Optimization of the wort cooling phase

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Abstract: The optimization of the wort cooling line aims to improve the efficiency of the cooling conditions, namely in terms of aeration, color and extract loss. These factors have a significant impact on one of the most crucial brewing processes - fermentation. Therefore, this optimization has an impact on the final quality of the product, so that the product's offer is guaranteed with characteristics that fulfils the consumer's requirements. This thesis' objective was to study the operation of the cooling line of the wort, and to intervene to eliminate the failure causes of SCC priority indicators. Three parallel studies were carried out: optimization of dissolved O_2 in the wort where restoring the basic condition of the equipment and changing set-points contributed to the increase of yeast yield of fermentation and propagation; optimization of the color measurement of the wort by restoring the correct functioning of the sensors and analysis of deviations, and, finally, study of the extract loss through characterization of the line and failure modes. By reducing the wort aeration, levels of dissolved O_2 within specification were achieved, resulting in a qualitative improvement of yeast performance. Also, the increased aeration in the propagation contributed to a more consistent yeast, capable of more efficient fermentations. At color level, laboratory and inline results were approximated, and unexpected readings that were observed during fermentation were successfully eliminated and/or justified.

Keywords: Wort Cooling, Extract Loss, Color, Aeration, Kaizen.

Introduction

One of the main objectives of Sociedade Central de Cervejas e Bebidas (SCC) is to be the beverage company, operating in Portugal, which leads the satisfaction of consumers and customers, producing and distributing passionate brands of drinks that are part of their lives (SCC, http://www.centralcervejas.pt/en, [Accessed May 08, 2018]). Given the current competitiveness of the industry, this is a differentiating factor that can benefit the company if the quality of its final product is assured. As it is very important to avoid nonconformities, it is imperative that the process itself can be controlled.

Wort Aeration

The first indicator to be studied is the wort aeration, that is a very important field that has been studied by the breweries in order to optimize the growth of yeast and productivity of the fermentation. The brewer's yeast has the ability to metabolize and synthesize components, both under aerobic conditions and under anaerobic conditions. From here it is possible to observe the importance of aerating the cold wort before the addition of the yeast. If it is unable to grow, it will result in slow fermentations (with high final pH and other flavour changes), low viability (low oxygen content (O_2) can lead to yeast autolysis) and possible contamination of bacteria that grow faster than yeast itself, competing for the same substrate and deteriorating beer (Institute of Brewing and Distilling, 2016). Not only can poor aeration be a problem, but too much ventilation can lead to difficulties in the process. As yeast needs O_2 to grow, too high aeration can lead to excessive yeast growth, which causes a large extract loss, as the yeast will begin to consume it for your metabolism, and the extract available to be used for fermentation will consequently be less. Measurement of extract loss is done using the Balling formula. When conducting his experience in 1843, C.I.N. Balling found that 2.0665 g of extract led to the production of 1 g of alcohol and 0.9695 g of CO_2, and 0.11 g of dry yeast was also produced (Heineken, 2008). Therefore, its mass balance was as follows:

$$Extract\ loss = Alcohol + CO_2 + Dry\ Matter$$

Of this equation, Balling calculated that for 100 g of beer:

$$OE = \frac{(2{,}0665 \times AL + RE) \times 100}{(100 + 1{,}0665 \times AL)}$$

where **OE** represents the original extract, **AL** represents the alcohol content and **RE** is the real extract.

Different yeasts need different levels of O_2 for proper growth. Since yeast growth has a direct effect on the level of alcohols and esters produced during the fermentation, different beers will have different levels of dissolved O_2 to provide the desired number of esters and

alcohols. (Morales *et al.,* 2015). The amount of O_2 dissolved in the wort greatly affects the growth of the yeast, so much so that some mode of control is necessary to ensure the consistency of this controlled growth. There are several factors that condition the dissolution of O_2 in the wort. These may depend on the wort itself, namely at the temperature and concentration level, or the conditions of the injection system itself such as the pressure and the type of injection system: compressed air or oxygen. This maintenance is highly valued not only to control the optimal functioning of the yeast, but also to ensure the excellence of the finished product without many breakages of material (White & Zainasheff, 2010).

