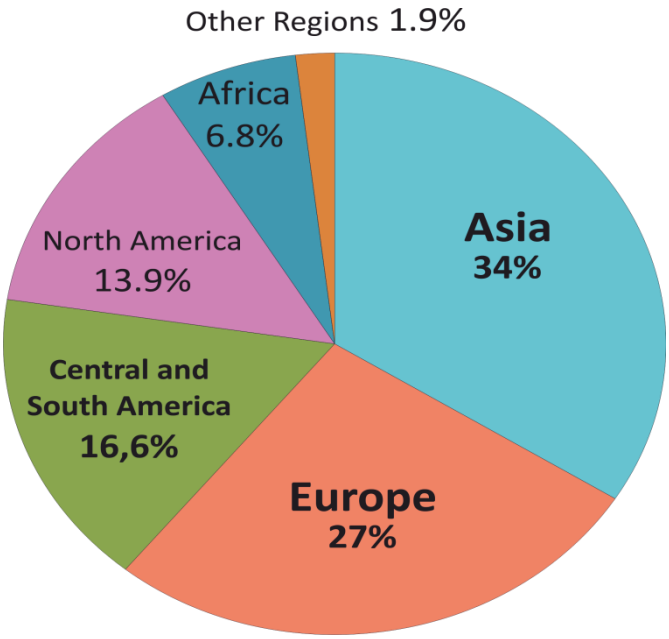

Figure 1.1 - Share of the global consumption of beer.
Source: Kirin Beer University Report 2015

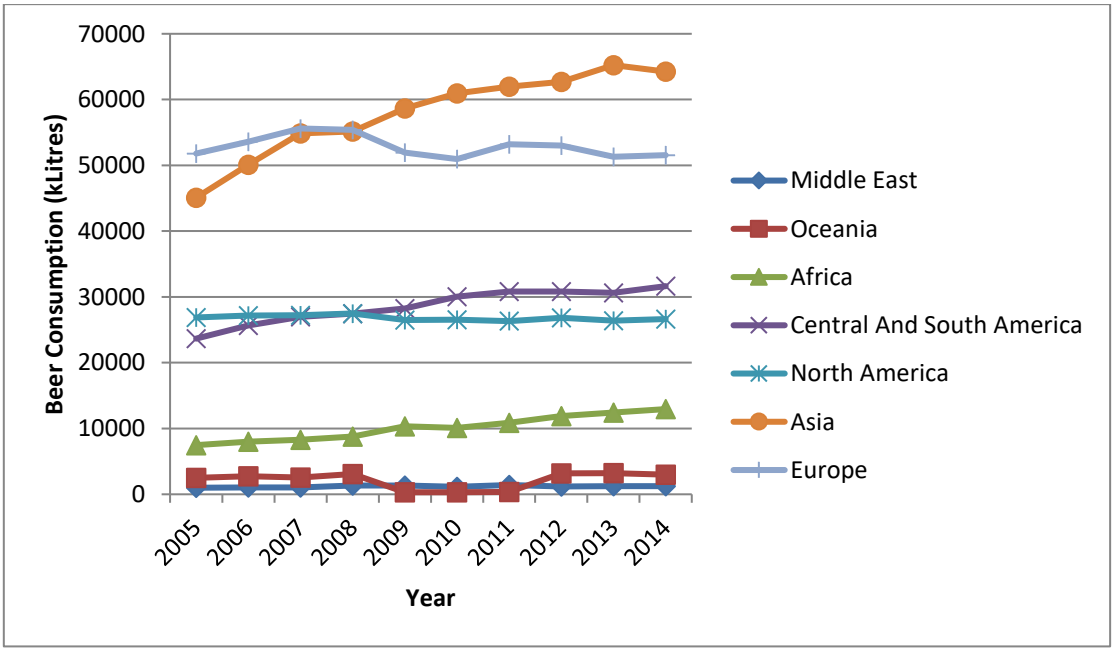

Figure 1.2 - Variation of beer consumption from 2005 to 2014 by area.
Source: Kirin Beer University Report 2015

One of the most important aspects of brewing in a modern industrial world is beer quality. Quality control effectively manages to maintain the characteristics of a beer that make it unique and add value to it as a product.

2 - SCC, The company and the Products

2.1 - The company

SCC (Sociedade Central de Cervejas e Bebidas, S.A) is a company group that not only produces beer and cider but also mineral water and other drinks. It is currently owned by the Heineken group since 2008. One of the group's companies is the Vialonga factory, which is responsible for malt production and brewing of beers such as Sagres, Cergal, Imperial and Jansen and Strongbow Ciders.

Historically, the company was founded in 1934, by a merger of four of the larger breweries in Portugal at the time: *Companhia de Cervejas Estrela, Companhia de Cervejas Coimbra, Companhia da Fábrica de Cerveja Jansen* and *Companhia Produtora de Malte e Cerveja Portugália.*

In order to represent these companies in an exhibition, in 1940 the Sagres beer wascreated and became the flagship product of the company

In the beginning of 1968, the Vialonga brewery started being constructed, being inaugurated at 22nd of July of the same year. Originally, it produced 110 million Liters of beer, 50 thousand tons of malt and 21 million Liters of other beverages. Figure 2.1 shows how the factory is nowadays.

Figure 2.1 - SCC's Vialonga Factory. Source: Sociedade Central de Cervejas

After being nationalized and sold over a series of years, the group has belonged to several different bigger groups, such as Bavaria, Parfil and Scottish & Newcastle. In 2008, Scottish & Newcastle were bought By Heineken, and so the company took control over SCC.

Other parts of the company include the Luso factory, that is responsible for the production of mineral water, and NOVADIS, which is a distribution company that resulted from the merger of several smaller companies and delivers the group's products to the costumer.

2.2 – Products

Figure2.2 depicts the most prominent products that were produced in SCC during the development of this project.

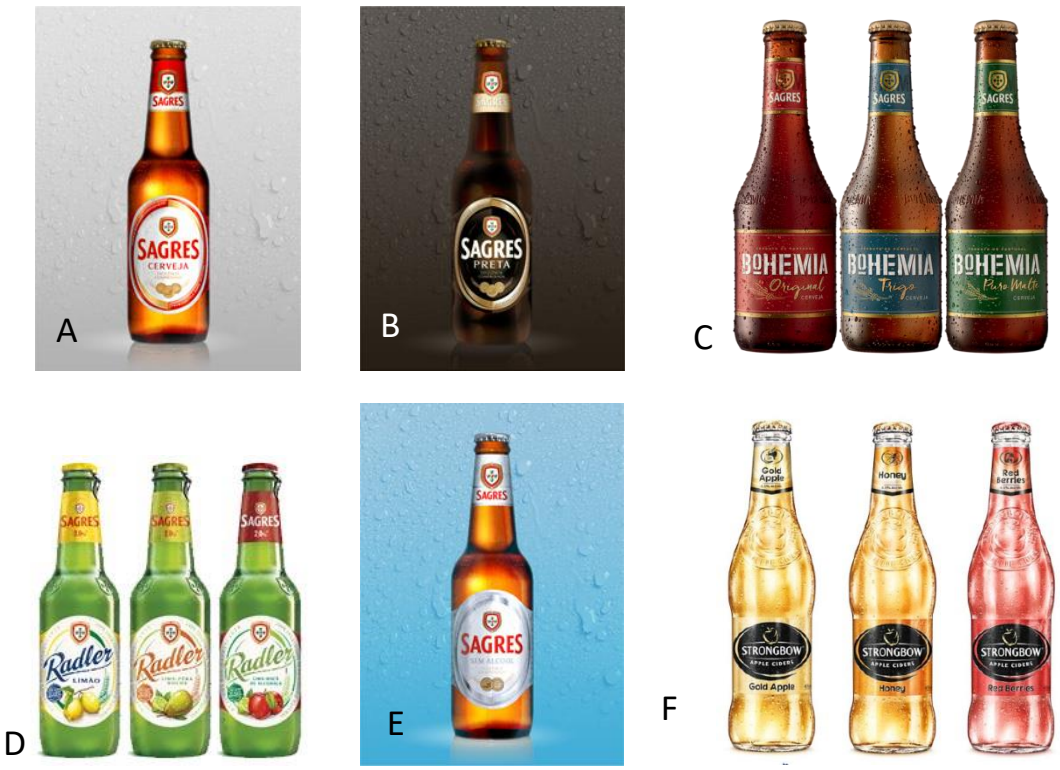

Figure 2.2 - SCC's Products. A - Sagres Branca, B - Sagres Preta, C - Sagres Bohemia, D - Sagres Radler, E - Sagres S/Álcool, F - Stongbow Ciders. Source: Sociedade Central de Cervejas

Sagres Branca is a pilsener lager type beer, produced using water, barley malt, Maize Gritz and hops. It is the company's flagship product, presenting a bright golden color and a soft bitterness and dryness. It has an alcoholic volume of 5%.

Sagres Preta is a Munich lager type beer. It is a dark, with a more proeminent caramel flavor, that is present due to the use of roasted malt. It has an alcoholic volume of 4.1% and just like Sagres Branca is most commonly produced in a 33 cL bottle, as shown below.

Sagres Bohemia is the beer segment of the company that is meant to be consumed during meals. **Sagres Bohemia Original** is a Marzen type beer, with an amber color and an intense fruity flavor. **Sagres Bohemia Trigo** is a Weisen beer, that uses wheat malt besides the barley malt, and is not filtered, having a hazy aspect and low bitterness. **Sagres Bohemia Puro Malte** is a beer that is made of 100% malt and hops, having more intense and herbal flavor.

Sagres Radler is a segment that comprises Radler type beers, that are based on the combination of beer and natural fruit juices. Currently there are 3 types of radler beer produced: **Sagres Radler Limão** consists of mixing beer with lemon juice, **Sagres Radler Lima-Maçã de Alcobaça**, that mixes the beer with lime and apple juice **and Sagres Radler Lima-Pêra Rocha**, that uses lime and pear juice instead. These are all low alcoholic volume beers with approximately 2%. Like Sagres Preta, there are also non-alcoholic versions of radler beer, **Sagres Radler Sem Alcóol.**

Sagres Sem Álcool is the brand's non-alcoholic beer. It is only slightly fermented so that it retains a certain degree of the beer's character and is able to only have an alcoholic volume of 0.3%.

Strongbow Ciders, although not totally produced in SCC are also filled, bottled, carbonated, kegged and pasteurized in its facilities. These are sour apple ciders, that come in three different flavours: Gold Apple, Honey and Red Berries.

Besides these main products, there are also other beers produced by SCC, such as **Cergal,** which is an economic beer, **Imperial**, that is a beer that targets a younger audience and **Jansen**, that is the oldest brand of non-alcoholic beer in Portugal.

All of these products are relevant to the work that was conducted, because they are all produced in the brewery's facilities and all of them are subject to microbiological control and the results of these tests contribute to the microbiological quality indicators.

3 - The brewing process

Despite being a very ancient process in its origins, brewing is always evolving and the process nowadays comprises a lot of different, complex techniques. This chapter breaks down and explains simply the main stages of brewing.

Since the main goal of this work was to improve the quality of the microbiological quality indicator for the filtration of beer, there is a broader explanation of the filtration process in later chapters. The process that is explained in this section is the process that is followed in SCC, since there are many different equipments and procedures that can be used to produce beer.

3.1 - Raw Materials:

Water: Water is the main component of beer, and its quality is of major importance to the beer that is produced. The water used should be flavourless and free of contaminants. The mineral composition of the water should be controlled to keep the specification parameters of the beer.

Malted Cereals (Barley): Barley is a cereal with a high level of starch that is used in most of the beer that is produced in SCC. It is a source of sugar for fermentation, and is malted in order to produce enzymes that enhance the breaking of complex sugars, like starch, into more simple ones, like glucose.

Non-Malted Cereals (Maize Gritz): Maize Gritz is added to the wort to increase the amount of sugars available for fermentation. Depending on the beer recipe that is been followed, other sources can be used to increase the level of sugars such as rice, Wheat and sugar syrup.

Hops: Hops are the flowers of the hop vine (*Humulus lupulus*). They are added to the wort in order to give certain aromas to the beer. The bitterness of beer is a result of the addition of hops, that help to balance the sweetness of the malt. The hops are also responsible for some other herbal, floral and citric aromas of the beer. They also affect the head retention (ability to retain foam) [2] and have an anti-microbiological effect, that flavours the activity of brewer's yeast over undesirable microorganisms [3].

Yeast: Yeast is the unicellular microorganism responsible for the fermentation of the wort that will be transformed into beer, converting the sugars into energy, carbon dioxide, ethanol and several other substances that give the beer its characteristic flavor profile. It is a funghi and the genre of yeast most used in beer is *saccharomyces*, although some lambic beers (made by spontaneous fermentation) use the *brettanomyces* genre. The genre and subgenre of yeast used will imply different conditions for the fermentation, and consequentially different characteristics in the beer. For example, while Ale Beers use *saccharomyces cerevisae* and

have an optimal temperature of fermentation that ranges from 15 to 25 ºC, Lager beers use *saccharomyces uvarum* and have an optimal temperature of fermentation that ranges from 5 to 15 ºC [4].

3.2 - The Brewing process stages

Malting: Malting is the process that converts barley into malt, which is much easier to mill and has a higher concentration of enzymes that further enable a better brewing. A good malting is achieved by a controlled process of steeping, germination and kilning [5].

Steeping consists in wetting the grain in cold water and laying it out as a shallow bed, assuring that it is not immersed in water for too long and asphyxiated. There should be an alternate sequence of wetting and removal of water, and the timing of such alternations allows controlling the amount of oxygen and water. Temperature must also be controlled for optimum growth (12 to 18ºC). Cold wet air can also be used in order to improve the efficiency of the temperature/humidity/aeration control. During steeping, the grain produces gibberellin, a hormone that allows the plant to start producing enzymes that will break down the food reserves of the grain.

The wet grains are transferred into germination boxes, whose main goal is to control the production of enzymes by the grain, as well as the amount of cellular and proteic breaking down caused by those enzymes. To achieve such goal, the conditions of germination should be controlled in order to have a temperature from 12 to 20ºC and a humidity of approximately 44%.

If the plant were allowed to grow further, it would generate a new barley plant. But instead, a kilning process is used, in which the plant is heated with hot dry air, stopping its growth. This also allows for a better conservation of the malt.

In the end of the malting process, the small roots and shoots that have grown throughout the process are mechanically removed. Figure 3.1 represents this process

Figure 3.1 - The Malting Process (Adapted from Encyclopedia Britannica)

Milling and Mashing: After malting, malt should be milled in order to produce smaller particles. This milling allows for a bigger surface area that will enhance the extraction of enzymes from malt in the mashing. The mashing consist in mixing the crushed malt with cereal

adjuncts and hot water, so that the enzymes present in malt can break proteins and sugars into smaller molecules, creating a soluble malt extract, called wort. First, water temperature ranges from 45 to50 ºC by 20 minutes. Then, the temperature increases to 65ºC in order to reduce the starch's crystallinity and make it easier to digest by the enzymes. In the end, the temperature is raised until 76ºC in order to stop enzymatic activity and further enhance the amount of soluble compounds on the wort (also known as extract). Figure 3.2 represents this step

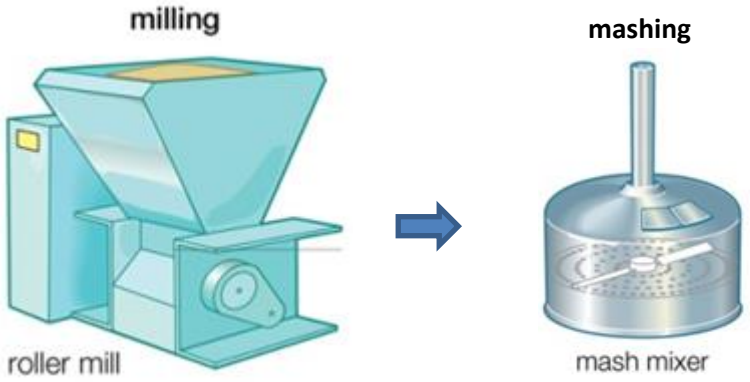

Figure 3.2 - Milling and Mashing (Adapted from Encyclopedia Britannica)

Wort Separation and Boiling (Brewing): After the mashing, the solid portion must be removed from the wort. For that purpose a mash filter (plate and frame) is used. The filtration usually takes up to 90 minutes. The wort is filtered and directed to the boiler, and the solid remains are washed with water and discharge to a container in order to be sold as animal feed, allowing the valorization of a residual product. The filtered wort should be bright and clear before boiling. The boiling step is a unique step in beer brewing and has several objectives:

- Making the beer sterile, thus getting rid of possible microbiological contaminations that could harm the beer's quality
- During boiling, hops are added to the wort, and so this step is also responsible for the addition of flavouring compounds and aromas, like the bitterness that is characteristic from hops.
- Coagulating excess proteins and tannins to form solid particles, refered to as trub. These particles will form a slight haze, that is characteristic of the wort at this stage.
- Removing volatile components that are usually related to undesirable flavours, such as dimethyl sulfide.
- Concentrating the sugar of the wort by evaporation of the water

After Boiling, the wort is sent into a whirlpool, where large solid particles are removed by centrifuge force. Figure 3.3 depicts this stage of the process.