Wort Color

The wort color is also an important parameter that chatacterizes beer. Among the various ingredients used for beer production, the color of the beer is determined mainly by the selection of the grains used in the process and, more specifically, by the type of processing that these grains suffer, although the addition of fruit can also, in the cases where applicable, have a major impact. Barley contains very low concentrations of pigmented substances, and it is the malting process that results in the formation of color. The germination and knilling phases of the malting process determine the extent of color formation from Maillard reactions and, in some cases, caramelization and pyrolysis reactions. In addition to these heat-induced color forming reactions, the oxidation of polyphenols derived from barley bark or vegetative matter from hops may contribute to color formation during beer storage/aging (Coghe *et al.*, 2003). The measurement of the wort color in Vialonga is made using two Optek AF26 color sensors installed before the existing panel in the wort aeration stage. The sensors are installed inline, perpendicular to the pipes, and are composed of an emitting source, which contains a lamp emitting light for the wort, and a receiving source installed on the opposite side of the pipe, which receives light passing through the wort and measures the absorbance and turbidity values of the wort, at different wavelengths.

Extract Loss

The extract loss is one of the main opportunities for improvement associated with the beer production process. It consists of the mass balance that quantifies the difference between what was obtained from raw material extract and what was generated in the wort. This parameter is very important for the company, since a high drop of extract, results in a wort rich in fermentable sugars, resulting in a weak fermentation and, consequently, in a beer with low alcohol content, below the requirements necessary in each recipe.

There were some shortcomings in the process and in its control. The occurrence of excessive foaming in the fermenters during the fermentation process is also associated with high extract fractions, since this foam formation could be associated with excessive yeast growth, which enhances the yeast fermentability of the yeast beyond the desired, a higher CO_2 content is released in the alcoholic fermentation that will contribute to this greater foaming effect (Bamforth, 1985).

It was also found that there was no QA (*Quality Assurance*) matrix built for the beer transfers and that there were several key points of the cooling phase without preventive plans, and all the measures that were taken were corrective, which does not meet with the SCC's quality objectives.

Results and Discussion

Wort Aeration

Excessive foaming

After a first analysis of the data history of the first three months of 2018, some differences were observed in the O_2 values measured by the sensors located in the lower circuit and upper circuit, where it was verified that the wort aeration in the upper circuit was more efficient and, therefore, the dissolution of O_2 was higher.

In order to study this difference between both circuits, there was a need to restore the basic condition of the equipment in order to dissipate any measurement error that compromise the veracity of the results. After that, the aeration results of the fermenters before and after calibration were compared. According with the physical state of the sensors observed during the calibration, it was expected that after the

the results obtained for the air dissolved in the wort would come closer and reflect a more reliable O_2 reality that was effectively dissolved after aeration.

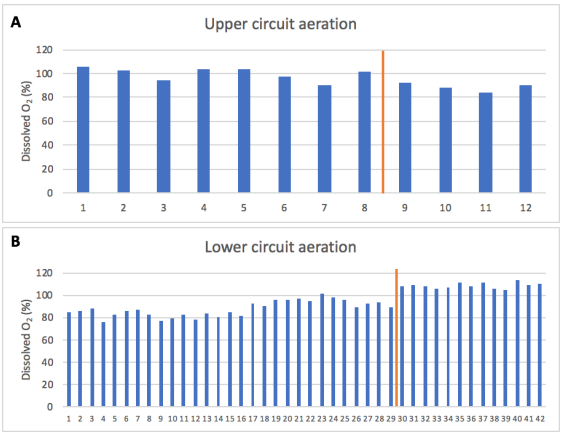

Figure 1 - Representation of aeration data history for the upper (1A) and lower (1B) circuit in percentage of comparison to an optimal value (100%); in both charts, the calibration date was marked with the orange bar.

As it is possible to observe, the maintenance and calibration of the O_2 sensors had the desired effect, restoring the accuracy and precision of the results. This correction of values was very evident for the lower circuit, where the average values before calibration were slightly lower.

Yeast control

Among the parameters that demonstrate the wort quality, the multiplication rate reflects the quality of the wort aeration, since if there is over aeration, the dissolution of O_2 in the wort can be extremely efficient. In case of excessive aeration, the yeast will multiply too much, leading to an inefficient fermentation, since the fermentable sugars will not be fermented by the yeast, but rather metabolized by it.

After analysis of the results of the yeast's multiplication rate, it was observed that this parameter was inaccurately calculated, and there was margin for optimization. The previously defined calculation for the yeast's multiplication rate was given by the quotient between the amount of yeast collected at the end of the fermentation (including purges) and the yeast medium inoculated by fermenter.

$$yeast\ multiplicating\ rate\ (kg) = \frac{recovered\ yeast}{average\ weight\ of\ inoculated\ yeast}$$

This calculation did not produce reliable results in some batches. For example, for a different recipe from Sagres Branca that required fewer brews than usual, the value for inoculated yeast was much lower than the average value. This way, the calculation method was corrected in order to individualize each fermenter and use the correct amount of yeast that was inoculated in that same fermenter.

$$yeast\ multiplication\ rate\ (kg) = \frac{recovered\ yeast}{inoculated\ yeast}$$

After the change described above, the results of the yeast multiplication rate using the standard equation SCC and the optimized equation:

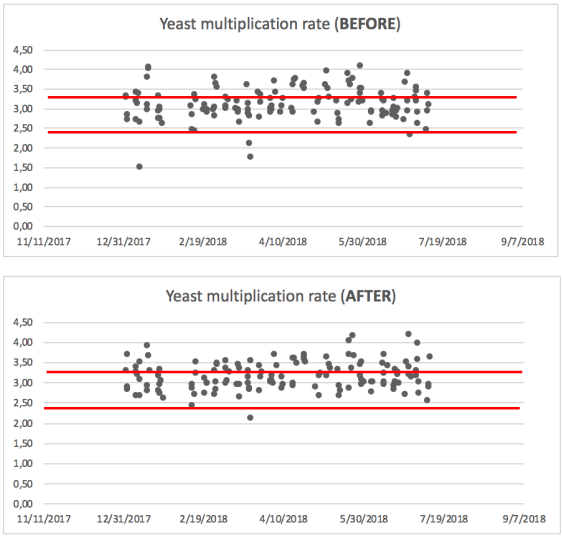

Figure 2 - Multiplication rate results are recorded with the new calculation formula, using the actual yeast mass value inoculated by fermenter.

It is clear that the wort aeration was excessive, which induces the need to reduce the amount of air injected into the wort cooling line.

Aeration optimization

Taking into account the excessive wort aeration verified by the analysis of the results previously obtained, a study was made to understand to what extent could this parameter be optimized, in order to obtain dissolved O_2 values within the established specification, and without implying a destabilization of the yeast, reflected in its quality parameters, such as the multiplication rate, content in dead cells (since with a low content of air, the yeast would not have enough air to survive), viable population, diacetyl (low aeration generates a superior lag time in the fermentation and the appearance of this off-flavour) and final SO_2 (yeast in poor state of conservation due to the presence of CO_2 that is not removed, making the yeast use more

nutrients available to reproduce itself at a higher rate, forming more SO_2, which is an intermediate product of yeast metabolism).
The existing aeration was defined for the 6 brews of a fermenter and generated a wort overly ventilated (standard case). Thus, a reduction was made in proportion, based on the parameters defined as optimal for the wort aeration, and two different setpoints were tested - test 1 and test 2.

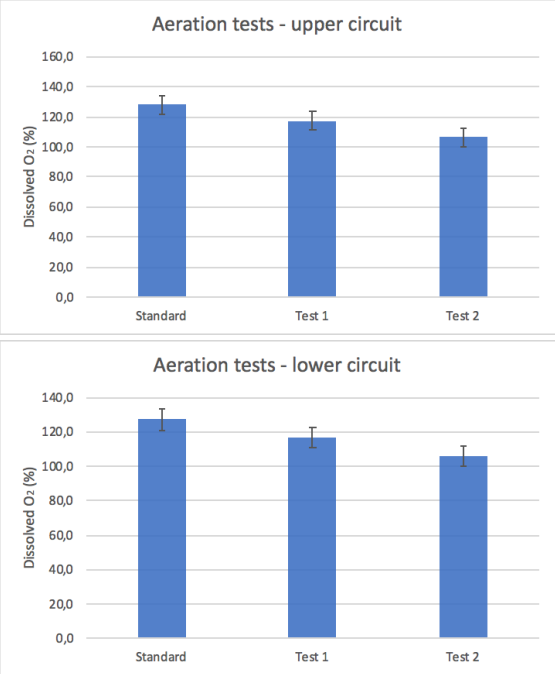

Figure 3 - Tests with set-points of different aeration for the lower circuit: realization of standard with aeration imposed by standard; test 1 and test 2, both with different set-points applied. Scale in comparative percentage to an optimal value (100%).

After calculating the average values, only in test 2 an O_2 value inside specification was achieved. Therefore, the new aeration set-point (test 2) was tested in six fermenters from each brewing line and for both aeration circuits, from which the following results were obtained, compared to the standard:

Table 1 - Results of dissolved O_2 and yeast quality for standard and test (6 tests), for brewing line 1: average O_2 (in ppm), multiplication rate, dead cells (%), SO_2, viable population (x10^6cells/mL) and diacetyl.