Fermentation: The wort is cooled and aerated, and then it is transported to the fermentation vessel, where it is inoculated with yeast. For lager beer the bottom-cropping *saccharomyces*

uvarum is used. The fermentation occurs at a temperature of 8 to 13 ºC. During fermentation, yeast uses the sugars present in the wort in order to produce CO_2 and Ethanol and other compounds that are also responsible for flavouring the beer. When the sugars in the wort are depleted, the fermentation ends and the yeast beggins to flocculate and deposit at the bottom of the vessel. The fermentation can also be stopped by cooling the vessel, and the yeast will also flocculate. In the end of fermentation we refer to the fermented wort as green beer, and the yeast cells used can be removed from the bottom, whirlpooled in order to remove excess beer and stored and reused in other fermentations, for 3 to 5 life cycles. Figure 3.4 represents this step

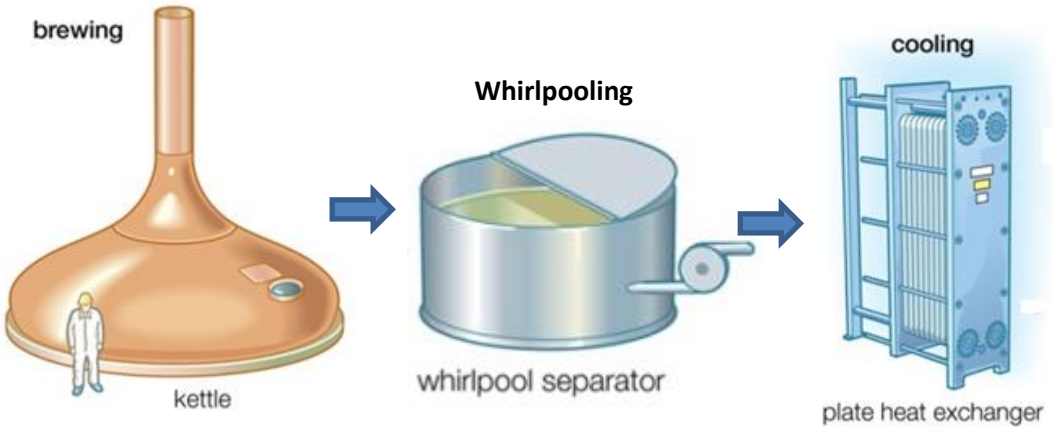

Figure 3.3 - Wort Boiling, Separation and Cooling (Adapted from Encyclopedia Britannica)

Storage: After fermentation, green beer is rested in large tanks in order to improve and stabilize its properties. This is done by storing the beer at very cold temperatures (under 0ºC). Beer colloidal stability is one of the properties that is greatly affected by this step. The reduced temperatures lead to the flocking of colloidal particles, mainly polyphenols and proteins, which are responsible for a harsh and over-bitter flavor in beer. This haze will set during maturation and deposit on the bottom of the tank. The longer the beer is left to mature, the less haze it will have, due to the deposit that is formed. The time of maturation can be managed in order to respond to the demand for product, since this haze is also removed during clarification, and the longer it ages, the less haze is required to be removed. Figure 3.5 is a representation of this step

fermentation

Figure 3.4 – Fermentation vessel (Adapted from Encyclopedia Britannica)

Storage

Figure 3.5 – Storage (Adapted from Encyclopedia Britannica)

Clarification/Beer Filtration: In order to further remove haze from beer and to obtain a product that is more appealing visually, beer is filtered through a bed of diatomaceous fine earth, called kieselguhr. It also allows to remove most of the polyphenols and proteins that were generated during maturation. One of the problems with this method is the disposal of the kieselguhr after the filtration and the health hazards it can create (the fine powder can cause problems in the respiratory tract of those who are exposed to it over long periods of time). Despite this, it is still the most efficient and cost effective method for haze removal, although significant advances are being made in membrane filtration technology that makes it a viable alternative for smaller productions of beer. In some breweries other filtration aids are used in conjunction with kieselguhr to assure an optimal rate of removal of particles by adsorption, such as PVPP [6], but in SCC this is not done. It is also at this stage, after filtration that levels of CO_2, Oxygen and the dilution of beer can be adjusted.

Filtration is one of the final steps of beer production. After it, Beer is sent to Bright Beer Tanks (BBT) where it is stored before going to the filling facilities, where it is bottled and packaged in order to be sent to the market.

A very important part of the whole production process is **pasteurization**, that occurs at the bottling hall and allows to eliminate any possible microbiological contamination, using

steam to expose the beer to very high temperatures for a very short period of time. There are two different types of pasteurization that can occur: **Tunnel Pasteurization** is made in tunnels after the beer is bottled and **Flash Pasteurization** occurs right before the beer is bottled. While less expensive, Flash pasteurization action only affects the beer while tunnel pasteurization also targets the bottles. These processes are represented in Figure 3.6 below.

While pasteurization prevents from selling a product that is contaminated by a microorganism, the excretion of metabolites by a possible contaminant can affect the taste and other properties of the beer. This is the main reason why it is important to assure that contamination is reduced to a minimum or eradicated in each stage of the process, thus justifying having an efficient microbiological quality control.

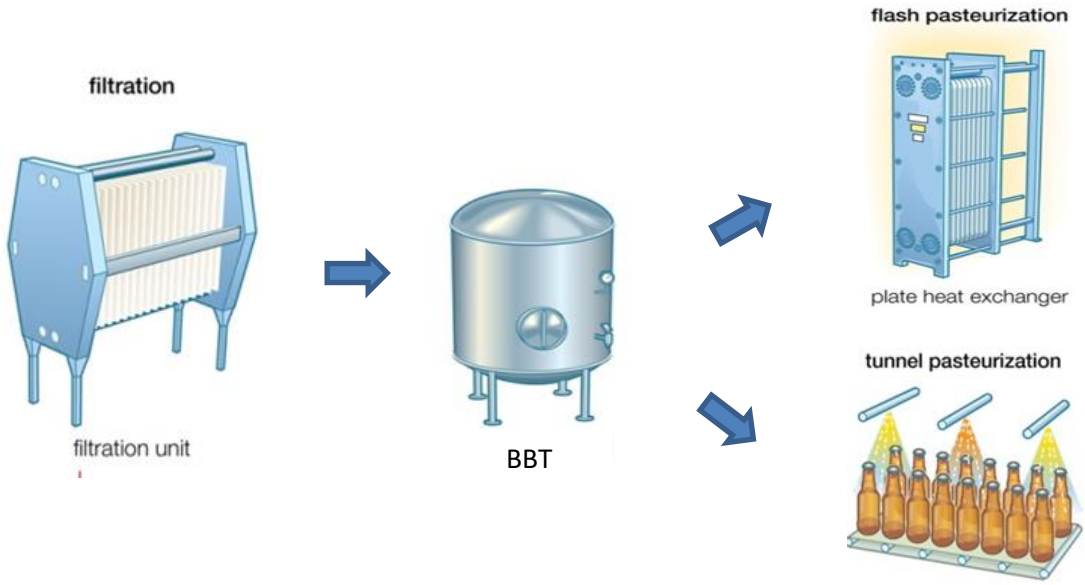

Figure 3.6 - Beer Filtration and Pasteurization (Adapted from Encyclopedia Britannica)

4 - Beer Filtration in SCC

As previously stated, beer filtration or clarification is a the part of the process in which green beer is filtered in order to remove the particles responsible for the haze that it presents, turning into bright beer. These particles are both protein agglomerates and polyphenolic compounds and leftover yeast from the fermentation stage that was not effectively removed by centrifugation.

4.2 - Beer flow on the filtration area of operation

In SCC, the filtration area of operation is subdivided into various processes that are performed adjacent to the filtration of beer. Firstly, there is **Beer Reception from the Cellars** where beer is transferred from the storage tanks into the filtration site. This is done by using a system of panels that are interconnected with pipe curves, that can be adjusted in order to control the origin and destination of beer.

After the beer leaves the cellars, it is directed towards the **Nathan**, which is a buffer tank for the filtration stage. This step is only taken for Pilsener Beer and for the other types of beer the Nathan is bypassed. From there it is directed to the **Manifold**, as seen in figure 4.1, which is a valve network that allows directing the beer to the proper filtration line.

Figure in Annex A

Figure 4.1 – Manifold

Before being filtered, beer is cooled down to around -1ºC in a heat exchanger, with a notable exception for non-alcoholic beer, that is cooled to around 4ºC, due to the fact that the absence of alcohol increases its freezing point and it could possibly freeze and stop the flow of beer to the filters. A plate type heat exchanger is used, in which the beer flows on even plates and on uneven plates a cooling solution of water and glycol flows. The transfer of heat occurs through the plates and allows the cooling to occur. This cooling will result in an increase of the beer viscosity, that despite reducing the flow rate of beer leads to a higher level of precipitation and coagulation of the proteins that are supposed to be filtered, making them less soluble and so more effectively filtered.

In SCC a **plate and frame filter** is used in order to perform this filtration, and kieselguhr is used as a filtration auxiliary. Because of this, this filter is also known as the **Kieselguhr Filter**. A plate and frame filter consists of a series of plates and frames that are mounted together and disposed horizontally, covered by a filtering cloth that is permeable to liquids being filtered. The assembly of the plates and frames creates two separate cavities, and the beer flows from one to the other, as the solid particles remain trapped in the interface that separates the cavities. In order to regulate the flow of beer a press is used. Figure 4.2 is a representation of a plate and frame filter.

Figure in Annex A

Figure 4.2 – Side View of a plate and frame filter in SCC

Plates and frames are used in order to increase the surface of the filter, since the flow of beer is directly proportional to the filtering surface. **Darcy's law**, that explains the flow of a fluid through a porous bed, like the kieselguhr cake and the filtering cloth, is capable of depicting this.

$$\Delta P = \frac{\mu * v * l}{\pi}$$

Where ΔP is the pressure drop in the filter, μ is the viscosity, v is the linear speed of the beer, l is the length of the filtering cake and and π is the porosity of the filtering cake. Since the filtering surface is inversely proportional to the filtering cake length (for the same amount of kieselguhr), it is proven that larger surface areas of plates and frames allow for a more efficient filtration, by reducing the pressure drop.

Besides the use of a cloth, a bed of kieselguhr is also added as an auxiliary element that creates a filtering cake on the cloth surface, increasing the retention of solid particles. The use of kieselguhr allows for two different types of retention to occur: On a larger level, big particles get physically trapped in between the grains of earth; on a smaller level, adsorption of some molecules on the surface of the kieselguhr particles is also possible, since kieselguhr is a very porous type of earth with a large surface area.

The kieselguhr used in the filtration process has various particle sizes, and the amount of each type of kieselguhr used is regulated and optimized to better suit the process. The main inconvenience of using kieselguhr is that it increases the resistance to the flow of beer through the filter, because of the accumulation of solids in the kieselguhr bed, that reduces its porosity and leads to a raise of pressure in the inlet of the filter in order to maintain the flow.

For the addition of kieselguhr to the filter it must be previously mixed with deaerated water on mixing tanks and packed into the filters before each filtration cycle.

After kieselguhr filtration, the beer is directed to the **Carboblender**, as seen in figure 4.3, where it is diluted and carbonated. The carboblender is a machine that has a integrated system of several pipes and different measurement instruments, such as flow meters, densimeters, turbidimeters, among others. This system allows to determine several parameters of the beer, that are key to assure the quality and uniformity of the beer that is produced. The readings of this machine allow determining the beer extract, and knowing so to adjust the dilution rate so that the beer that is produced has the right dilution.

It is also noted that the water used in dilution is previously deaerated and demineralized in another machine called **Aldox**, that uses a packed column where the Oxygen is removed by desorption with CO_2 being used to remove it. This water is also passed through a 10 MW/cm^3 **UV Lamp**, in order to assure any microbiological contamination is neutralized.

The Carboblender is also responsible for the adjustment of the carbonation of beer, using CO_2 recovered from the fermentation stage. The conditions of temperature and pressure for this process are very important, since according to Henry's Law, the amount of CO_2 that is dissolved on the beer depends of both of them. Being so, the valves of the machine control the pressure in order to assure that the right amount of CO_2 is dissolved in the beer.

After carbonation, the beer is sent to a **Trap Filter**, as seen in picture 4.3. This filter is a fiber membrane filter that has a very small pore size. This step is meant to retain any particles that may not be effectively removed by the kieselguhr filter. This allows for a more effective filtration a safety protection for the beer that is already past them, since it allows to safeguard already filtered beer from a kieselguhr filter malfunction.

Figure in Annex A

Figure 4.3 - Trap Filter

After the Trap Filter, the beer is directed to the **Additive Tanks and Injection Stage**. While for most types of beer produced this step is bypassed, non-alcoholic beer requires the injection of hop oil in order to intensify the beer aroma. Likewise, the Cider that is filled on the facilities (which is only diluted and not filtered) is injected with Potassium Metabissulfite, that is a anti-oxidant and preservative that allows for a longer shelf lifetime and lower levels of microbiological contamination.

Finally, the beer is sent into a series of panels through which it reaches the **Bright Beer Tanks (BBT)**, as seen in picture 4.4, by a hose. These tanks are highly isolated thermally to allow for the beer to remain at low temperatures, preventing microbiological spoilage and maintaining the level of dissolved CO_2.~

Figure in Annex A

Figure 4.4 - BBT Front Pannel

Before being sent into each tank, the tanks are counter-pressurized with a layer of CO_2 and Compressed Air. The air leaves the tank as the beer goes in. This pressure outlet makes it impossible for the beer to contact with the foreign atmosphere or possible foreign microorganisms. Being the final step of the production, the beer in BBT is sampled for all of the quality control measures necessary, such as pH, oxygen concentration, colour, acidity, among others.

During this work, an automatic **Kieselguhr Dosing System** was added to the facilities. This system consists of a mixing tank where kieselguhr of three different particle sizes is pre-mixed with water and fed to the kieselguhr tanks that were previously used on the kieselguhr

filters. This system lowers the amount of work that the operators of the filtration have to employ in this stage, increasing safety and allowing for a finer dosing of the kieselguhr itself.

4.3 - Beer Recovery

During the startup of a filtration cycle in the kieselguhr filter, the filter must be packed with kieselguhr. This packing is done by mixing the kieselguhr with dearated water and it being fed to the filter until there is a cake formed in the filtration interface. So in order to perform this packing it is required to fill the filter with water before beer is sent into it.

This causes the beginning of the filtration cycle to be much diluted beer, since it is mixed with water. Since the beer being produce has to obey quality standards and the dilution of beer has to be controlled, this initial beer is not suitable to be sent into a BBT like regular beer is, because the carboblender couldn't adjust its dilution properly, because this beer is below the target level for beer dilution. Instead, this highly diluted beer is sent into BBT 6 and is accumulated there to be recovered until the tank is full.

When the tank is full, this beer can be injected into the manifold and re-filtered and incorporated into a higher concentration beer. This injection into a higher concentration beer allows for the carboblender to properly adjust the dilution.

Besides the recuperation of the beginning of filtration cycles, the ending of each filtration cycles is also recovered. When the beer flow stops, the filter and all of the equipments after it are still filled with beer. This beer is then pushed into BBT 6 for recuperation just like the beer from beginning of cycles.

4.4 – Cleaning of the filtration facilities

In order to assure the quality of the beer produced it is essential to maintain hygiene standards throughout the filtration process and to assure the integrity and purity of the product, both from a microbiological and chemical standpoint.

There are two main types of cleaning that occur on the filtration site: **Cleaning In-Place (CIP)** and **Cleaning Off-Place (COP)**. CIP corresponds to all the cleaning processes required to clean the inside of the production circuit and equipment, maintaining hygienic conditions in the places where the beer flows. COP is the cleaning of the outside of such equipment, in order to prevent possible interference and contamination due to residue accumulated on the surface of the equipment.

While COP is performed manually, there are several automated different CIP programs that are related to the specific needs of the equipment. Some of the factors that CIP programs have to take in account are the amount of residue, the nature of the surface being cleaned, the temperature of the process, the amount of mechanical action necessary and the nature and concentration of the cleaning process. The CIP process is automated and optimized taking all of these factors in account.

4.4.1 - CIP processes in the filtration section

In the filtration section, the main CIP processes are the sterilization of the filters, the CIP to the filters and production circuit, the CIP of the Aldox and additive tanks, The BBT CIP, The CIP to the BBT Circuit, hoses and panels, The CIP of the CO_2 and compressed air circuits and the CIP of the deaerated water circuit.

The sterilization of the filters occurs between each cycle of filtration. The filter is sterilized in closed circuit with hot water at 90ºC for 120 minutes. This allows to remove all of the residues from previous filtration and to assure that there is no microbiologic contamination. After the sterilization the filter must be cooled with water before the next filtration can take place.

The CIP to the filtration circuit is performed weekly, on the production's maintenance downtime, since it cannot be performed while the filters are working. A solution of 2% (v/v) of Sodium Hydroxide is used to clean the whole production circuit for 80 minutes. After this the circuit is flushed with water to remove any remaining residues of the cleaning product.

The CIP to the Aldox and additive tanks is also done during weekly downtime. While the cleaning of the Aldox is undertaken using an acid detergent (P3 Horolit V), the cleaning of the additive tanks uses a chlorate alkaline detergent (Ansep CIP).

The BBT CIP is performed whenever a tank is emptied and sent into the filling facilities. There is a automated central with two tanks: One that has a detergent, Trimeta-Duo at 1-2% (v/v) and another that accumulates the water that is used to remove the detergent from the circuit. The water with residual detergent is used as a pre-cleaning stage before the use of the actual cleaning solution, and is also recycled while it remains of low detergent concentration (the concentration is checked via a condutivimeter). This process occurs at high turbulence levels to assure a effective mechanical action on the surface of the BBT for a proper cleaning.

The CIP of the Circuits, Hoses and Pannels is done weekly during the downtime of the production. It consists on the cleaning off all the circuits and Hoses used on the process, which are connected through the panels in closed circuit and uses a Trimeta Duo solution as a detergent.

The CIP of the CO_2 and Compressed Air Circuit is done semestrally, and a Trimeta Duo solution is used as a detergent. Besides this cleaning process, a second sterilization step is performed, using 1.5 bar steam.

Finally **the Deaerated Water Circuit CIP** Is also done weekly on the production downtime and consists of a closed circuit cleaning process using a 2% (v/v) Ansep CIP solution.

The cleaning of the filtration facilities is of capital importance to maintain a product free of contamination.

5 - Quality Control, Structured Problem Solving and Microbiology

5.1 - Quality control – an introduction

Quality control is, according to ISO 9000, which is the international standard for product quality management, the "part of quality management focused on fulfilling quality requirements". So there is a certain amount of requirements that need to be fulfilled so that the final product is safe for consumption and that the overall characteristics of a type of beer don't vary significantly between different batches of the same product. This takes a key role in a competition environment, where several different brands have to produce the best product in order to appeal to the consumer.

Quality control has also been evolving over the years. From the beginning of the industrial revolution and up until the beginning of the 20th century it was based solely on checking if products meet specification criteria. Some great improvements were made during WW II by the mathematic Walter Shewart, who applied statistical analysis to the methods of quality control, such as the use of sampling while analyzing if the bullets were up to standard [7]. The biggest advances came later in the century with Japanese quality control techniques originated a great step forwards regarding the productivity of the companies. The development of Genichi Taguchi's methods, that introduced the idea of a loss function, that had to be minimized in order to achieve better results in both quality and financial performances [8], coupled with the development of TPM (Total productive maintenance) allowed for a breakthrough in quality control, and such methods are still relevant and used until this days.

There are several systems that help assuring the quality of products in the food and beverage industry. **ISO 22000** is the international standard for organization that deals directly with food safety management. It deals with maintaining a food safety management system, assuring compliance with requirements, an effective communication with customers and suppliers about quality requirements and to seek certification from external organizations in order to assure trustworthy and independent evaluation results.

Another important system for quality control in the food industry is **HACCP** is a Dutch-originated quality control system. It stands for Hazard Analysis and Critical Control Points. It is a preventive system that detects possible problems and creates control points so that it can control biological, chemical and physical hazards of food and beverages, enhancing the importance of good hygiene practices and safe product handling. SCC is a HACCP certified company, and its products and methods all comply with the system requirements.

5.2 - Total Productive Management

5.2.1 - Total Productive Management and Total Quality Management

Total Productive Management (also known as Total Productive Maintenance) is the main quality control system used in the brewery. It is based on the use of combined techniques and philosophies from two different quality control methods, **Total Productive Maintenance** and **Total Quality Management**.

Total Quality Management is, according to the American Society for Quality, a management approach to long-term success through customer satisfaction. Although there is no consensus on where it was first implemented, the first time it was used to a big degree of success was by the U.S. Navy in the 80s. The key concepts that were implemented were [9]:

- Quality is defined by customer's requirements
- Top management has direct responsibility for quality improvement
- Increased quality comes from systematic analysis and improvement of work processes
- Quality improvement is a continuous effort and conducted throughout the organization.

Using techniques such as the PDCA (Plan-Do-Check-Act) cycle, cross-functional teams responsible for process improvement over the long term and the use of the seven basic tools of quality, this method has been applied successfully in many organizations around the world.

Total Productive Maintenance [10] is a maintenance program, firstly introduced by Seiichi Nakajima in Nippon Denso, which was part of the Toyota Group in the 70s. The main goal of TPM is to optimize the productivity of a plant by continuous improvement, also improving employee morale and job satisfaction. A simple way to explain the goals of TPM is stating that it should aim to achieve a series of "zeros". The "zeros" that are attained as goals for TPM are:

- Zero Waste
- Zero Defects
- Zero Break-Downs
- Zero Accidents

Implementing changes in order to achieve those goals will attain for a more profitable and productive operation. The program is not only suited for the machines that operated, but also aims to improve the quality of the work force labor, focusing on optimizing both the machine's productivity and the operator's skills in order to improve such interaction.

Although they have similarities such as the requirement for employee involvement, attention to long term planning and the mindset of continuous improvement, Total Productive Maintenance and Total Quality Management are two very different tools. While the first one is mainly focused on the equipment of the plant in order to reduce losses, the second is aimed to

improve quality by means of a more efficient management. While they can be viewed as separated methods, the reduction of defects proposed by Total Productive Maintenance allows for a better overall quality and the planning and management of the production idealized by Total Quality Management also affect the productivity greatly. So the use of both philosophies and their respective methods will allow for a more productive company, whose products present a higher quality, to meet the costumer's demands..

Total Productive Management (TPM) has six fundamental areas of improvement: **Safety, Higiene and Environment**, that accounts for the reduction of accidents and danger situations (known internally as near-accidents) and for a better management of resources, **Distribution**, that is related to the improvement of scheduled deadlines for deliveries, **Expenses**, that aims to reduce the cost of operation, **Employee Motivation**, that adopts continuous improvement practices and team work improvement measures, **Productivity**, that targets the overall reduction of breakdowns in equipment and time management and **Quality**, that targets to reduce defects and make the final products meet the criteria of the costumer's demand.

5.2.2 - Key Performance Indicators

In order to measure the quality of the performance of a process, and to be able to establish objectives for further improvement, it is necessary to have Key Performance Indicators (KPI). Those indicators are defined according to the strategic needs of the organization, and there are several number of possible KPI in any structure, giving the management team data to be able to perform better diagnosis of possible problems. They are applied in a series of areas: in **Safety and Environment**, the number of accidents and amount of emissions are two very important KPI. Accordingly, **Expenses** uses several financial KPI to measure revenues, **Distribution** uses the delay time on deliveries as KPI, **Employee Motivation** is measured by a series of annual satisfaction surveys among employees, **Productivity** uses several KPI such as the downtime of the equipments and **Quality** has a lot of KPI related to number of product defects and costumer reclamations.

One very important KPI, as established in Total Productive Maintenance is the **Overall Equipment Efficiency** (OEE) [11]. It can be determined by the following formula:

$$OEE = A \times PE \times Q(FTR)$$

Availability (A) is the proportion of time in which a piece of equipment is available to be producing. It can be calculated as:

$$A = \frac{(Planned\ production\ time - Downtime)}{Planned\ Production\ Time}$$

Performance efficiency (PE) is the proportion of finished products made during a cycle and the maximum productive capacity of the product in such interval.

$$PE = \frac{(Cycle\ time \times number\ of\ products\ processed)}{Production\ Time}$$

The Quality rate (Q) is also known as the FTR, and is one of the company's main Quality KPI. It represents the proportion of conform units produced relative to the total production, or in other words, the amount of products that were made up to standard at the first time.

$$Q = FTR = \frac{(Number\ of\ products\ made - Number\ of\ products\ rejected)}{Number\ of\ products\ made}$$

5.2.3 - TPM Pillars

For the implementation of TPM there has to be a structure, with coordination teams for the main areas of work that the company comprises. These teams are called Pillars, and the brewery has 8 in their organization. They serve not only as individual bases for the overall improvement of the company but also as way to communicate data from the operation teams to the direction of the company.

The main activities of each pillar are to reduce losses and solve problems, by assigning improvement teams, training and improvement of the employees, and defining the tools required for problem solution, as well as auditing the teams to assure they are working efficiently. Figure 5.1 simply represents the pillars of TPM.

People Development is the pillar that focuses on the specific formation of employees in order to be able to better fulfill their duties. The main action areas of the pillar are acquiring better equipment diagnosis tools, repair skills, technology systems, Quality and statistical analysis tools, among others.

Safety (& Environment) is the pillar that creates better safety conditions for workers and assures the creation of an environmentally clean workplace, resulting in a green perspective over the use of environmental and energetic resources.

Progressive Quality is the pillar that is responsible for satisfying the costumer's needs for a good product. They are responsible for setting the quality standard for the products and assuring they are met. It is also a responsibility of the quality pillar to study defects and their causes, in order to better understand the reasons behind problems and allow a better continuous improvement of the production.

Planned Maintenance is the pillar that focuses on the improvement of the conditions of the functioning equipment. The main goal is not only the resolution, but also the prevention of problems regarding the equipment, by making periodical inspection and improvement of the equipment. This allows to reduce the amount of downtime due to breakdowns.

Autonomous Maintenance is the pillar that focuses on the conditions of the workplace. It is managed by the workers, and its goal is for the workers to progressively know the machines they operate better and to be able to work in conditions that allow for the equipments not to be deteriorated. One of the main tasks of this pillar is to assure there is a CILT plan (Cleaning, Inspection, Lubrification and Tightening).

Focused Improvements is the pillar that is responsible for the optimization of processes by continuous improvement of the equipments functioning. The main goal is to eliminate flaws in the productive processive by extensive analysis of its indicators. Therefore it is a pillar mainly focused on production, maintenance and engineering.

Early Product Management is the pillar responsible for the creation of innovative new products and projects in order to improve flaws in production. It is highly related to **Project & Early Equipment Management,** that develops the processes in which such new products or equipments are implemented.

Finally **Logistics** is the pillar associated with creating the ideal bureaucratic conditions for the other pillars to work efficiently.

Figure in appendix

Figure 5.1 - SCC TPM Structure

5.3 – Structured Problem Solving

5.3.1 – Structured problem solving fundamentals

In order to properly tackle the problems detected by the quality control system there must be a structured approach to problem solving. This allows for a quicker path to a solution, by identifying weaknesses, systemic problems and their reasons.

A structured approach to problem solving is particularly useful on systematic or reoccurring problems, being so repetitive human or equipment problems. It is also very effective if the performance problems are found.

Following a PDCA logic that will be more profoundly covered later, Structured Problem Solving can be reduced to 8 basic steps that are as follows:

1 – Claryfing the problem – This step requires the study of the problem itself, by comparing the idealized standard with the situation. This step is important to qualify losses and prioritize actions

2 – Breaking down the problem – This step consists of a profound study of the problem. Learning the functioning of the standardized process and breaking down bigger problems into smaller ones is the main goal of this step, so that better solutins can be found for the problems

3 – Target setting – Like the name indicates, this steps simply consists of setting targets for what is supposed to be achieved. The targets should be ambitious and objective, so that results can be compared in the end of the problem solving process

4 – Determining root causes – This step requires the use of problem solving tools such as multidisciplinary teams, Brainstorming, 5 W's among others to determine the root cause and the method of failure

5 – Developing countermeasures – In this step ideas to tackle the causes of problems are developed. All ideas should be considered and studied in a cost-benefit relation, so that the ones that are used are the most suitable.

6 – Implementing countermeasures – This simply consists of implementing the countermeasures.

7 – Confirming the results – This step consists on comparing the results before and after countermeasures were taken, in order to determine if there was actual improvement. Comparison with the targets that were previously set is also important, to determine the degree of success of the improvements

8 – Creating new standards – After all the improvements take place, a new standard must be created in order to sustain the gains of the process.

It is Important for the success of this structured problem solving method that it is applied in the context of a team, preferably a multidisciplinary one, in order to assure better comprehension of the different aspects surrounding the process and multiple different views on possible solutions.

5.3.2 – Microbiological defect reduction route

The microbiological defect reduction route is based on the principles of structured problem solving, and is itself an adaptation of the process, suited to improve the results of the FTR Micro BBT indicator. The team that was scheduled to improve the FTR Micro BBT followed this route in order to assure positive results.

5.3.3 – Other quality and TPM tools

There are a lot of auxiliary quality tools that are used by SCC and other companies in the context of TPM to improve the capacity of the company in solving problems, and they are frequently part of the regular route for reduction of defects

LUP (Lição de um ponto) or One-Point Lessons are simple directions to a critical point in a task that requires standardization. It is a small, one point work instruction, so that it is easily comprehended and implemented by the workers. Any worker in a given area can make one LUP for their team, in order to allow for a better share of knowledge between the workforce. This greatly contributes to the increase of the standardization of tasks and helps to spread good practices adopted by everyone. Once approved by the responsible of an area,

LUPs can be placed in the common areas for the workers or near the critical spot they relate to.

The **5 S's system** is the foundation of the TPM pillars in the brewery. It is a Japanese workplace philosophy that is used to maintain the organization and cleanliness of the workplace, while allowing for the standardization of processes and for more efficiency on routine tasks. This philosophy also aims to reduce what it describes as the three M's: Muri, which means overburdening and unreasonability, Mura, which means inconsistency and unevenness and Muda, which means waste. The Five S's stand for the steps in the process:

Seiri (Utilization) that relates to the concept of necessity of use. It selects the material that is necessary for the operation and deals with material that is not necessary for the operation, allocating it to places where it might be more useful or selling it. It also identifies materials that while not strictly necessary might be useful as a preventive measure. This approach also helps to bring attention to the material conditions, while evaluating its necessity, and is essential for a good maintenance and management of resources. It also regards important important issues, as reducing waste, optimizing space occupation and avoiding unnecessary purchases of equipment.

Seiton (Organization) is related to the organization of the workplace, allowing for optimal storage of material and easy access to everything that might be needed for work in a minimum time. Every item used must be in its right place. This practice effectively minimizes the effort that workers must put in their daily tasks. One of the main issues with this practice is that workers may have different preferences in their organization methods. Because of this, this step frequently requires the delimitation of areas for different purposes and the labeling or tagging of equipments, in order to assure that there is a standard for organization in the workplace that everyone can follow.

Seiso (Cleaning) is the step that requires for the cleaning of the workplace. This cleaning is essential in order to reveal problems that could further affect the workplace. A very important factor for this practice is the fact that registration of the cleaning practices is done, in order to guarantee that the conditions idealized are met. This practice also helps the workers in getting a sense of ownership and pride of the workplace. Because of this it also allows for a reduced risk of accidents and an overall better presentation of the workplace.

Seiketsu (Standardization) is the step that defines standards for the cleaning and organization tasks that are required for the 5's system, in order to maintain those conditions. It assures that the first three S's are followed through over and over and periodically, involving the creation procedures for all tasks at hand. A very important point in this part of the philosophy is that the creation of procedures follows a universal standard, so that this standard is the same for every different sector of the organization and can be followed and understood easily by every member of the company.

Shitsuke (Discipline) is the step that is tied to the adoption of good practices in the workplace. The basic premise of this practice is that the worker should follow all the rest of the philosophy through. It requires the employees to follow the procedures by a way of

self-discipline, and allows to achieve better and more trustworthy results. Reporting, evaluating and giving recognition about the results of following the 5 S philosophy is part of this final step of the cycle, and is essential to the motivation and manutention of these good practices.

In SCC, there an extra S added to this philosophy due to its importance, and that is **Safety**.This regards the well-being of employees and the reduction of accidents.

The 5 S's philosophy is commonly represented as a cycle, and should be performed as such, for a continuous improvement of the workplace cleanliness and organization. Figure 5.2 below represents the 5 S Cycle.

The **Kaisen** philosophy comes from the Japanese terms Kai (change) Zen (the best). Its meaning is somewhere close to continuous improvement. It is basically a process of improvement until perfection of a process. It follows a strategical option of low investment and attention to detail in order to achieve a better result. This way Kaisen intertwines with TPM, and there are Kaisen teams formed by workers to achieve cheap, lasting improvements to solve problems.

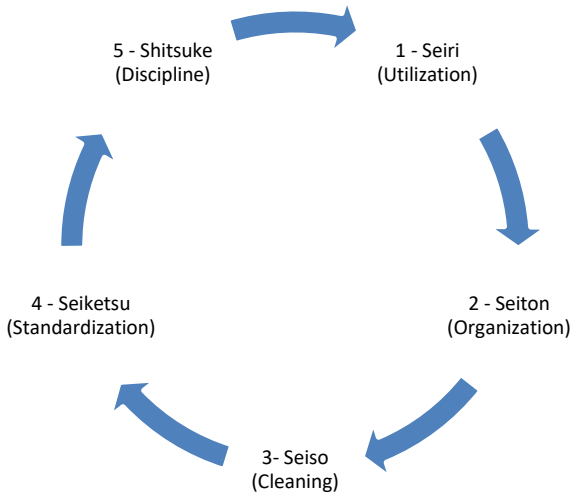

Figure 5.2 - The 5 S's Cycle

The **PDCA and SDCA management** is a management tool that relates to the method that is used for the improvements. PDCA means Plan, Do, Check and Act. SDCA has a similar meaning, but instead of Plan, the S stands for Standardize. These act as two separate loops that can be joined in an infinite loop when working together, as shown in figure 5.3.

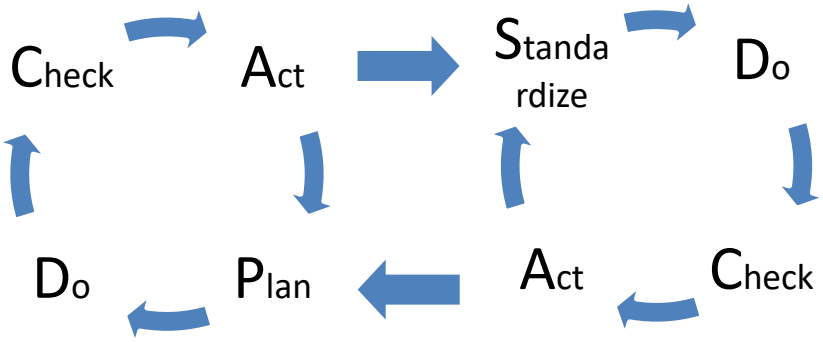

Figure 5.3 - The PDCA/SDCA Cycle

The microbiological defect reduction route followed in this work is closely related to the PDCA cycle, and it can be roughly affirmed that the first three steps (Studying the problem, Checking standard conditions and identifying root causes) are the Plan-related part of the cycle. The fourth step regarding action is correspondent to the do-related part. Likewise, the fifth and sixth steps of the route regard checking and acting, since they deal with evaluating the results of countermeasures and setting new standards.

The SDCA cycle is connected to the PDCA cycle. While the PDCA part of the cycle is comprised of a philosophy for improving the functioning of a process, the SDCA is responsible for the implementation and normalization of the improvements that were previously defined. This makes the SDCA part of the loop more closely related to the monitoring of the process itself, making it effectively a responsibility of the pillars of the company.

The **5 Why's** are a failure analysis method that is based on finding successive causes to a problem. Its main goal is to find the root of the problem, in order to achieve a fitting solution. Associated to the 5 Why's are the **5 M's**, that represent the causes behind the problems detected in the 5 why's analysis. This 5 M's are Material, Method, Manpower, Machine and Measurement. Material is associated with the condition of the materials used in the process, method has to do with the way in which the process is conduced, Manpower addresses human mistakes in the operation of the system, Machine deals with the suitability of the materials used in the process and Measurement has to do with the environment that surrounds the process.

QA (Quality Assurance) Matrix is a quality management tool that helps to quantify the importance of different factors in a given problem. It attributes the cause of a problem to the 5M's that were previously mentioned, consisting of a table where possible causes of failure are registered, checking methods for those hypothesis are reviewed and a final determination of the actual weight of the problem is made.

Ishikawa diagrams are diagrams that show the relation between cause and effect in any given problem. They are shaped like a fish bone, and are often known as fish bone diagrams. They are a very valuable tool for brainstorming while working on an improvement team. They tend to work very well when coupled with the 5 Why's analysis, and a

representation of the 5 M's in an Ishikawa diagram is a very common way of easily depicting the contribution of various causes to a problem.

A **Cleaning, Inspection, Lubrication and Tightening Plan (CILT)** is a document that comprises all of the tasks that are required for the cleaning and maintenance of a certain equipment or section of the factory. It should be readily available for operators of equipment and made in such way that it is of easy reading and comprehension. One of its most important features is the fact that it should include a registry of the activities that it describes, allowing to assure that they are properly completed.

A very relevant fact is that while most of these tools are merely qualitative, there can be slight modification to reach a quantitative result to any analysis. In this work, for instance, the importance of each of the 5 M's attributed to the problems identified in the 5 why's analysis is classified in a scale of 1 to 10, with any problem above 5 being classified as significate and above 8 as highly significate. This allows prioritizing action and determining which factors are more relevant to the problem itself.

5.3 - Beer Quality

5.3.1 - Different types of quality control

As mentioned before in this chapter, a good quality beer must fulfill certain quality requirements. The quality control is divided into three different areas:

- **Physical and Chemical Quality Control**, that assures the product physic and chemical properties are within standard values. Some of the properties analyzed are color, head retention, pH and the concentration of CO_2 and SO_2.
- **Microbiological Quality Control**, that assures the product doesn't have any relevant external contamination that can spoil the beer and/or be a health hazard.
- **Organoleptic Control**, that assures the beer flavor and aroma are up to standard and does so by the use of tasting test with workers trained to detect off-flavors. The changes in flavor detected can also be a good information provider for the other quality control areas.

This work that was developed in the quality department of the brewery was done so in order to achieve a better score on the microbiologic FTR indicator. In order to do so, it is key to understand the role of microbiology in beer quality and how the microbiology quality control works.