	Brewing line 1							
	Average O_2	Multiplication rate	Dead cells	SO_2	Viable population	Diacetyl		
						7th day	8th day	9th day
Standard	12 - 14	3 - 4	5 - 7	OK	10 - 12	NOK	OK	OK
Test	9 - 11	2 - 3	4 - 6	OK	12 - 14	NOK	OK	OK
σ (test)	±0,14	±0,16	±1,50	-	±1,45	-	-	-

The reduction of wort aeration provided a reduction of the dissolved O_2 values. As seen in Table 1, the existing aeration was excessive and generated an over aerated wort. With the new set-point, the wort aeration generated results within the values specified as optimal, as three of the test fermenters reached these values, while the remaining three were very close. There was also a significant improvement in the viable population, multiplication rate and dead cells content after fermentation. This is indicative that excessive aeration which had previously occurred proved to be toxic to the yeast, as the content in dead cells was high and above acceptable (7%). The diacetyl levels were efficiently reduced until the 8th day of fermentation, which kept within acceptable limits after the tests, as well as the SO_2 formed in the brewing wort, which is indicative of a good fermentation, without presence of undesirable secondary compounds.

Table 2 - Results of dissolved O_2 and yeast quality for standard and test (6 tests), for brewing line 2: average O_2 (in ppm), multiplication rate, dead cells (%), SO_2, viable population (x10^6cells/mL) and diacetyl.

	Brewing line 2							
	Average O2	Multiplication rate	Dead cells	SO2	Viable population	Diacetyl		
						7th day	8th day	9th day
Standard	12 - 14	3 - 4	6 - 8	OK	15 – 17	NOK	NOK	NOK
Test	9 - 11	2 - 3	6 - 8	OK	12 - 14	NOK	OK	OK
σ (test)	±0,18	±0,23	±1,27	-	±1,55	-	-	-

The results obtained for brewing line 1 are reproducible for brewing line 2, where the reduction of aeration produced even more positive results, since all six trials generated values of dissolved O_2 in the wort, in contrast to the standard fermenters. Although there have been no significant improvements in the number of dead cells, diacetyl and SO_2 formed at the end of the fermentation (it is still positive that there are no changes), there was a slight improvement in the amount of viable population remaining after fermentation. Nevertheless, a less positive result was registered for the cylinder-type fermenter CC6, where the low viable population was due to the fact that the used yeast was a 6th generation yeast and, therefore, increasing the probability of mutation. In this way, the fermentation will have a different profile to what was expected. Generally, the same yeast is only used five times (or up to the 5th generation), but due to an inefficient propagation that generated quality defects after the first fermentation, this new yeast was destroyed, having to resort to the use of an old yeast in one more fermenter. In general, it can be concluded that the reduction of the aeration of the wort was quite positive, translating into more efficient fermentations and maintaining a healthier and consistent yeast. The new aeration set-point was introduced in brewmaxx

in alteration of what was previously imposed on the recipe.

Propagation optimization

Yeast propagation starts in the laboratory in two sterile flasks with a small amount wort and with two slopes of yeast in each flask. After until 48 hours it is transferred to the Carlsberg flask, multiplying the yeast present in the sterilized wort. About 48 hours later, Carlsberg flask content goes to a fermenter vessel with a volume 100 times greater, where it is agitated and aerated for 3 to 4 days, in order to guarantee the best fermentation conditions, and then transferred to another fermenter vessel with 10 times the size of the previous, where the last phase of yeast multiplication takes place for 5 days. The amount of yeast is then sufficient to proceed to a fermenter, where zero fermentation will take place. The wort is continuously aerated at all stages of propagation.

After analysis of the data history, an opportunity for improvement in propagation was visible: after zero fermentation, the viable population in the fermentor was very low, being below the specified values as optimal (greater than 14 $x10^6$ cells / ml) which indicates that the aeration set-point was not the most suitable (red). In order to improve fermentation capacity of yeast in the subsequent fermentation, the set-point of aeration was changed, so that O_2 was more easily dissolved in the wort, and consequently the yeast had more O_2 to consume, contributing to a greater growth of this. Two tests were carried out with distinct set points (yellow and blue), which were translated into the following results:

Table 3 - Aeration quality parameters for a standard aeration (red), yellow test, and a blue test. Results in comparative percentage to an optimal value (100%).

	Multiplication rate (%)	Viable population (%)	Consistency
Average	87,5	69,5	OK
	83,5	97,3	OK
	81,5	71,4	OK

When comparing the results, it can be concluded that the yellow test yields a viable yeast population higher than the obtained with the previous set point, and very close to the optimal value (greater than $14x10^6$ cells/ml). From another point of view, consistency has always been maintained within the values specified as correct for different aerations with different set-points, so it can not be considered as a differentiating factor, but confirms that one more quality parameter is reached. Taking into account the results obtained for the propagation of yeast, the new set-point of aeration, according to the yellow test, was established at this stage of the process and its value in the recipe was changed in Brewmaxx. This optimization provides a more effective propagation, obtaining a much more consistent yeast for the consequent fermentations, which causes the latent phase of the yeast (in which it is growing before starting to ferment the extract) to be shorter , thus accelerating the fermentation process, and consequently giving the opportunity to increase production. (*Lodolo et al.,* 2008).

Briefly, aeration optimization has generated very positive and promising results. Not only the O_2 dissolution efficiency was improved, but also the propagation of yeast allowed to obtain a more robust population, without harming its consistency, and therefore with greater fermentation capacity. The effectiveness of this optimization was translated into the improvement of the qualitative parameters of the yeast, such as multiplication rate and dead cells, and allowed to reach aeration results within the range specified as optimal in SCC.

Wort color

Disparity between inline vs. laboratory results

The first step in optimizing the measurement of the cooled wort color is to conduct an in-depth analysis of the data history to see if there are any deviations from the expected, and if such deviations are considerably relevant.

In order to be able to analyze the inline data regarding previous fermentations and to compare them with the data obtained from the laboratory, it was necessary to build a statistical method that provided this possibility. Thus, a statistical model of Shewhart was designed for the wort color, which compared the values obtained by the sensors inline and compared them with the values obtained in the laboratory, in agreement with what was already implemented for the extract values. The results obtained from the statistical test for Sagres Branca in brewing lines 1 and 2, which compares the measurements of the second

brew of each fermenter with the value measured in the laboratory for the same fermenter, are shown in the following figures:

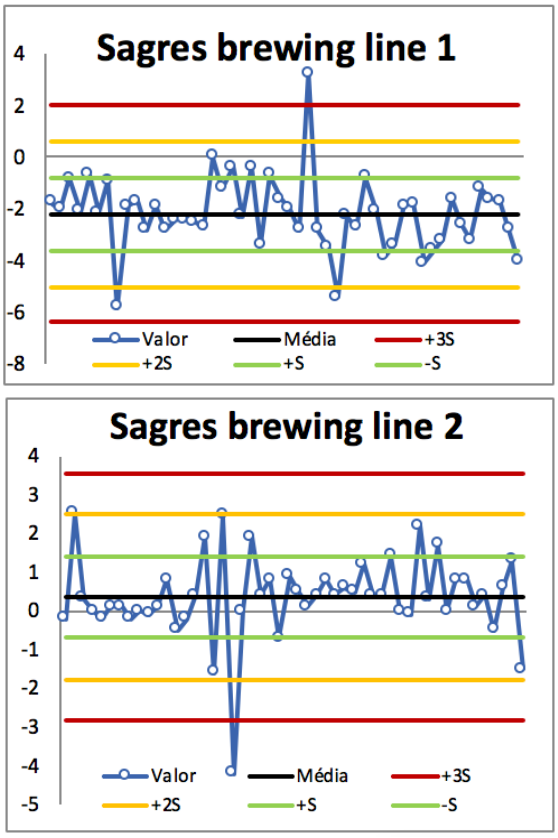

Figure 4 – Results of Shewhart's statistical method for Sagres Bramca (Brewing lines 1 and 2)

As can be seen from the graphs above, the values measured inline for brewing line 1 are on average 2°EBC below the values measured in laboratory, while the values for brewing line 2 are about 0,5°EBC above those measured in the laboratory. On the other hand, in both brewing lines it is verified that the presented deviations are within the defined limits, reason why they do not fail any proposition of Shewhart's method of control.

Before formulating any hypothesis about the deviations found, it is important to replace the basic condition of the equipment involved in the measurement of color. For this, it was found that there was no maintenance plan for the color sensors. An electric maintenance plan was then formulated, which includes replacing the lamp every 12 months, and a mechanical maintenance plan, which provides for the revision of the sensor's condition and its calibration annually, and replacement of the air filter installed after the dryer to ensure that the compressed air supplying the lamp is sterile and does not provide condensation on the optical lens. The first hypothesis came from the fact that the wort circulated in the line at a temperature below 15ºC, while the measurement done in the laboratory is done at room temperature (25ºC). A color measurement test was then suggested in the laboratory at a temperature equal to the temperature of the in-line wort (below 15°C), but since there were problems with resetting the basic condition of the sensor, this test could not be performed, since the potential deviations associated with the lack of calibration would not be eliminated. Therefore, the increasing tendency of color values throughout the fabrics was studied and solved, as it was thought to have an equal impact on the deviations between inline and laboratory values.

<u>Wort color growing along fermenter filling</u>

In theory, wort cooling does not cause any changes in wort color (except in temperature, which naturally lowers with cooling). Nevertheless, after analyzing the first results, an increase in the color of the fermenters was observed (Figure 5). In parallel, it should be noted that the measurements made in the laboratory in Alcoolyzer are constant during all brews, which is in agreement with the expected one, since the recipe in each brew is the same.