5.3.2 - Microbiology Quality Control

The microbiological profile of beer is a key feature in order to study its overall quality. Foreign microorganism can contaminate beer at any given stage during the brewing process. Despite this, beer has several characteristics that reduce the danger of contamination, such as:

- Alcohol concentration of about 5% (v/v), which inhibits microbiological growth.

- The pH is slighty acid.
- High concentration of CO_2
- Low concentration of O_2
- The hops used release some natural anti-microbiotics into the beer.
- The brewer's yeast naturally produces some phenolic compounds that are also anti-microbiologic
- The overall temperature of production is relatively low and that also doesn't allow for growth.

Despite this factors that make it less likely for a contamination to occur it is still possible for a foreign microbiological agent to grow on beer, since it has a high content in sugars and protein. After all, brewing itself is a microbiological process, so it has to be somewhat possible for an organism to grow on beer. The contamination of beer, depending on the microorganism, can produce several unwanted effects, such as:

- A raise of acidity caused by the bacteria's organic acids
- A raise in the alcohol concentration caused by unwanted fermentation
- Unwanted flavors due to various by-products of the microbiological growth
- Excessive hazing of beer and formation of a pelicule at the surface

The microorganisms can contaminate both the beer directly or any of the raw materials used for its production.

5.3.3 - Microbiological contamination types

There are several types of microorganisms that can contaminate beer. They can be categorized several ways. Firstly they can be sorted by **contamination type** [12]**:**

Aerobic Bacteria are gram-negative bacteria that usually grow on beer due to a lack of proper hygiene of the equipments. They belong to a long range of different species, such as *Micrococcus*, *Enterobacter,* among others. While most of these bacterias are not beer spoiling, *Enterobacter* is generally found on the water used in the process and can act as an inhibitor for yeast growth during fermentation, altering thus the composition of the beer.

Lactic Acid Bacteria (LAB) are gram-positive and facultative aerobic organisms, that grow on environments of low oxygen and high Carbon Dioxide concentrations. Such conditions are very common during fermentation, Storage, filtration and storage of beer. The two main species of LAB found on beer are *Lactobacillus* and *Pediococcus*. These bacterias produce great amounts of lactic acid and can spoil beer by raising turbidity, acidity and can also produce unwanted diacetyl, that creates an off flavor on beer.

Anaerobic bacteria are the most damaging microorganisms that can be found "commonly" on beer. They can only grow in the absence of oxygen, and are usually found under biofilms of other bacteria that are formed on the equipments. In order for them to appear there has to be a serious lack of hygienic conditions. They

can alter beer by producing both increased turbidity and acidity and can also produce H_2S, that creates a flavor that resembles rotten eggs.

Yeast is a funghi, and can also be a contaminant on beer. Brewer's yeast is considered a contaminant if it is not totally removed after fermentation. A residual amount of brewer's yeast can be found during Storage, but it should be fully removed during filtration. Besides brewer's yeast, wild yeast can also be a contaminant in beer. Rogue strains of *Saccharomyces cerevisae* and other strains such as *Bretannomyces* are the main type of wild yeasts that appear in beer. They can be responsible for beer spoiling, by creating several phenolic compounds and an excess of alcohol that alters the beer flavor.

Funghi such as F*usarium* and *Aspergillus* can be found on barley. They produce mycotoxins that can be detected even after the whole production of a beer.

There are also other ways to classify contaminations. Regarding the damage they represent to the final product, contaminations can be **indirect**, **potencial** or **effective.** Indirect contaminations consist of microorganisms that won't grow on the product, and therefore are not harmful. Potential contaminations consist of microorganisms that might spoil the beer under certain conditions, but also might not be harmful, such as LAB, that can only be harmful in the absence of oxygen. Finally, effective contaminations are those in which the microorganisms do spoil the beer.

Another possible classification of a contamination is relative to the phase that it occurs in. All contaminations that occur during the brewing process are regarded as **Primary Contaminations.** Likewise, contaminations that occur after the production phase, during filling or bottling of the finished product are refered to as **Secondary Contaminations.**

It is a given fact at this point that contaminations should be avoided, in order to preserve the quality of the product [13]. It is therefore essential to maintain good hygienic conditions during production and to maintain a close monitoring of each step of the production, in order to detect any problem as soon as possible. This can be done by retrieving samples that are analyzed in the microbiology laboratory.

5.3.4 - Microbiology Laboratory

The microbiology lab is where samples of all intermediary phases of the process as well as the final product are searched for contamination.

In order to assure that the methods employed are adequate and the results achieved are reliable, the Company has a program called **Laboratory Star System** (LSS). This program makes yearly audits to the lab to assure that the methods employed are reliable and that the staff has the necessary skills to produce good results. Because of this, SCC has implemented a **Lab Skill Aptitude Test**. Every lab technician must pass this test in order to perform laboratory analysis. New employees must undergo a formation process, supervised by a tutor who was already approved in the test. As Microbiological tests go, the test consist in the retrieval of an aseptic sample from the production, the seeding and incubating of the sample and the correct

count of the number of colonies present in it. The process is done in duplicate by both the tutor and the examinee. In the end the total count of the examinee must be within 10% of the count done by the tutor.

The **Sampling Procedure** should be representative of the actual true conditions of the product being sampled. Especially regarding microbiological samples, it is essential to diminish the influence of outside interference in the sample. Aseptic conditions should be guaranteed at all times..

In order to detect contamination and properly control the various phases of the brewing process, the microbiology lab uses a series of methods to search for the potential contaminating microorganisms. The microorganisms that are searched in each phase of the process and the sample that is taken for analysis are presented in table 1:

Table 1 - Different types of contaminants

Table in Annex B

Through a series of analysis that are described on the methodology section of this document, it is possible to determine if there is a contamination. The analysis methods can be qualitative, quantitative or both. For instance, incorporation in differential culture media makes it possible to identify the type of bacteria present and to determine their concentration. The concentration of microorganism is measured in cfu/ml, or colony founding units per milliliter. The NBB-C test, a liquid culture media made to look for the presence of anaerobic bacteria is a qualitative only test, because it doesn't allow for quantification. Methods like bioluminescence are only quantitative, because they don't actually allow determining the species of microorganism that is present but giving a measurement of the degree of contamination of a surface.

As previously stated, FTR is the main quality KPI, and it also applies to microbiology. Although samples are taken of multiple parts of the process for further troubleshooting, The FTR criterium is only based on the results of the tests on beer, at all of its production phases. The FTR criterium to determine if a sample is within quality standards in the beer filtration stage, in the BBT is represented in table 2, for the contaminations that can occur in beer only, on a per sample basis:

Table 2 - Tolerance limits for contaminations in BBT

Table in Annex B

This being the criterium, any samples that don't meet these standards are considered out of control. Each phase has a FTR indicator for Aerobic microorganisms, anaerobic microorganisms and for Anaerobic Broth microorganisms, which are microorganisms that grow on strictly anaerobic conditions, such as *Pectinatus* and *Megasphaera.* Figure 5.4 represents the structure and weight of each type of contamination to the overall FTR.

Figure in Annex B

Figure 5.4 - FTR Micro Structure

6 - Methodology

6.1 - Microbiology Laboratory Methodology

6.1.1 - Sampling

As previously mentioned, sampling should be aseptic and representative of the product. The recipients in which the samples are taken should be sterilized previously. Sterilization of bottles, cups and other material used is performed on an autoclave at high temperatures and pressures (121ºC and 2-4 bar, for 3 minutes), in order to reduce the risk of contamination as much as possible.

BBT and Kieselguhr Filter samples – These samples are taken from taps into previously sterilized bottles. These samplings must be performed under a flame that was produced by a portable gas torch, in order to exclude outside interference. The bottles must have a cover that allows for the sample to be closed under the flame.

Storage tanks and Trap Filter samples – These samples are taken using sterilized hypodermic syringes. The fact that the sampling process does not involve any kind of external contact makes the use of flame unnecessary.

CO_2 and Air Samples – For these samples a bottle with 200 mL of a NaCl solution (0.9% w/v) is used. This bottle has a cover with two holes with tubes in it, so that one tube is submersed in the solution and the other is not. This bottle should be sterilized before using. A rubber hose is used to connect the submersed tube to the valve that allows to sample the gas. The valve should be open to allow for the gas to pass through the solution, and all the microorganisms that could be in the gas circuit will be retained in the water

6.1.2 - Seeding

The laboratory has a positive pressure room for the seeding of samples that require incubation. The positive pressure makes it less likely that foreign microorganisms enter the room and contaminate the sample, and by doing so making it not representative.

Samples are filtered through a 0.45 µm sterile cellulose membrane (S-PAK® sterile membrane Filter, Millipore Corporation), in a laminar flow chamber. In this chamber the filters are placed into previously sterilized funnels and the samples are poured into this funnels. The flow of the sample through the membranes is helped by a vacuum pump (EZ-Stream™ Pump, Millipore Corporation). After the whole sample went through the membrane, it is removed from the funnel with a sterile tweezers and placed on a petri dish that already has a previously prepared solid differential culture media.

The differential media used are **mWLN (Modified Wallerstein Laboratory Nutrient Agar)** that can detect aerobic microorganisms, **mWLD (Modified Wallerstein Differential Agar)** that detects aerobic microorganisms but restrains the growth of eukaryotic microorganisms such as yeast and other funghi through the addition of cyclohexamide, **Raka-Ray** (Oxoid, CM0777) allows the detection of anaerobic microorganisms and **YMCA** (Yeast and Mould

Copper Agar, Oxoid CM 920**)** detects the growth of wild yeasts by inhibiting brewer's yeast growth with the addition of copper.

A different method is used to search for strictly anaerobic microorganisms. A liquid culture media called **NBB-C** (Döhler, NBB®- Concentrate)is used. 12,5 mL of this media is placed on a 200 mL bottle with a cover. The beer sample fills the bottle then, and the bottle should lose its pressure by closing, shaking and slightly opening the cover to allow gas to escape. All of this process should be done in the presence of a flame to reduce possible foreign contamination.

6.1.3 - Incubation

This is the step that creates conditions that allow for the growth of the microorganisms in the samples. The petri dishes and NBB-C Bottles are place into Laboratory Ovens with controlled temperature, to allow optimal growth. For mWLN and mWLD, the samples are incubated by 3 days at 30ºC ± 1ºC. YMCA is incubated for 3 days at 26ºC ± 1ºC. The NBB-C Bottles are incubated for 11 days at 30ºC ± 1ºC and the Raka-Ray samples are incubated for 5 days at 30ºC ± 1ºC.

6.1.4 - Analysis/Observation

After incubation, samples must be analyzed in order to determine which and how many colonies of microorganisms were found. For the identification of aerobic microorganisms, mWLN and mWLD samples are searched for colonies. The first step in identification is observing the colonies with bare eyes. Yeast colonies will be white and opaque while bacteria colonies are either transparent or blue due to the absorption of the media, but present some brightness. The following step is to observe the culture on the microscope (400x) and identify the morphology of the colony. Aerobic Bacteria is very small compared to yeast, and the morphology of the yeast determines its type: spherical organisms correspond to brewer's yeast and rod-shaped organisms are likely wild yeast.

To detect LAB Raka-Ray is analyzed. Every colony is subjected to the catalase test. If the test is positive, they are anaerobic bacteria but not LAB. If the catalase test is negative, a gram coloration must be performed, and if the organisms are gram positive and catalase negative, they are indeed LAB. Besides these tests, the microscopic observation of the colonies is also important: rod shaped LAB are *Lactobacillus sp.*, while spherical LAB are *Pediococcus sp.*

To search for strictly anaerobic organisms like *Megasphera* and *Pectinatus,* the NBB-C bottles must be analyzed. If there is turbidity on the bottle or formation of a sediment on the bottom, a small sample of the bottle must be taken using a sterile pipette. A gram coloration must be performed. If the microorganisms found are gram positive, they are *Lactobacillus sp.*or *Pediococcus sp.*. If they are gram negative they can be *Megasphera* or *Pectinatus.*

6.1.5 - Gram Coloration

To perform a Gram coloration a sample of the colony should be dissolve into a drop of sterile distilled water in a microscope slide. The slide is then rested on a heating plate for the water to dissolve, immobilizing the sample. When dry, the sample is subjected to a sequence

of stainings with different solutions: First a Crystal Violet solution (BD Difco™, Gram Crystal Violet, 212525) for a minute, then a iodine stabilizer (BD Difco™, Gram Iodine, 212542) for another minute, a decolorizer (BD Difco™ ,Gram Decolorizer,212527) just for removal of excessive coloration and finally Safranin (BD Difco™, Gram Safranin, 212531) for 30 seconds. In between each of these steps the slide must be washed with water. The slide is then ready for observation. Gram-Positive organisms will be coloured blue or violet and Gram-Negative organisms will be coloured pink or red.

6.1.6 - Catalase Test

This is a very simple test: a colony should be dissolved in a solution of H_2O_2 (3% v/v). This solution reacts with Catalase and produces oxygen, which will manifest bubbles if the organisms are Catalase positive.

6.1.7 - Bioluminescence

This analysis allows to perform a quick analysis to the amount of organic matter that exists on a surface. To apply this technique, a scrub and a specific solution in a tube are used (3M™, Clean-Trace™ Surface ATP UXL100). The scrub is passed on a surface and then put in the tube, which is shaken and put in an illuminometer. The solution in the tube contains an enzyme called Luciferase that reacts with ATP and emits light as a result. The amount of light is measured by the illuminometer in RLUs (Relative Light Units) and is proportional to the amount of organic matter on that surface.

7 - Experimental Work – Improvement Team

An improvement team was assigned by the Quality Pillar in order to improve the FTR Micro BBT, which was presenting unusually bad results. The team was expected to improve the results in this area, allowing for a better overall microbiology FTR score. As previously said, the TPM route for reduction of microbiologic defects was followed during this work. It is important to note that the route was not fully completed by the team. The last step of the route, regarding the improving of the quality system to accommodate the changes that were made can only be considered complete if the improvements that were proposed can sustain consistent results over a long period of time.

A very important part of this team's work is the fact that it was highly based on the work of a previous team for the reduction of microbiological defects in beer filtration that took place in 2013. A lot of the problems that the team identified were still unresolved issues already found by this previous team [1].

7.1 - Team Composition and Activity planning

Firstly a team should be assigned to perform the route's tasks. It should be a multidisciplinary team, with members of different areas of the factory giving contribute in order to achieve better results. The team composition is represented in table 3.

After the team was assembled, a Masterplan was developed in order to plan the activities that had to be done during the team's operation. The plan went as is depicted in Figure 7.1.

Table 3 - FTR Micro BBT Team Composition

Job	Team Function
Microbiology and Sensorial Quality Manager	Team Sponsor, facilitating the communication between different areas, Auditing the team and analyzing results
Lab Technician	Team Leader, Planning and scheduling of actions & experiments
Brewing Tecnologist	Interface with the production, Planning and scheduling of actions, Data Collection
Lab Technician	Laboratorial support, Sample Collection
Filtration Team Leader	Realization of experiments, Interface with the production, LUPs
Filtration Operator	Support on the production floor, LUPs
Maintenance Specialist	Technical support
Intern (Quality)	Overseeing all of the team tasks and giving support to all of the team's work

Figure in Annex C

Figure 7.1 - Masterplan for the team's activies

The masterplan was detailed week by week, throughout 2016. The blue squares represent the planned window of time in which events should take place and the green ones shows the weeks in which each step was actually carried out.

During the first week there was no activity done regarding the team because it was still going through the planning phase, and some team members were receiving training and formation on how to work within the company.

After that, the execution of the plan followed the actual plan very closely, with the notable exception of an improvement intervention that was already planned to be carried out before the team started its work on week 9.

Step 1 – Identifying the origin of the defects

The first step of the route is mainly based on the collection of data that can help in finding problems.

1.1 – Assuring the results are reliable

The first task that should be taken care of is to assure the reliability of the results obtained by the laboratory. The first thing that should be noted about this is that the laboratory itself has a number of yearly audits and certifications.

The company's Laboratory Star System certified the lab with one star due to the quality of the analytical methods employed. The lab is frequently audited internally too, assuring a series of parameters are up to standard, such as: the skill of the staff; the continuous improvement of the processes; the identification, tagging and use of properly calibrated equipments; the logistics of sampling, making it adequate for the process; Documental & Archive control, among others.

It is also worth noting that the company conducts bimestral interlaboratory tests called **Heineken Microbiological Ring Tests** (HMRA). In this tests two samples are sent to the lab in order to be analyzed. The lab must identify which (if any) microorganisms are present in the sample, and must also determine the concentration of such microorganisms. A score between 0 and 100% is given to the lab regarding the responses it gives. The lab had a perfect score during the team's window of activity, which indicates a high level of reliability.

In order to further assure that the lab can provide reliable data for the team it is necessary to perform an audit to the laboratory. Although the laboratory fulfills the requirements of the company's Laboratory Star System and being certified as so, the company provides a checklist for improvement teams to use in this cases, and the team did so.

1.2 – Analyzing the history of results

1.2.1 – FTR Micro BBT study by different factors

The analysis of FTR micro BBT from previous years is key to understand how the indicator performs and if there are significant alterations to the regular behavior of the indicator. This is the overall FTR Micro BBT indicator score over the last 5 years. All of the basic data was retrieved from SAP's registry of results. Figure 7.2 is a graphic depicting these values.

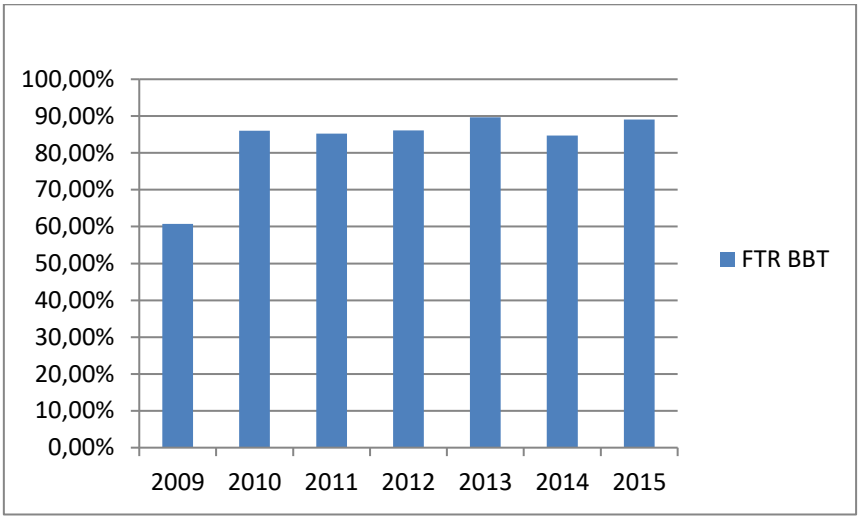

Figure 7.2 - Micro FTR BBT value by year

We can see that after 2009, when the results were far from satisfying, the indicator remains steadily above 85%, peaking in 2013 with a value of 90%. This is likely due to the fact that the last improvement team that was focused on the FTR Micro BBT was held during that year.

It is also very important to separate the data in order to show the results of different types of contamination. The following Figures 7.3, 7.4 and 7.5 show the 5-year results, but for the different types of contamination:

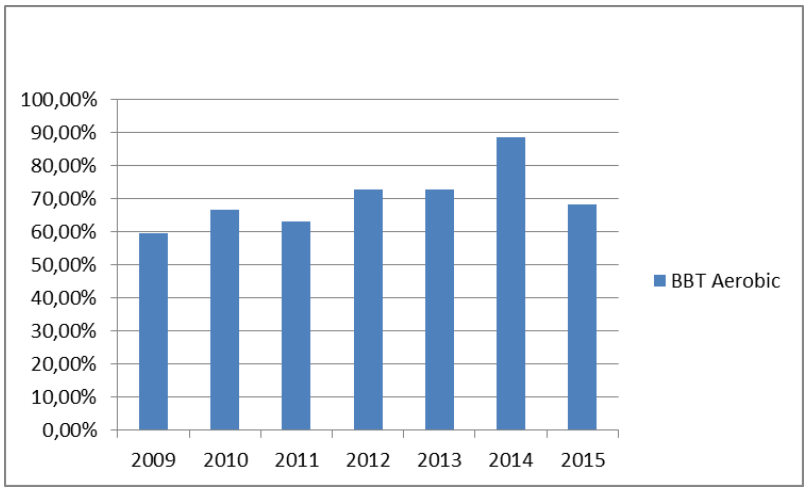

Figure 7.3 - Micro FTR BBT Aerobic value by year

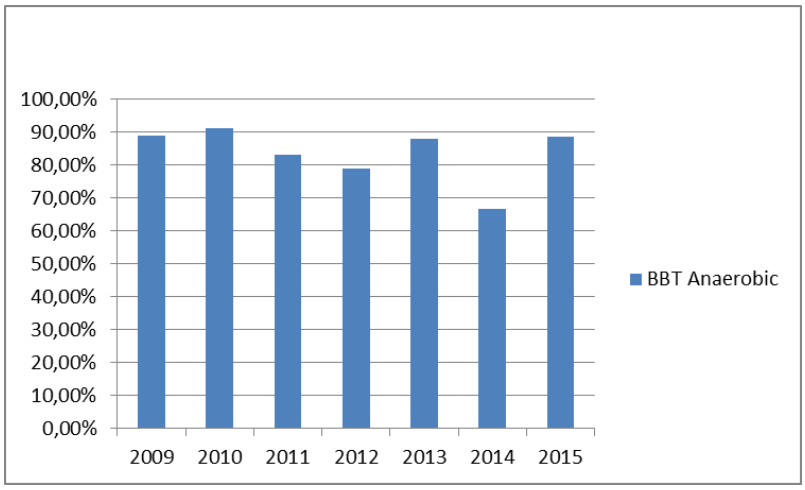

Figure 7.4 - FTR Micro BBT Anaerobic value by year

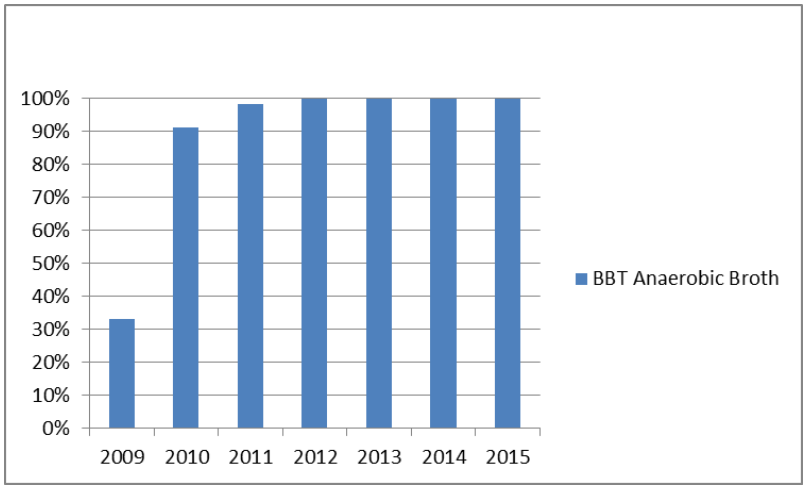

Figure 7.5 - FTR Micro BBT Anaerobic Broth value by year

As shown in the graphics, there hasn't been any strictly anaerobic bacteria found since 2011, which is a great accomplishment regarding the fulfilling the basic conditions of hygiene in the filtration facilities, since these types of microorganism only appear in case of severe problems. Aerobic contamination is the most prominent type of contamination, and these are generally regarded as a hygiene indicator. Taking both these factors in account, it is safe to say that although there is a good basic level of hygiene, the conditions aren't perfect and there may be room for some improvement. Finally the Anaerobic FTR, which represents the LAB, is shown to vary a lot between years, and there isn't a pattern that can be traced regarding it's behavior.

After analyzing a 5 year span, it's important to take a closer look at the results of the year that occured before the start of the team. Given so, the results over the year of 2015 and the relation between the FTR Micro BBT and the rest of the FTR Micro indicators are shown in figure 7.6:

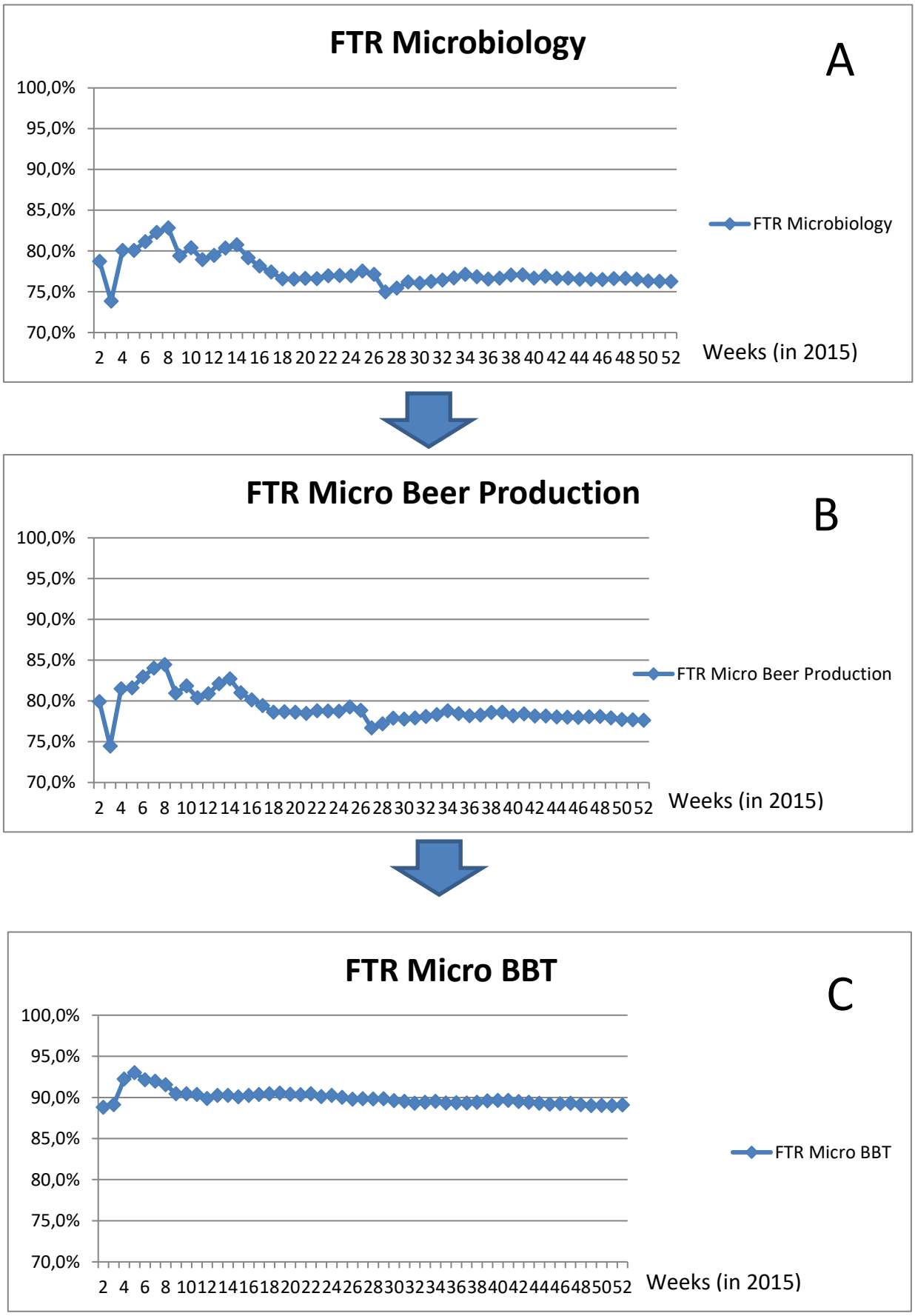

Figure 7.6 – Structure of FTR Micro Results for related KPI's for 2015. A is the the FTR Microbiology, which includes B, that is FTR Micro Beer Production. C, the FTR Micro BBT is also included in B

One of the things that can be concluded by the examination of these graphics is that overall the FTR Micro BBT is one of the factors that has a more positive contribution to the overall FTR Micro, being that there are way more severe fluctuations that were not caused by variation of the FTR Micro BBT.

After analyzing the KPI itself during 2015, it is possible to break down this indicator by product type and by BBT, in order to understand if there are any fundamental differences between products or BBT. These differences are shown in figure 7.7.

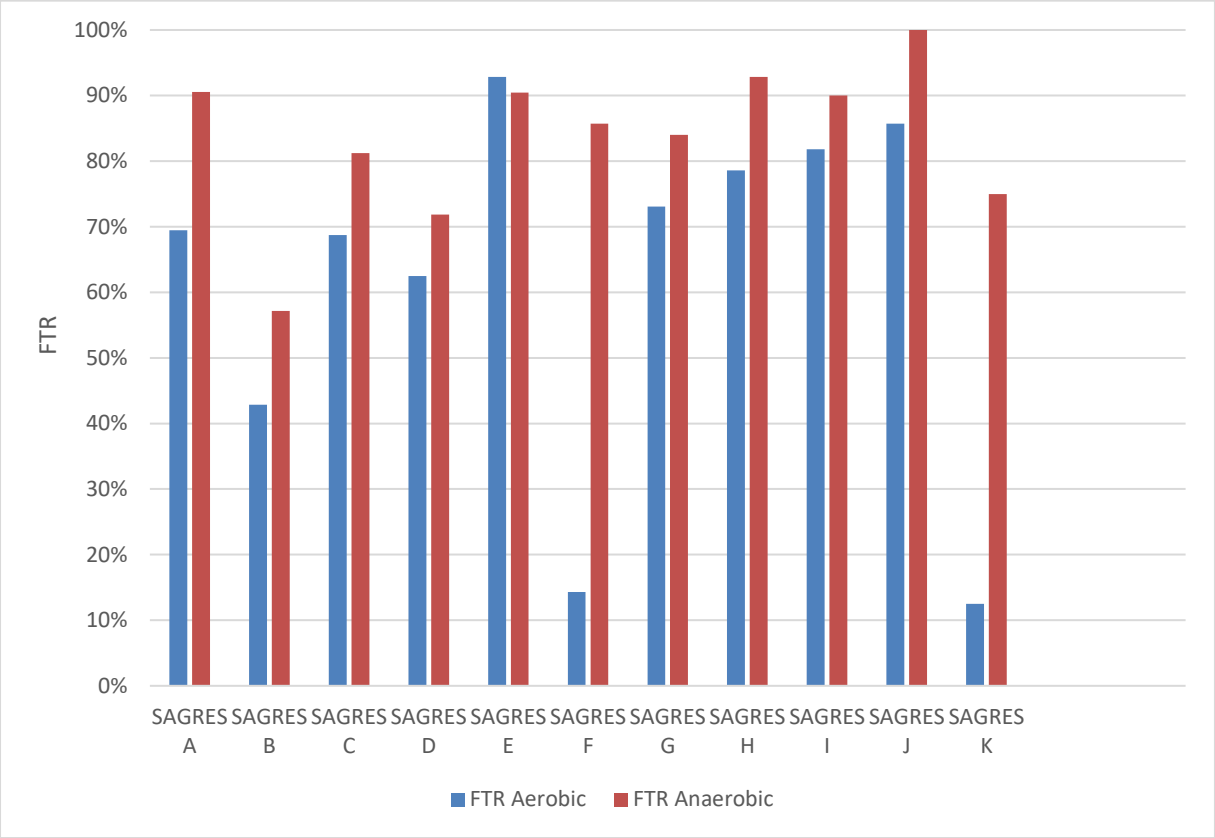

Figure 7.7 - FTR Micro BBT value in 2015 by type of product

Although sample sizes vary greatly, one conclusion can be reached: the two lowest scoring products are non-alcoholic beers. Being known that alcohol is an inhibitor of microbiological growth, these results are somewhat expectable. However, since there are some differences in the process of producing non-alcoholic beer, namely the addition of Hop Extract, the additive injection system becomes a key point to be analyzed further in the team's work.

There is however a notable exception: Radler Beers are either non-alcoholic or present a lower alcohol concentration, yet they perform exceptionally well[1]. This can be attributed to a series of factors, namely the increased acidity that the addition of a fruit compound brings to the product. The fact that the beer used in their production has to be filtered beforehand also

requires that it is filtered and stored before mixed. Being that most contaminants are aerobic bacteria, and the storage occurs at a very low concentration of oxygen, the extra-time of storage the beer spends might allow for some of the microorganisms to be eliminated by the lack of oxygen. Lastly this might also has to do with a laboratorial limitation: Due to its increased viscosity, Radler Beer tends to cause fouling (the accumulation of suspended particles) of the membrane used on the filtration of the sample, thus not allowing for the sample to be properly filtered. For these reason, instead of filtering 100 ml of sample only 10 ml are filtered in order to allow for a regular filtration. The results of the counting of microorganisms are then multiplied by 10, in order to remain comparable to regular samples so that the concentration unit used is cfu/100 ml. Although the results are scaled to make sense, the reduced amount of sample can be less representative of the final product.

Regarding the tanks used, the most noticeable pattern was that tanks that had the same size present similar results. The table presented beforehand groups the BBTs by their size, and allows for the conclusion that bigger tanks tend to present better results than the smaller ones. BBT 9 is an exception, given it is the smallest tank and is very rarely used comparing to the rest. These results are depicted in figure 7.8.

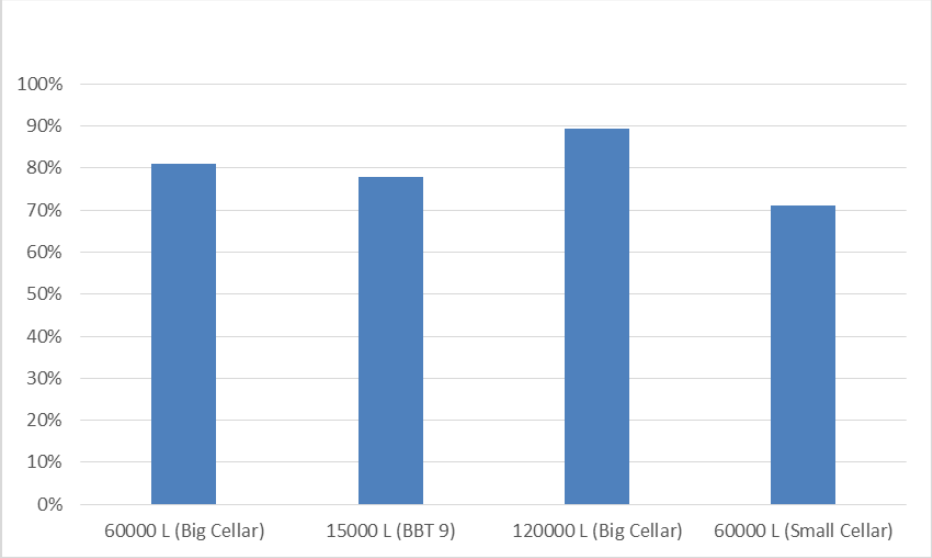

Figure 7.8 - FTR Micro BBT by Tank Size in 2015

The fact that bigger tanks have better results can be due to several reasons. A larger volume can accommodate the same amount of contaminants as a smaller tank, but would have a much smaller concentration. Also the smaller tanks are usually used for special beers, like Bohemia, Imperial or Cergal. These beers tend to have higher tendency to present contamination and being more stored in these tanks, it is predictable that the results will be worse.

1.2.2 – Study of the influence of previous phases on FTR Micro BBT

Other very important factor that can be studied by the analysis of previous results is the influence of previous contamination on earlier production stages. In order to quantify this, a study was made crossing the data from the step before filtration, the storage phase, and comparing it to the filtration's stage results. Since the sampling process is random and only a

fraction of both the BBT and the storage tanks are sampled, a comparison of the values of FTR Micro BBT And FTR Micro Storage alone wouldn't allow to fully understand the relationship between both indicators. So that made it necessary to check the origin storage tank of each BBT. Figure 7.9 shows the origins of contamination during 2015.