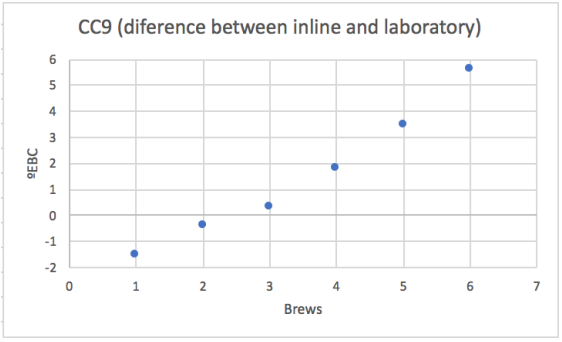

Figure 5 - Color measurement for the 6 brews of the cylinder-conic fermenter 9 inline vs. laboratory.

A study was then carried out to understand the reason for this increase in color throughout the brews. Initially it was thought that the reason could come from the fact that the passage of wort by the sensor could lead to the formation of condensed water molecules in the lens and, therefore, to compromise the reading. In the event that condensates form on the lens, the intensity of light (emitted by the source emitting)

would be compromised, and the receiving source would measure a value of light intensity lower than the actual value and hence assign a color value higher than must. To prove this hypothesis, a test was performed with water passing after each one of 6 brews. The results are as follows (figure 6):

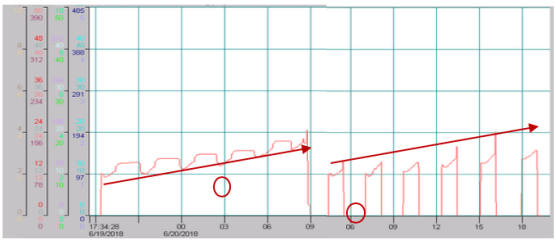

Figure 6 - Wort color (in ºEBC) measured for each brew in subsequent fermenters; standard (left), without water passage between brews, and test (right), with water passing after each of the brew.

As noted above, the passage of water after each brew confirms accumulated dirt on the optical lens. Nevertheless, the results are not completely conclusive, since despite the fact that the value of the read between brews - readings between zero values represents the absence of color - the growing tendency throughout the fermenter's brews has not been eliminated. The condensates form on the lens due to the temperature differences between the circulating fluid and the environment. In the recipes made in Vialonga and in order to guarantee an inoculation that does not compromise the integrity of the yeast, the wort is cooled below 15ºC. Thus, the temperature difference for the environment is higher than 10°C, exceeding the limit established by the supplier for the correct color measurement by the sensor.

A compressed air inlet was installed with pressure regulation for each sensor window to avoid creating condensation, maintaining a pressure of 0,1 bar. However, if the air filter is not according to its basic condition, the compressed air may not be sufficient to eliminate the presence of condensates. Through a detailed analysis of results, it was concluded that the presence of condensates in the lens can only be eliminated by evaporation when cleaning the pipes through CIP (Cleaning-in-place), carried out with caustic soda at high temperatures (higher than 70°C). As this procedure only takes place after filling the fermenter with the last wort manufacture, the condensates remain and accumulate progressively in the lens, thereby generating higher color values throughout the factories filling the same fermenter. A maintenance plan for the filters was built, so that these problems can be avoided in the future.

The color values were linearized using the historical value of the old fermenters. The results of 12 different fermenters were crossed by brew, obtaining an average of color values for each brew. The graphs summarizing the results obtained for each brewing line. Are represented in the following figure:

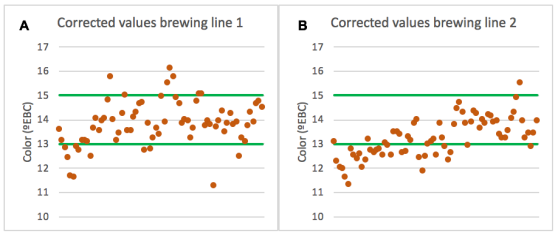

Figure 7 - Color values (in ºEBC) corrected for brewing line 1 (7A) and 2 (7B). The upper and lower limits of the specification are shown in green.

For brewing line 1, 79.2% of the values were within the specification (between 13 and 15), while for brewing line 2 only 57% of the values reached the specified margin. The average values for each brew were assumed and a new offset parameter was created in Brewmaxx for each brew of a fermenter.

Table 4 – Average values of difference of color in relation to the brew used as standard (2nd brew).