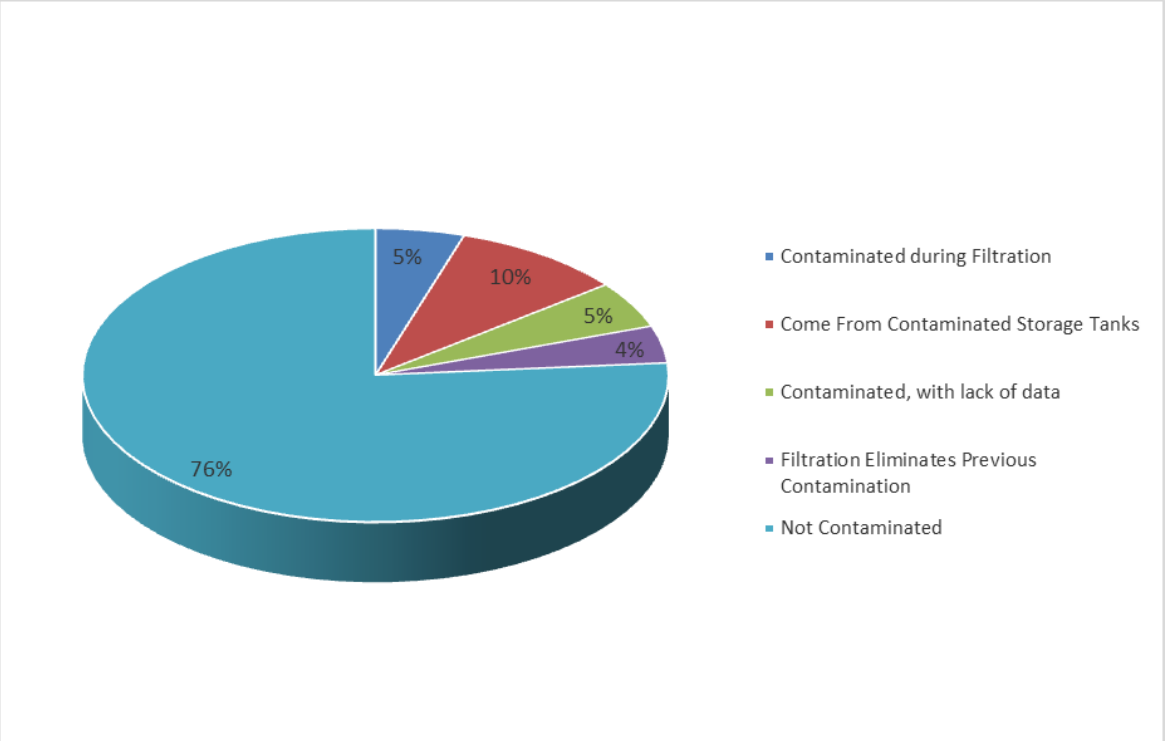

Figure 7.9 - Origin of contamination of BBT Samples during 2015

Only the data from Aerobic and Anaerobic FTR Micro indicators was used, since the Anaerobic Broth FTR Micro indicator never shows any contamination. This explains why the results don't add up to the actual value of FTR that is presented previously for the year of 2015.

So the first thing that is worth noting from figure 7.9 is that the actual percentage of contaminated samples is 20% , and from the samples that were not contaminated there is a small percentage (4%) that corresponds to the filtration eliminating contaminations that existed in the storage tanks. This is an expected effect of the filtration that this data allows to quantify. Figure 7.10 shows the origin of contaminations during 2015

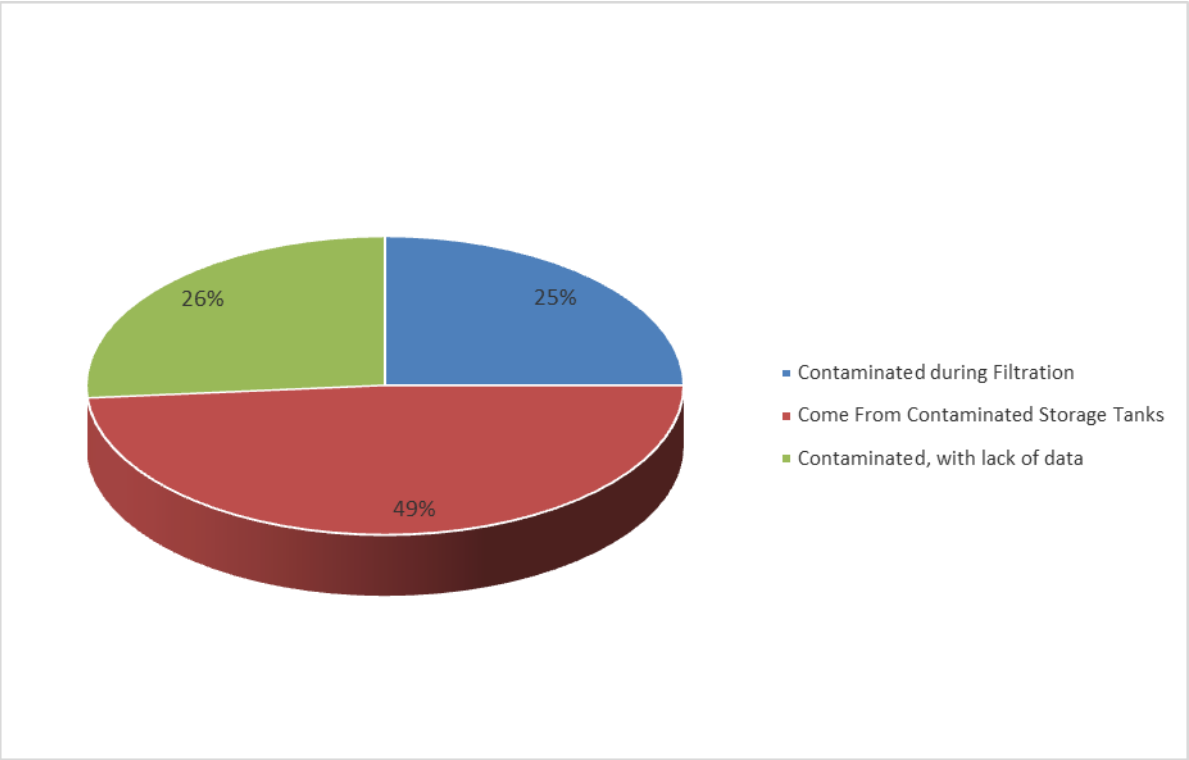

Figure 7.10 - BBT Contamination Sources during 2015

However, inside the 20% of the samples that presented contamination, about a quarter of the samples (25%) presented contamination only in filtration, which clearly indicates that there can be no previous influence on that fraction of the results. While 26% of the samples from BBTs lacked data that could determine in which storage tank they were held, nearly half (49%) came from previously contaminated tanks.

Although a quick analysis of this data would allow to conclude that nearly half of the contaminations can be originated in previous phases, the reduction effect that filtration has on contamination doesn't allow to jump to that conclusion. While it is possible that the contamination was already present, nothing assures that it wasn't removed during the filtration and then contaminated again during the transference to the BBTs.

1.3 - Preliminary QA matrix

The following step on the reduction of defects route was the execution of a preliminary QA matrix (as described in the TPM chapter of this work). This matrix should include the possible sources of contamination in order to facilitate the identification of the key points that will be studied by the team. This matrix was based on the matrix done by the 2013 improvement team [1]. From that data it was possible to conclude that the major critic point in the process was the beer recovery circuit and the BBT where the recovery beer rests (BBT 6)

1.4 – Data Registry Systems

In order to properly register the rehearsals made during the team's work, a series of different forms had to be used to accommodate the information gathered.

The most used form was the Lab's standard Extra-Routine registry. The daily control samples are registered in a different form, where it is only possible to register BBT and Trap Filter Samples. The Extra Routine form allows the identification of each individual sample, thus making it ideal for an investigation work, where multiple different samples must be taken.

Besides the extra routine form, other forms were designed for specific rehearsals. These forms allowed for a different organization of information, so that the most relevant characteristics of the samples that were taken can be highlighted and its study simplified.

Step 2 – Restoring the standard conditions of operation

The second step of the route focuses on assuring that every step of the process is done according to the standard procedure, and to determine if the equipment or the process itself is adequate and not causing problems.

2.1 – Initial Cleaning

In order to unveil problems that might have been covered by the deterioration of the equipment or dirt, a Total Cleanout was performed on 19/2/2016. In order to perform a deeper cleaning it was performed on a Friday, extending the usual weekend production pause for maintenance, so that the functioning of the equipment is not disturbed by the cleaning procedure. Some before and after pictures were taken and are shown in figures 7.11 and 7.12.

Figure in Annex C

Figure 7.11 - UV filter before and after TCO

Figure in Annex C

Figure 7.12 - Manifold before and after TCO

After the cleaning the operation returned to normal and the facilities were inspected in order to determine if there are any significant problems hidden by dirt.

2.2 – Identification of possible critical points

After the cleaning, the team proceeded to identify points that could be a possible source of microbiological contamination. These points are generally places where due to a lack of hygienic design or malfunctioning of the process, the conditions required for a microbiological contamination to occur are met.

Some of these critical spots were already previously identified by the 2013 improvement team. Those points are as follows:

Beer Recovery Circuit design: The design of the beer recovery system doesn't allow for it to be emptied between each recovered batch of beer. This causes an accumulation of beer that is prone to microbiological contamination, as the circuit cannot be properly cleaned.

Valve System in the Recovery System: The valves that are responsible for the injection of recovered beer into the filters create a dead leg in the system. Besides that, the automation of the valves is such that the CIP cycles through one valve and the recuperated beer cycles through the other, making it impossible to obtain an efficient CIP of the system. This problem is depicted in figure 7.13.

Cleaning of the recovery system: The CIP of the beer recovery system is not performed in a single step. Since there are 3 filtration lines, the beer that is sent to be recovered can come from any of them, and although Lines 2 and 3 are cleaned together, Line 1 can only be cleaned by itself. This feature wouldn't carry out any problem, but the vertical design of the final part of the system can cause accumulation of product in line 1during the cleaning of lines 2 and 3, and the same critic is valid for the opposite process. Figure 7.14 shows this.

Figure in Annex C

Figure 7.13 - Redundant Valves in the Recovered Beer Injection. Source: Teixeira, B., Melhoria do sistema de gestão da qualidade microbiológica da Filtração de cerveja.

Figure in Annex C

Figure 7.14 - Accumulation Spot on a Panel. Source: Teixeira, B., Melhoria do sistema de gestão da qualidade microbiológica da Filtração de cerveja.

Besides these problems that remained unresolved since 2013, other possible contamination spots were identified:

Tanks for the cleaning of parts: The tanks used for the cleaning of parts have no registry and control over the changing of the water and detergent used to clean the parts. Besides, the tank in the small cellar that is used to store parts used in the weekly CIP process is frequently not filled with water to clean the parts.

Possible dead spot on the BBTs: Obsolete temperature probes were found on the BBTs. It was not known if the removal of these probes could have resulted in a spot of product accumulation. This was found not be a problem, since after examination the removal of the probes was done correctly as can be seen in Figure 7.15.

Figure in Annex C

Figure 7.15 - Probe removal spot from the inside and outside of a BBT

Open doors and bad level meter design of the kieselguhr tanks: The tanks that inject kieselguhr into the filters are not properly isolated. The doors that cover them are left open very often to reduce the amount of labour that goes into pouring the kieselguhr in. This creates a possible spot of microbiological contamination. Besides this, the level meter is designed so that it cannot be closed, thus leaving the surface of the meter open to the outside, which is also a possible contamination source. Figure 7.16 highlits this problem.

Figure in Annex C

Figure 7.16 - Kieselguhr mix tank level meter

CIP Tanks: The CIP central top doors are frequently open, due to a problem in the high level alarm for the control system of the tanks. This causes the tanks to overflow and may create danger for those working near the CIP, besides the obvious waste of water and cleaning products. There is also a dead leg can compromise the efficiency of the cleaning process. This dead leg is represented in figure 7.17, and the CIP Tank Doors can be seen open in figure 7.18.

Injection of additives: Given the poorer results in non-alcoholic beers and since the injection of additives section is almost only used for these products, it was suspected it could be a possible point of contamination. The examination of samples taken allowed to conclude that there was no evidence of constant contamination there.

Previous Contamination: Although not exactly a point, contaminations that occur prior to the filtration stage are also likely to affect the filtration stage microbiologic quality, and the extensions of such contributions were previously stated in the analysis of past results part of this work.

Figure in Annex C

Figure 7.17 - Dead Leg in a CIP Tank

Figure in Annex C

Figure 7.18 - Open CIP Tank

Step 3 – Identification of root causes for constant contamination problems

In this third step of the route the critical points previously identified were analyzed in order to reveal if they were indeed sources of contamination.

3.1 – Identification of contamination sources

In order to identify contamination sources samples were taken by the team and analyzed in multiple instances of the filtration process. The goal of this analysis was to validate the different parts of the process and determine if the contamination was recurring in the spots where it was expected to be. The results of those different analyses are now presented.

3.1.1 - Validation of the filter sterilization

Six samples of the last cleaning water of the sterilization of the filters at the end of a filtration cycles were taken, both at the Kieselguhr and the trap filters. These samples were conducted from March 8th to April 19th. The samples were analyzed for Aerobic and Anaerobic microorganisms, and the results of this analysis are shown in figure 7.19 below:

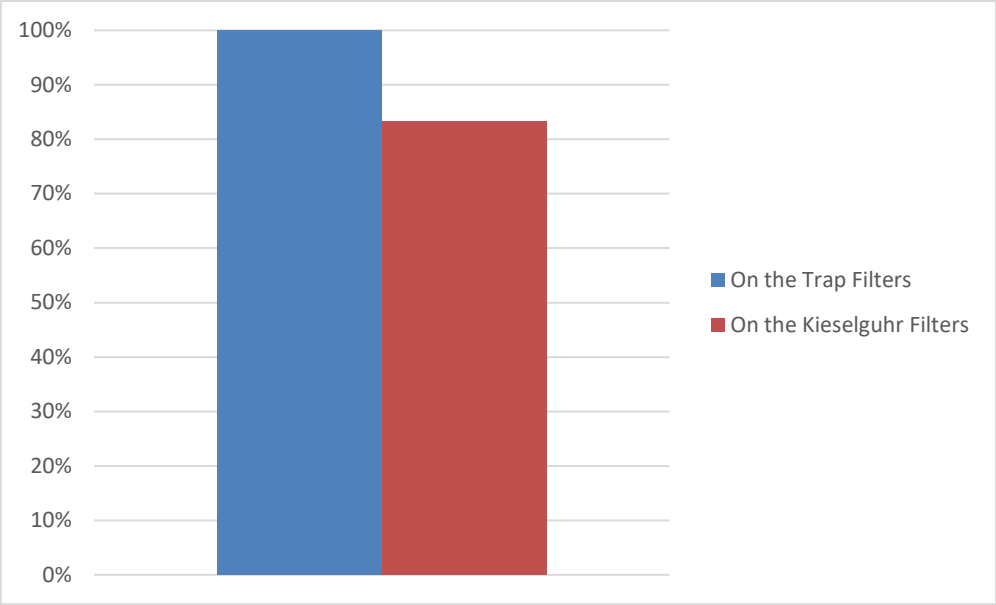

Figure 7.18 - Percentage of non-contaminated filter sterilization samples

Although some samples were contaminated on the Kieselguhr filters, all of the samples taken from the Trap filters presented no signs of contamination. Given that the Trap filters are placed after the Kieselguhr filters, it is safe to assume that they are responsible for a certain degree of microbiological contamination reduction. And since the Trap filters are always contamination free, the sterilization process is considered to be adequate.

3.1.2 - BBT CIP Validation

During a larger period of time (from March 3rd until June 26th) a larger amount of samples were taken in order to validate the CIP of the BBT. 45 samples of the final cleaning water of the BBT after the CIP occurred were taken, as well as 35 samples of the beer that filled the BBT after cleaning. This samples allows to study both the efficiency of the cleaning process and itself and its relevance to the microbiological quality of the beer. Both aerobic and anaerobic analysis were made, and in order to compare the results obtained to the previous results from the FTR indicator, a "General FTR" was calculated for this data, by assuming that no strictly anaerobic organism was found. This makes the value comparable to the results of FTR in other years and is plausible, because as stated previously, there haven't been cases of these contaminations for several years. The results are presented in tables 4 and 5 below:

Table 4 - CIP Analysis Results

CIP Water Samples						
Aerobic			Anaerobic			"General FTR"
Sample nr.	Contaminations	FTR	Sample nr.	Contaminations	FTR	
45	14	68,89%	45	2	95,56%	88,15%

Table 5 - Beer After CIP Analysis Results

Beer after CIP Samples						
Aerobic			Anaerobic			"General FTR"
Sample nr.	Contaminations	FTR	Sample nr.	Contaminations	FTR	
35	15	57,14%	35	4	88,57%	81,90%

For comparison purposes, the 35 samples where both the water from the CIP and the beer were both taken were compared. In order to achieve a measureable value for the correlation of both, a simple conditional probability was calculated by the formula below:

$$P(A \mid B) = \frac{P(A \cap B)}{P(B)}$$

In this Equation, P(A) is the probability of the beer being contaminated, P(B) is the the probability of the water being contaminated and $P(A \cap B)$ is the probability of both being contaminated. So $P(A|B)$ is the probability of the beer being contaminated if the water from the CIP is contaminated. This allows estimating the influence of the CIP of the BBTs on the microbiological quality of beer. The result from the calculation is shown below:

$$P(A|B) = 81{,}82\,\%$$

Given the high probability of this occurrence, it is safe to say that the cleaning process is vital to the microbiological quality of the beer, thus making the CIP of the BBT a definitive critical spot that needs improvement in order to enhance the final quality of the product.

Besides using these values to measure the influence of the cleaning process and determine whether the KPI was up to standard, the monitoring of this indicator over time allows for the detection of problems. This is exemplified in figure 7.20, which compares the "General FTR" that was being followed, both before and after April 26th.

The difference of results highlighted by the graphic allowed for the detection of a problem with the CIP process, namely on the Central CIP tanks, as was previously stated in the critical point identification.

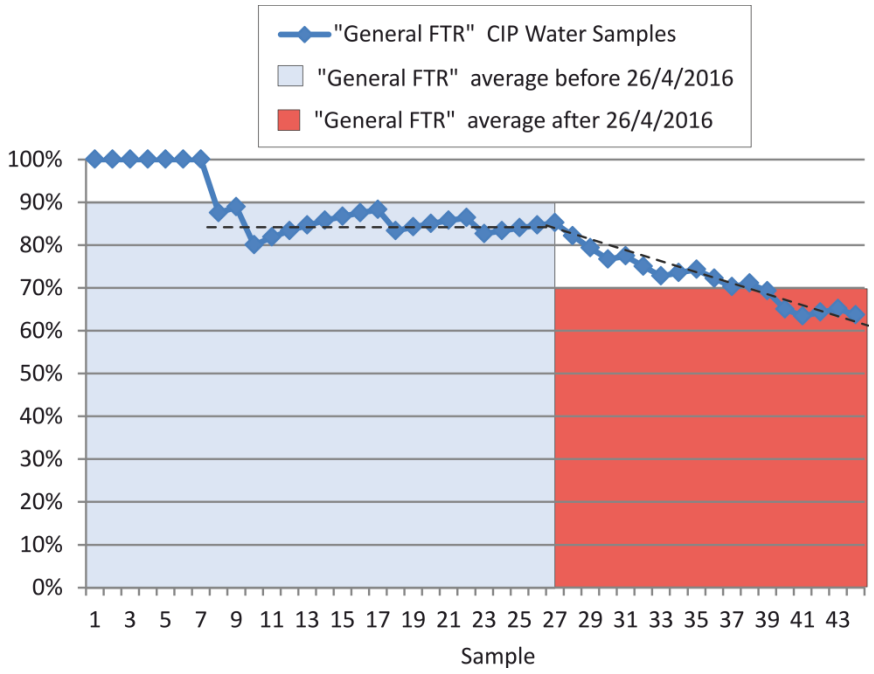

Figure 7.19 - General FTR CIP Water Samples from 3/3/2016 to 21/6/2016

***3.1.3 - Recovery Beer Process Analysis*:** A trajectory analysis was made on the recovery system of beer. 4 full trajectory analysys Samples were taken and analyzed for aerobic and anaerobic microorganisms. The analysis process consisted on retrieving these samples both before and after the injection of the recovery beer. This allows determining the impact of this process. 3 full process analyses were made, and figure 7.21 summarizes the layout of the beer recovery system and the results obtained on the various phases of the process.