	Brewing line 1	*Brewing line 2*
1st brew	-1.0	-0.6
2nd brew	0.0	0.0
3rd brew	1.0	0.8
4th brew	2.0	1.9
5th brew	3.7	3.2
6th brew	5.8	4.4

Unexpected readings across brews

After observing the graphs with the results of the color of the wort, some unexpected readings were evidenced throughout each manufacturing. At the start of the sensor reading, the color value is abnormally high, constituting a peak for the first 10 minutes of whirlpool transfer to the cooling phase, and then increasing until the transfer is complete. The peak observed at the beginning of each brew is indicative that, at the beginning of the wort transfer from the whirlpool to the cooling stage,

the wort has a more intense color than in the rest of the brew. It is in the whirlpool that the wort is clarified, in order to sediment most of the trub, which is undesirable to the final composition of the beer. This clarification is due to sedimentation of the trub, the wort being transferred in three stages, since the equipment has three vertically arranged wort exits, so that it is transferred from its upper content, and allow the trub to deposit in the bottom, without going to the next stage.

A wort turbidity measurement test was also done for the first 22 minutes of whirlpool wort transfer to the cooling stage in two distinct brewing line brews, as the peak was most evident in brewing line 1 sensor measurements in from the beginning of the transfer, and the A, C, ABS and Color values were recorded. The samples were collected and transported to the laboratory, where a centrifugation was carried out at 1500 rpm for 20 minutes, so that the remaining liquid could then be decanted, and the deposited solids weighed, which would confirm the greater turbidity of the wort in this initial period. The results are shown below.

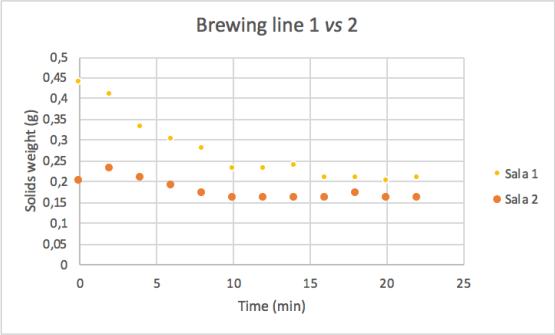

Figure 8 - Comparison between the mass of solids obtained after centrifugation for brewing line 1 and 2.

By analyzing the previous results its concluded that in the first 10 minutes of transfer, the wort is cloudier because the trub is still in sedimentation, which is translated into a higher value of color. The phenomenon described is more evident in brewing line 1 than in 2. This is because the wort is stationed longer in the whirlpool in brewing line 2 than in 1 - about 4 minutes longer. This allows the trub to sediment more efficiently in brewing line 2, which lessens the entrainment phenomenon noted above. The increasing tendency of the wort color value, verified throughout each brew, is explained by the stationarity of the wort in the whirlpool, before being transferred to the cooling phase. While transferring, the wort that remains in the whirlpool is subjected to the high temperatures that exist inside this equipment, leading to Maillard's reaction.

Extract loss

Extract loss is one of the main opportunities for improvement associated with the beer production process. It consists of the mass balance that quantifies the difference between what was obtained from raw material extract and what was generated in the wort. In preventive terms, it was found that there was no QA matrix built for the transfers and that there were several key points of the cooling phase without preventive plans, and all the measures that were taken were corrective, which does not meet with the SCC's quality objectives.

A plan of action has been outlined in accordance with the methodology proposed by Le Quang Hei, HEINEKEN Vietnam colleague, for his Master Brewer thesis, entitled "*Extract Loss Reduction: Bottom-up approach to top-down deployment in Asia Pacific region breweries",* which was developed with the primary goal of completely eliminating the problem of extract losses, targeting the Asia-Pacific region in a sustainable way - so the breweries could focus on other KPIs (*Key Performance Indicators*) to the detriment to work constantly to rectify this problem (Hei, 2015).

<u>QA Matrix</u>

The QA matrix was constructed to analyze the critical points of the process, responsible for the high drop of the existing extract associated with it. The process was divided into seven distinct phases, for an easier and faster characterization of the existing critical points:

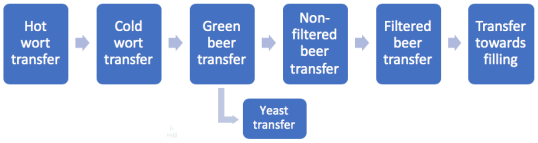

Figure 9 - Representation of the 7 stages in which the process was divided, for the construction of the QA Matrix.

At each stage of the process, the different possible causes for the extract loss were associated with each of the "five M's" - machine,

method, man, material and measurement. Weights were also attributed to each of the causes (2 - little relevant, 5 - relevant, 8 - priority), to assess in which phases the intervention is more or less a priority.

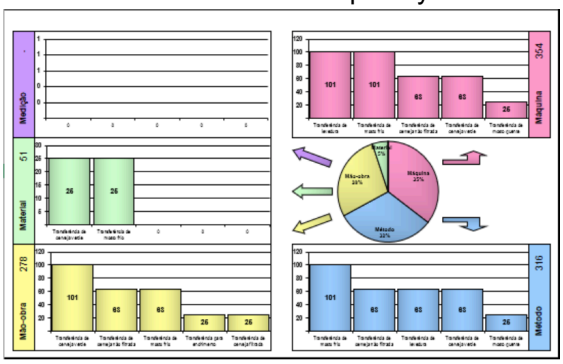

Figure 10 - Distribution of failure occurrence weights based on 5M.

The transfer of cold wort is the most critical phase of the process and is therefore the phase where the study must look with greater focus. High priority grades were attributed to faults in the wort cooling phase associated with the machine (equipment) and method, which makes this phase a focus of intervention. By weight distribution, it can also be concluded that the failures are mostly associated with the machine (35%), and also failures related to the method (32%) and man (28%). Failures associated with materiall are reduced (5%), and no flaws associated with measurement processes.

QM Matrix

Considering the analyzed QA matrix, the wort cooling stage was studied for the construction of the QM (*Quality Management*) matrix. This matrix reflects in a more descriptive way each loss found in the corresponding phase and provides a broader analysis of the weight of each M in the defect in question and the existence or absence of conditions of control and prevention. Failures were identified in 9 process components. 5M prevention and control conditions were defined, as maintenance (audits and maintenance plans) and management body, and next steps to be taken to the optimum condition of the line.

Conclusions and Future Research

The objective of this study was to optimize the conditions of the wort cooling phase installed at Sociedade Central de Cervejas e Bebidas (SCC), in order to meet the priority objectives defined by management at the beginning of 2018. This process was developed in both wort cooling lines into three specific components: aeration, color and extract loss.

Wort Aeration

The identification of defects in the wort aeration line and the definition of new set-points of air injection allowed to optimize the fermentative conditions of the yeast, reflected in a significant improvement in the qualitative parameters of the same, especially in the multiplication rate and dead cells. It is expected that the optimization of air injection produces significant effects on future fermentations in SCC, since ethanol production by *Saccharomyces cerevisiae* is boosted under optimal yeast conditions, and extract losses will be reduced, since the yeast growth is controlled, and its exponential phase is shorter, generating a population with high fermentability. However, due to a large number of varieties to be controlled, the optimization impact on yeast quality could have been even greater. For the future, a possible suggestion is the comparison of results obtained with yeast from the same generation, in order to discard this variable, since yeast age is a condition that has a high influence on its fermentation capacity (Powell *et al.*, 2003). In order for this optimization to continue, it is proposed to evaluate the potential replacement of compressed air injection in the line by pure O_2, since it would theoretically translate into a more efficient O_2 dissolution in the wort, eliminating the occurrence of microbiological contaminations in the aeration line, and there is the possibility of being an economic advantage for SCC, since although the costs of acquiring this gas are higher than compressed air, the quantity needed to use would be much lower (Institute of Brewing and Distilling, 2016).

Wort color

The method used to measure the wort color inline implemented in the SCC was improved in order to generate concordant values with the laboratory and to eliminate the unexpected values that appeared in different brews. It resulted in an improvement in quality results, namely in the Finished Product FTR, where the values obtained for the color reached the defined target. This work also contributed to the

development of the WCBO program, and to a greater sustainability of the production line, since the correction of the inline values allows a preventive control of the parameter, avoiding the occurrence of defects in color, minimizing the need to act correctively for these same defects. The present study had an enormous contribution towards the achievement of excellence in view of the policy of "zero defects" implemented in the company. In the future, efforts should be made to comply with the standards of the constructed preventive maintenance plan in order to avoid a disparity in color values. It is also suggested to carry out wort color measurement tests, using compressed air at the temperature of the brewing wort (13ºC), as well as laboratory color measurement tests at the same temperature as the wort circulating in the pipes, in order to eliminate any influence of temperature on the wort color.

Extract Loss

The construction of QA and QM matrices contributed in a high level for a better characterization of the wort cooling line, and an easier identification of the existing critical points associated with extract loss. With this study several flaws in the process were identified and were constructed several preventive maintenance plans that anticipate and avoid these situations.

In a more general view, this study made a great contribution to the company in monitoring the growth and development of new quality philosophies. The "industrial revolution" that is taking place nowadays at a great speed, requires the monitoring by the companies, automating and digitizing their processes and products offered to the consumer, and at SCC we always try to maintain their excellence and innovation, so that the uniqueness of its methods and products is differentiated and effective in the market.

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