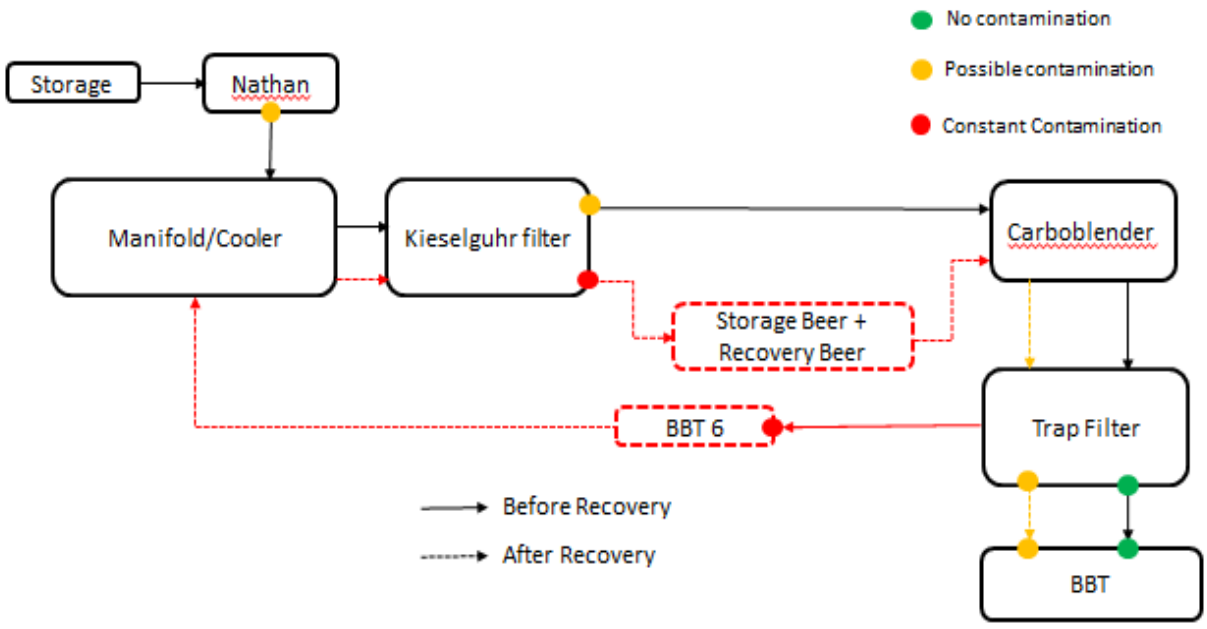

Figure 7.20 - Layout and results of the beer recovery samples

Looking at figure 7.21, it is easy to conclude that the system of recovery presents a serious problem, because it will always inject contaminated beer into the filter. Despite this, the filtration process is also capable of somewhat removing the contamination on the beer, given that the beer contaminations in the BBT after injection is not permanent.

Parallel to this analysis, since the recovery beer seems to be a source of contamination, an analysis of the recovery BBT (BBT 6) while being filled was followed through. On a given day, the recovered beer injection was made at 9:00h, the tank was then cleaned and the beer from the starting of a filter run started being recovered immediately after that. Samples were taken for two days, one in the morning and one in the afternoon, after each new filtration cycle starts and new recovered beers gets into the tank. Figure 7.22 shows the petri dishes where the samples were taken

Figure in Annex C

Figure 7.21 - Petri Dishes of the beer recovery samples, taken consecutively. Dish 1 – Day 1, 11:00h; Dish 2 – Day 1, 16:30h; Dish 3 – Day 2, 10:30h; Dish 4 – Day 2, 16:30h

It is very clearly visible that there is contamination from the begging of the recovery process and that the level of contamination keeps increasing. Besides this, the efficiency of the tank's cleaning process was already proven by the analysis of the CIP of the BBTs. This clearly indicates that the lack of possibility of emptying the pipes that lead to the recovery tank is creating a contamination, and this is a major contamination point.

3.2 – 5 Why's and 5 M's analysis

After the preliminary analysis, 5 Why's analysis were performed in order to help identify the root cause of problems and to determine possible solutions. Apart from this analysis, there were also other quality tools that were used in order to further understand the problems and come up with better solutions, such as the 5M's, that allows to quantize the amount of influence of various factors in the problem.

Three different 5 why's analysis were conducted, for the three biggest problems identified. The first two were part of the team's plan and were already signalized as contamination sources, being the Beer Recovery System Contaminations and the CIP tanks Contaminations. The latter was performed due to an unusual recurring contamination that occurred in the month of July, a Trap Filter Contamination.

3.2.1 - Beer Recovery System Contaminations 5 Why's

The main question was "why is there contamination in the recovery beer?" . The possible explanations for this were (Figure 7.23):

a) Previous beer contamination: This was proven only somewhat relevant previously.

b) Auxiliary parts contamination: The curves and pipes that are used on the panels are properly placed in the disinfection tank, which makes it unlikely for this to be a source of contamination. Although they don't present signs of contamination, it was found that there is not a proper register of the renewal of the cleaning solution, which may lead to contamination if the operators somehow forget to change it.
c) De-aerated water contamination: The routine analysis for the water used on this process don't reveal any possible contamination
d) CIP contamination: Although CIP is proven to be effective by the analysis performed to assure its validation, CIP frequency is an issue. This is due to the impossibility of emptying both the circuit that transports the beer to the recovery BBT and the circuit that injects the recovered beer into the manifold. These circuits are closed and so they accumulate beer in the pipes, which stagnates and is prone to contamination. The design of the circuit only allows for it to be cleaned when there is no filtration occurring, which means the circuits are only cleaned once a week.
e) Improper CIP procedures contamination: It was also noticed that there was a lack of uniformity in the way that the operators performed the CIP of the Beer recovery circuit. This was actually due to a problem with the method that was previously established, which required at some point that there was only to be a valve between the recovered beer tank and the cleaning product. This creates the danger that if the valve somehow fails the recovered beer will be in contact with Trimeta-Duo, thus being improper to be recovered.

3.2.2 - CIP tanks Contamination 5 Why's

The main question was "Why is there contamination on the CIP tanks?". The possible explanations found were (Figure 2.24):

a) Water contamination: There was no evidence that the water used on the preparation of the CIP solution is contaminated.
b) CIP product contamination: The product used in the CIP Solutions, Trimeta-Duo, is a disinfectant and is certified by the suppliers as free of contamination.
c) Leaking Pipes: The pipes on the CIP central presented small leaks on the solder joints. This makes the pipes susceptible to outside contamination. Since the leaks are very small there is no danger of compromising the overall CIP efficiency due to a pressure drop in the pipes
d) Dead Leg after the CIP pump: There is a significant dead leg after the CIP pump. It was primarily designed to install a second CIP pump, but since this never went through this segment of the circuit became an accumulation spot.
CIP tank doors open: The top doors of the CIP tanks were found open at several times. Further investigation revealed a combination of two problems. First, a malfunctioning condutivimeter, whose readings control the dilution of the CIP product, by regulating the amount of water and product used. This misreading dysregulated the amount of water and product that was sent into the tank. Then there was a breakdown of the

high-level meter, which was set to stop the entrance of water and product into the tank once it reached its full capacity. This made it possible for the tank to overflow, and so open the doors on the top of the tank, and therefore making it susceptible to outside dirt and contaminations. It is also worth noting that this occurs because of the bad design of the tank's doors, that allow them to be exposed to the outside.

3.2.3 – Trap Filter Contamination 5 Why's

This analysis was performed in order to identify the source of an unusual contamination that appeared during the month of July. Contaminations in the trap filter are not normal, and were never detected in past years before this occurrence. Unlike the CIP and the recovered beer problems, that have a restricted effect on the outcome of the product, this contaminations were detected on the product. So a 5 Why's analysis was performed, and the main question was: "Why is there contamination on the Trap Filters?". The possible explanations found were (Figure 7.25):

a) De-aerated water contamination: The routine analysis for the water used on this process don't reveal any possible contamination
b) Kieselguhr dosing system: The Automatic Kieselguhr dosing system was implemented right before these problems appeared. Since it was a possible source of contamination, tests were carried out in order to determine if there was any contamination. No evidence of contamination was found in either the CO_2 used, the kieselguhr mixing tank or the dosing circuit.
c) Incorrect functioning of the kieselguhr filters: During the same time that the contaminations were taking place, a lot of filter malfunctions were detected. Although it seemed unrelated to the results, a deeper investigation of the cause of these problems was necessary. It was finally found that there was a problem with the filter cloths, and there was a batch of cloths that had a hole in the side. This caused the problems, affecting the filtration efficiency, and thus making contamination possible. Besides the problem with this cloths, it was also noted that sometimes during the changing of cloths it is possible to damage them if the process is not done safely

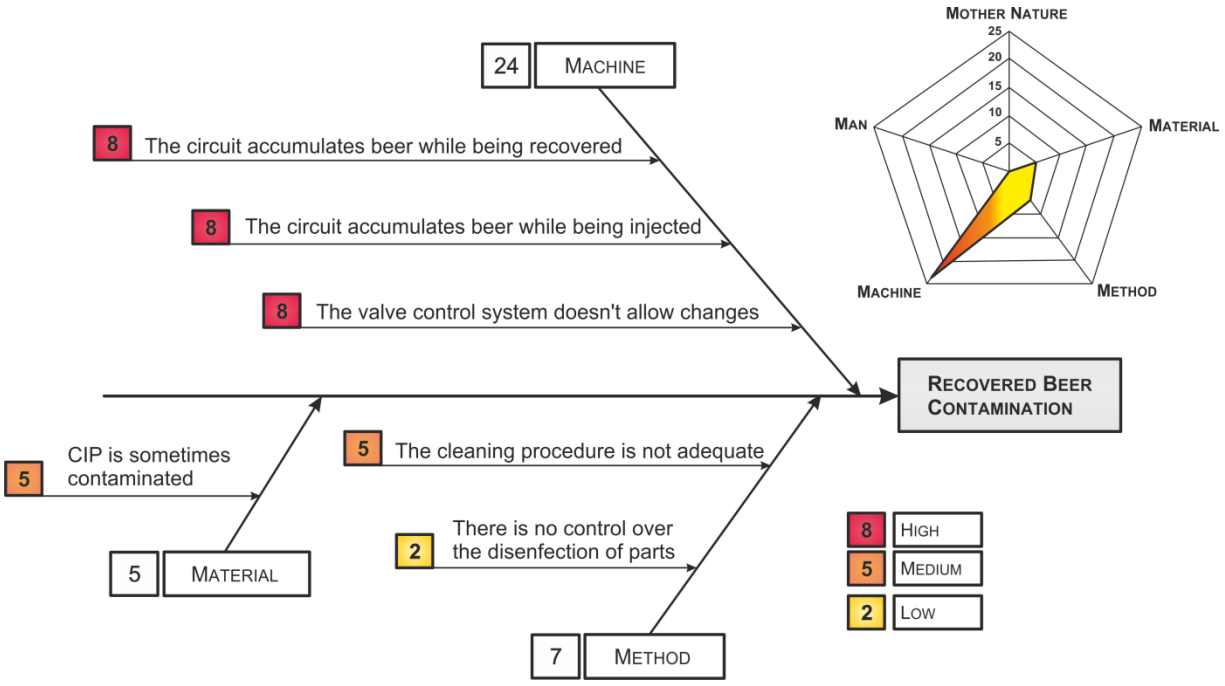

Figure 7.22 - 5 W's Analysis & Ishikawa Diagram for the Recovered Beer

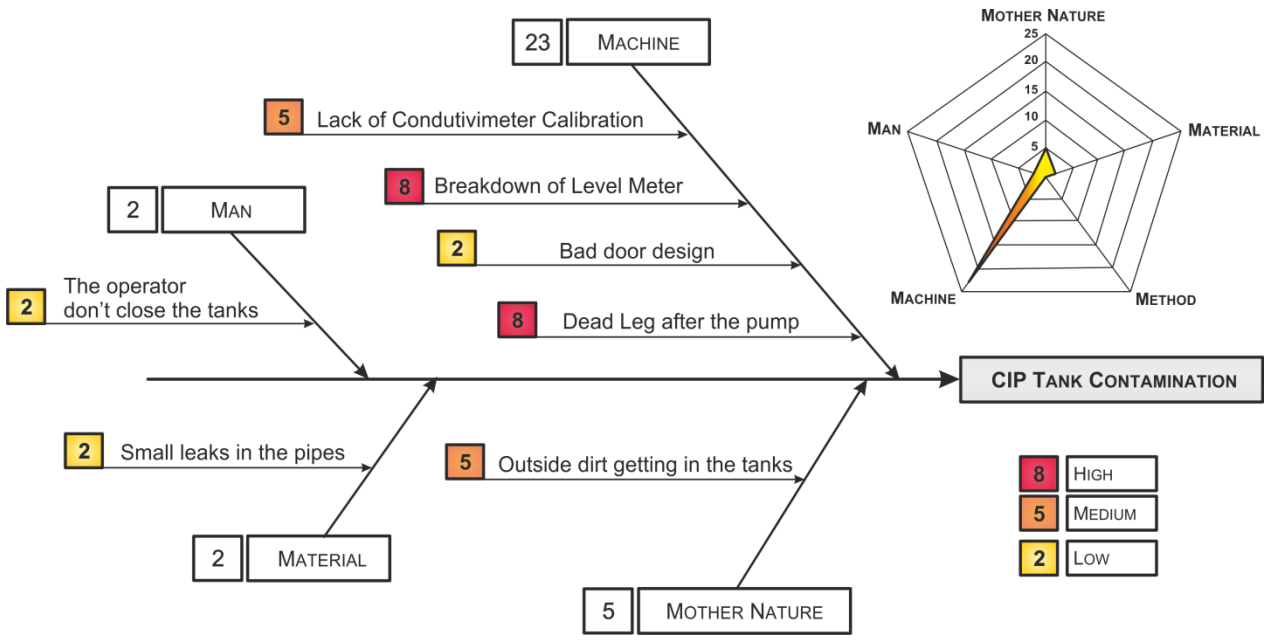

Figure 7.24 - 5 W's Analysis & Ishikawa Diagrams for the CIP Tank Contamination

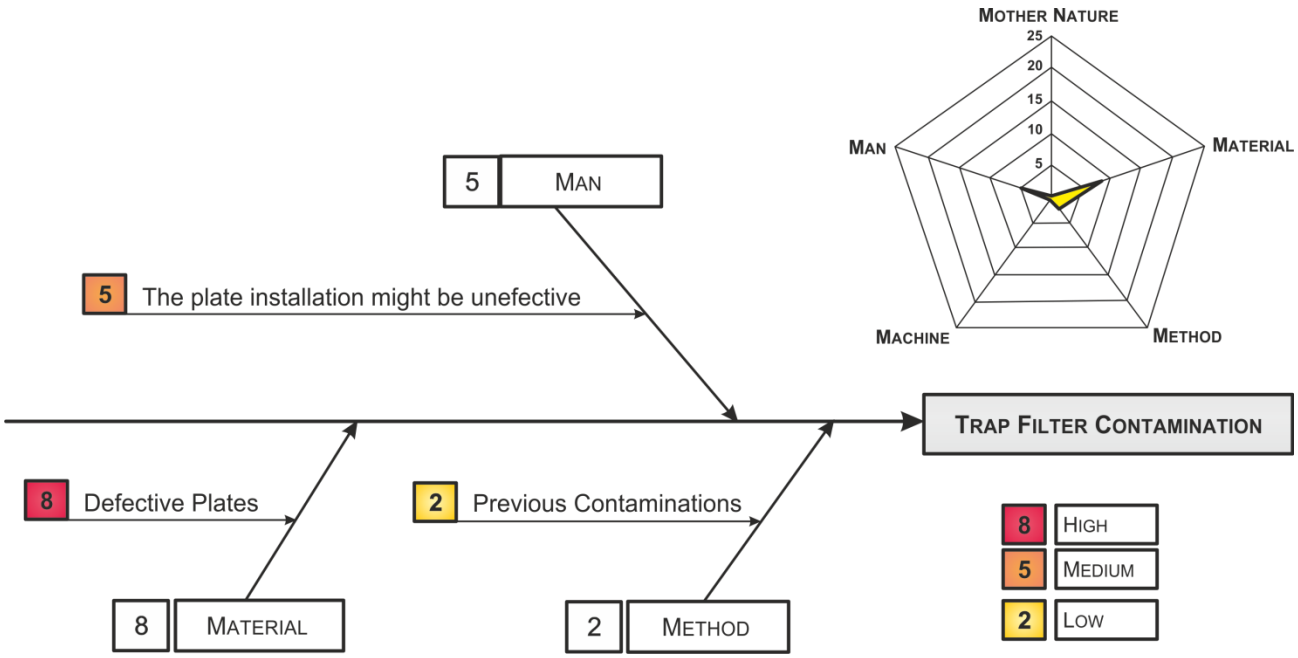

Figure 7.23 - 5 W's Analysis & Ishikawa Diagram for the Trap Filter Contamination

Step 4 – Implementing Improvement Measures

After identifying possible contamination sources and determining if they are actually sources of microbiological contamination, it is possible to come up with improvement measures that allow eradicating and preventing future contaminations.

4.1 – LUP and Improvement Proposal

The first measures taken were the execution of a One-point lesson (LUP) and an Improvement proposal. These are the procedures used to implement small changes in the functioning of the process. The objective of these initiatives was to improve the CIP efficiency.

The goal of the **Improvement Proposal** is to remove the dead leg on the CIP Central. This allows for a better CIP efficiency and removes an accumulation point that might generate microbiological contamination.

The **LUP** that was carried out regards the small parts tank. Although there was already a LUP explaining how to do the disinfection of parts in the larger parts tank, there was no procedure on how to do this on the smaller parts tank. Although this tank is only used for parts that are used on the weekly cleaning, a proper disinfection could be beneficial to the anti-microbiological efficiency of the process, and since it is a small tank it wouldn't be necessary to use a large amount of detergent.

In order to assure that the disinfection occurs, the concentration of the cleaning solution must be the same as the big tank, 0.5% (v/v). By quickly making the calculation of the dilution for the tank volume (approximately 200 L) It is estimated that 1 L of Topax is necessary to assure this concentration.

4.2 – Microbiological Validation of the CIP of the kieselguhr dosing systems

As part of the work of previous teams on the filtration of beer on SCC, a kieselguhr dosing system was installed during the time that the improvement team on microbiology was working. Since it only started working in July, it was necessary to perform a microbiological validation of this part of the process. This validation was not done as part of the team's work as a possible contamination source, but rather as a confirmation of the success of a new part of the process.

For this goal, two samples of the last cleaning water used in the CIP process were taken in the preparation tank's entrance and exit and were tested for aerobic and anaerobic microorganisms. Bioluminescence analysis of the tanks exit was also performed. Figure 7.26 is a schematic of the results of the analysis of those samples.

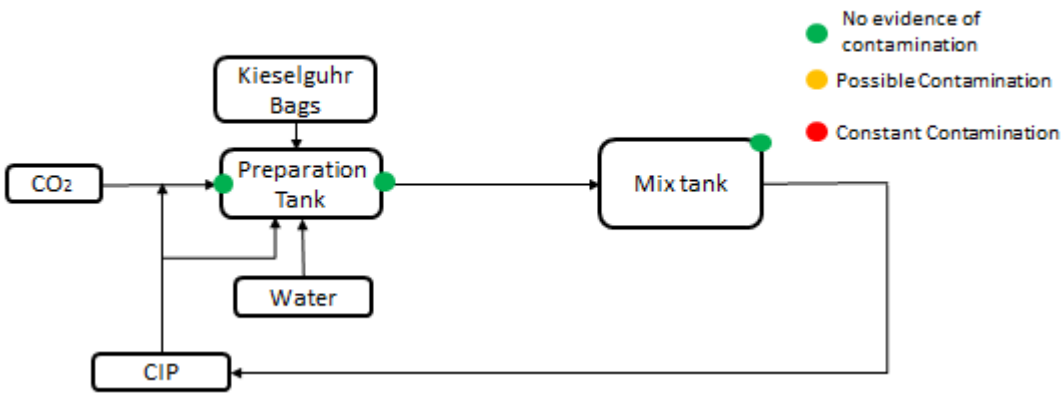

Figure 7.25 - Results of the new kieselguhr dosing analysis

Besides these samples, samples of both the water and CO_2 used in the process were tested and presented no evidence of microbiological contamination.

Given all the results, it was possible to validate the process, assuring that it doesn't carry significant danger of further microbiological contamination.

4.3 – CILT plan

As previously stated, the hygiene conditions of the workplace are a critical aspect for the eradication of microbiological contamination. As a part of the company's Standards, all sectors of the brewing process are required to have a **CILT (Cleaning, Inspection, Lubrication and Tightening)** plan that acts as both a guarantee of hygiene and quality standards and as a fundamental maintenance tool for all the machines used in the process.

The filtration section of the factory had a separate cleaning and inspection plans, but there was not a document that comprises both and allows registering the maintenance and cleaning procedures. This document was created by the team as an effort to promote a better maintenance of the equipment and improved hygiene standards. A sample of a section of this document is exemplified in figure 7.27.

It is due noting that this Plan follows the company's Visual Standards, that consist of the utilization of icons and color coding for an easier comprehension by the operators that are responsible for the tasks.

Possibly the most important aspect that was improved by this initiative is the creation of a cleaning and maintenance registry, that lists tasks and their periodicity and allows to see if they performed when due.

Figure in Annex C

Figure 7.26 - Sample of a CILT plan section

4.3 – Study of alternatives for the recuperation of filtered beer

As previously stated, the beer recovery system has a lot of design problems that can lead to contamination. This makes it hard to find a short-term simple solution for these problems, but leaves room to consider possible alternatives to this process.

Three different alternatives were considered: the incorporation of recovered beer in the boiling wort, the incorporation of recovered beer in the Nathan (the buffer tank for the filtration section) and incorporation of recovered beer in the beer storage tanks. Figure 7.28 shows the regular beer recovery system through BBT 6.

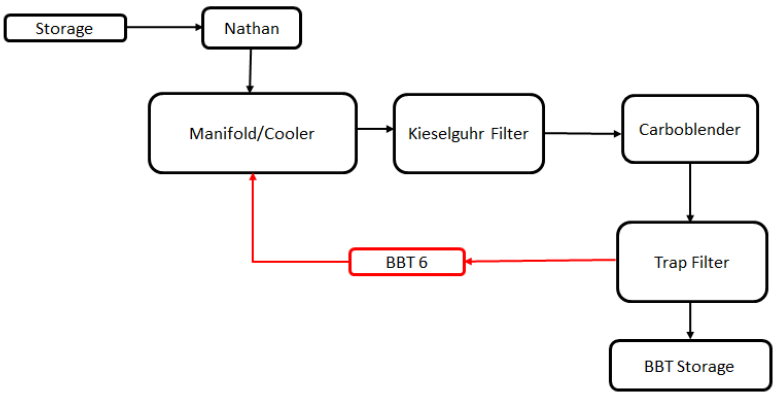

Figure 7.27 - Beer Recovery System (Source of contamination in red)

4.3.1 – Incorporation of recovered beer in the boiling wort

The first alternative for the recovered beer would be incorporation in the boiling wort. The beer from the beginning and end of each filtration cycle that is stored in the BBT 6 would be directed to the wort boiler during its operation. Since the amount of the beer that is recovered is very small comparing to the amount of beer that is on the boiler, the impact on the quality of the beer would be minimal.

The main advantage of this procedure would be the sterilization of the recovered beer, by the boiling of the wort. This boiling would eliminate any contamination that could remain on the recovered beer.

This process would require some investment in piping for the transportation of recovered beer. Another relevant point is the large amount of recovered beer from other parts of the process that is already recovered in the wort, and if this amount of beer that is incorporated there is too large there could be significant decreases in the beer quality. This idea is schematized in figure 7.29.

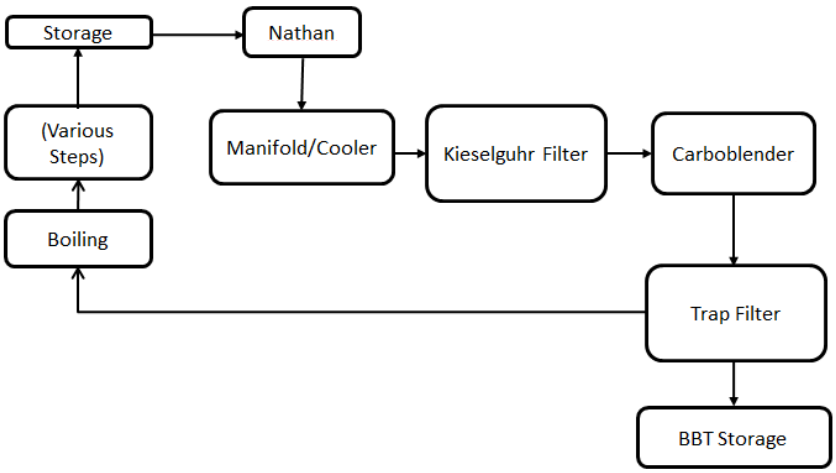

Figure 7.28 - Schematics for the Beer recovery to the wort boiling stage

4.3.2 – Incorporation of recovered beer in the Nathan

Another possible solution for the recovery of beer from the beginning and end of filtration cycles would be to incorporate it directly in the Nathan. This solution would make the BBT that accumulates recovered beer unnecessary.

In order to make this solution viable, a connection between the recovery circuit and the Buffer Tank would be necessary. This connection would represent a much smaller investment that the solution posed on 4.3.1, because the recovery circuit is physically very close to the buffer tank. The recovered beer, which is very dilute due to the water that was used to pack the filter with kieselguhr, would be sent into the buffer tank to be re-filtered, pre-diluting the beer before filtration.

This solution theoretically would allow to reduce the amount of time that beer stays accumulated on the pipes, and so it would be positive from a microbiological standpoint. Although being good from a microbiological perspective, this measure carries problems for the chemical quality of beer: one of the main characteristics of recovered beer is a high level of O_2, and inserting the recovered beer directly in the buffer tank would increase the level of O_2 in the beer that is to be filtered. For this reason this solution was also not carried out. This idea is schematized in figure 7.30.

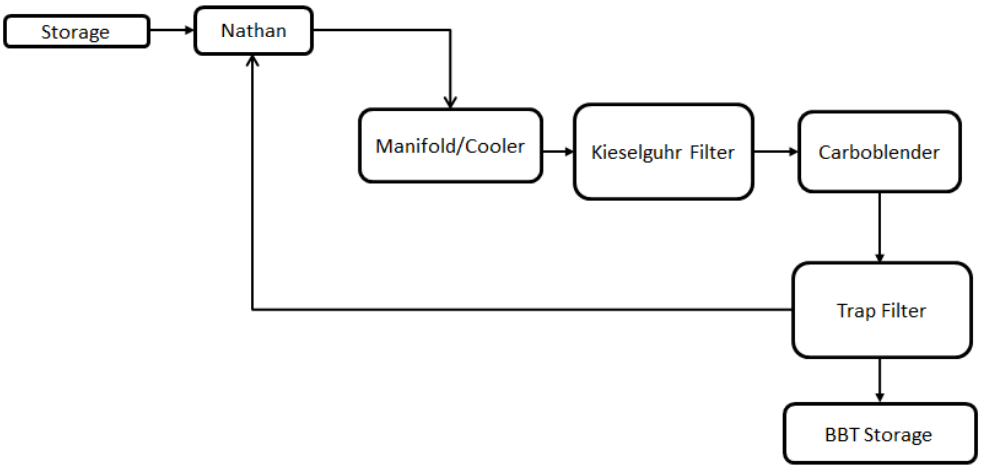

Figure 7.29 - Nathan's Beer Recovery System

4.3.3 – Incorporation of recovered beer in the Storage tanks recovery system

The last solution that was studied regarded the injection of recovered beer into the storage tanks. This process wouldn't imply any physical changes to the equipment already used, which is a very positive advantage over the other solutions.

Using the circuit that already exists, the recovered beer would not need to be sent to the BBT 6, and would instead proceed through the circuit until the manifold. The manifold has a direct pipe connection to the main distribution panel of the filtration section, which is right next to the storage tanks. This beer could then be sent into the recovery storage tank, whose content is diluted throughout all of the other storage tanks.

This solution shares some of the same advantages of the recovery into the Nathan, namely the lower accumulation time of recovery beer that would go from 2-4 days to 8-12 hours, which is the average time of a filter cycle. Both solutions also allow the dilution of any possible contamination in a larger volume of beer. The main advantage of the recovery into the storage tanks is that unlike that solution there is no problem with the excess of O_2, since it would be divided by all of the storage tank, whose volume is so much bigger than the volume of the buffer tank that the concentration of O_2 couldn't vary significantly

The main problem with this solution is that although there is no necessary physical alteration required, the control system of the valves that regulates the flow of beer through the filtration circuit would have to be altered and reprogrammed in order to allow for beer to be directed into the manifold instead of the BBT 6. This would also require some investment. This idea is schematized in figure 7.31.

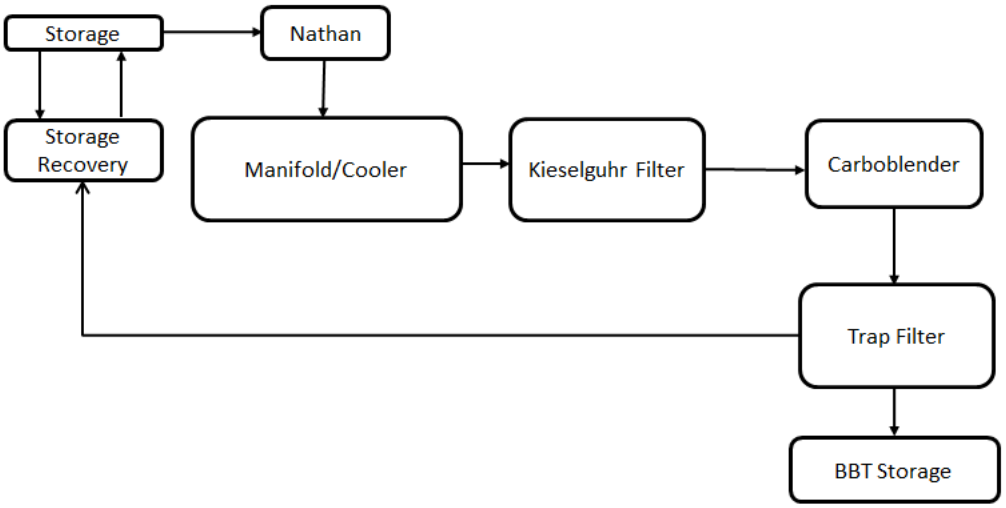

Figure 7.30 - Beer Recovery to the Wort Boiling Step

Steps 5 & 6 – Analyzing defects and Improving the quality system

The fifth and sixth step of the route regarded the overall analysis of the defects found and the actualization of the quality standards. In order to better understand how the contamination evolved over time, an analysis of the FTR Micro BBT indicator during the team's lifespan is necessary. Figure 7.32 shows the evolution of the indicator and the main events that influenced it, and 7.33 shows the evolution of the cumulative FTR Micro BBT indicator value.

The results of most events that occurred are very clear. The Total Clean Out that was performed in week 8 clearly resulted in an overall raise of the FTR, probably due to the improvement of the basic hygiene conditions on site.

The intervention on the additives dosing system was an improvement that was already planned before the team's work, and consisted of installing retention valves that allowed the cleaning of that system. But since it only affects the additives system, that is only used to produce alcohol free beer, the effect on the indicator is minimal.

When the CIP contamination was detected, the average of the results registered an decrease, although the week that immediately followed the detection registered a perfect score, which was unexpected, but could happen due to the randomness of the sampling process.

The malfunction of the carboblender at week 20 was due to a problem in a densimeter, which calculates the beer extract through differences in density, making it impossible to use the automatic mode that corrects the beer extract by dilution with water. The carboblender can still operate on manual mode, because the extract of the regular beer is known, the dilution factor could be calculated previously, but the injection of recovered beer becomes impossible, because it is highly diluted and its extract value is not consistent. The impossibility to recover beer lead to an immediate increase of the value of the indicator. This

data allied with the analysis of critical points confirms that the beer recovery system does contribute negatively to the overall microbiological quality of the beer.

The last events registered on the board are harder to analyze, but the problem with a bad batch of filter cloths that was mentioned in the search for contamination sources had a very negative impact on the overall performance of the indicator. The new kieselguhr dosers have not shown any sign of microbiological benefits, although they are important to ease the functions of the operators, and since they were installed during the last month of the team's work, it might still be too early to take any conclusions on their effect on this indicator.

Finally, After the freefall of the indicator in the last four weeks of the team's activity, the last week of work saw the solution for the filter contamination problem and the carboblender problem. Results are expected to return to normality after the team's work ceases, and to begin improving as the measures that were considered start being consistently applied. Figure 7.32 tracks the evolution FTR Micro BBT through the lifespan of the team and shows the main events that occurred, as well as the objectives and initial values.

The final step of the route regards the actualization of standards and checklists, in order to improve the quality control system. This step was not concluded by the team because some time is necessary in order to determine the effectiveness of the changes that were made and their relevance.

Figure in Annex C

Figure 7.31 - Evolution of the FTR Micro BBT results and events

Figure in Annex C

Figure 7.33 - FTR Micro BBT cumulative value

8 - Conclusions

Looking at the cumulative results during the lifespan of the project, it is clear that there was an improvement of the performance of the FTR Micro BBT.

Given the results, and despite the significant improvement, the results fall slightly short of the goal that was previously set (the value obtained was 87.05% and the goal was 91%). This happens both because there were a lot of extraordinary situations, such as the problems with the filtering supplies previously described, but also because the goal set by the team was very ambitious.

Further analysis allows to determine that if not by the problems that appeared later in the team's work the cumulative Micro BBT FTR would be closer to the maximum value reached, which was 88.95%, and is a lot closer to the goal than the final result obtained

It is also worth noting that without such an ambitious goal set the results would have probably fell even shorter.

Regarding the beer recovery system, of the three possible solutions studied, the least plausible was the recovery of beer into the Nathan, due to the excess of O_2. Both of the other solutions were found reasonable and could possibly be implemented in the near future. The best solution would be the recovery into the boiling wort, and this is expected to occur once the amount of beer recovered from other sectors of the brewery is largely reduced, the main problem being the amount of beer that is still recovered from the packaging section.

The continuous effort for the modernization and automation of the facilities was proven to have a positive effect on the microbiological quality. Even measures such as the installation of new kieselguhr automatic dosing system allow for the operators to have more time to pay attention to details, like the maintenance of the filtration facilities.

Despite the continuous effort for the modernization of the factory, the filtration section of the factory has had very few changes to its facilities in the last 10 to 20 years. Given how old the facilities are, the results achieved are actually remarkable, and only possible through a strict and effective maintenance plan and quality control.

Regarding future challenges, the growing demand of the consumer for different products is leading the company to produce an increasing number of different products such as Strongbow ciders, Radler and Bohemia beers. This rise in the variety of the production can have some unpredictable results on the microbiological quality of the products, because the amount of small batches increases over the amount of regular beer batches, with implications in the BBT use. Smaller BBTs are used more often than they were previously used, and thus the time gap between the uses of bigger BBTs is increased, and this limits the amount of time that each BBT is cleaned during a longer time span. Besides this, the beer recovery system that is only used for regular beer (and in big BBTs) is delayed due to this production of special beers that can't be recovered. Further study on the impact of these changes could not only be

helpful to reduce the problems that could appear on the microbiological level but also on the overall quality of product and effectiveness of the operation, allowing an adaptation of the brewery to the demands of an ever-changing modern market.

> Given the continuous effort for improvement and modernization, the use of more recent filtration technologies, such as microfiltration modules [30], could be an interesting solution for smaller batches of beer. This method generally couples the use of cross filtration with ceramic modules, and is not practical for large scale production due to an overall smaller flow of beer (typically 50-100 $dm^3/m^2/h$ against the regular kieselguhr filters that allow for 200-250 $dm^3/m^2/h$). This technique has shown promise is recent studies and is used throughout the beverage industry quite frequently. One of its main advantages is the fact that it allows for lower operational costs despite a larger initial investment. This makes it a more economic solution over larger periods of time. Despite not being appropriate for larger beer productions, it could be useful for smaller runs of products, such as the ones that are starting to increase in demand.

It is also very important noticing that SCC has a structured modernization plan, that has several investments planned to the filtration section in order to improve the hygienic design of the facilities, that is one of the most critical subjects for the improvement of the KPI. Besides this, these improvements should improve productivity, reduce waste and allow for a better control of the process. The work that is followed through here will be used to adjust and improve such planned investments in the future.

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Annex A

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Annex B

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Annex C

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