Control and monitoring of the production process with the aim of reducing product loss in the fermentation and filtration of beer.

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Abstract: All the breweries face daily challenges in order to become more competitive in the brewery industry and for this reason new methodologies and new equipment are frequently introduced to the beer production process aiming to reduce the production cost per litre of beer. The introduction of the new methodologies and new equipment intend also to render a more uniform product at the exit of the different steps/processes to avoid the necessity of performing frequent alterations to the diverse parameters from batch to batch.

The aim of the present thesis was to study where would be possible to reduce the production cost, either by reducing the waste of beer or by reusing the latter in the production sector. Firstly, the reduction of beer waste in the daily temperature measurement in fermentation vessels was studied and implemented by changing an analog saccharimeter for a digital thermometer; secondly, the reutilization of high gravity beer that was being wasted between maturation process and kieselguhr filtration was addressed through the introduction of an industrial centrifuge.

Keywords: Brewery, beer, production sector, production cost per litre, process economy analysis.

1. Introduction

The production of beer is supposed to have started in Mesopotamia or Egypt. The making of the beer was then taught to the Greeks and Romans by the Egyptians, which was then passed throughout Europe. [1] The beer is known for being the oldest alcoholic drink in the world, presenting evidence of the production and use of the beer in the Egypt back in the Predynastic era (5500-3100 BC).[2]

The beer industry evolved through the years having a more rigorous procedure and sanitary conditions leading to more complex beers and above all more homogenous beer.

Fermentation is frequently considered as being the rate-determining step in the beer production leading to a lot of effort to discover news ways of increasing the productivity. In this stage the enzymes in the yeast will convert the fermentable sugars present in the wort into alcohol and CO2.

The first step in fermentation is the addition of 0.5-0.7 liters of concentrated yeast slurry per hectolitre of wort, corresponding to (15 – 20) * 106 yeast cells per millilitre of cooled and aerated wort. [3] Many beers are produced using high-gravity brewing, where a wort of high concentration is fermented and then the derived beer is diluted at the end of the process, to reach the common beer gravity.

There are two types of brewing yeast systems in the fermentation, top and bottom fermentation. Normally, the ales are fermented with ‘top yeast’ while the lagers with ‘bottom yeast’, the top fermentation is conducted at a higher temperature leading to shorter fermentation time when compared with the bottom.[4(p5)]

Once the fermentation is finished, the beer must undergo a period of maturation; since it stills contains undesirable flavours compounds and these must be removed by conditioning. In the traditional lagering methods the beer is transferred to a separate tank. Nowadays, the maturation occurs in the same vessel as the fermentation. The presence of a relatively small portion of yeast which remains in contact with the beer has two effects. Firstly, more carbon dioxide is produced leading to carbonating the beer and purging of unwanted volatile compounds. Secondly, the yeast biochemically removes certain other flavour-active compounds, by catalysing the reduction of flavour-active vicinal diketones such as diacetyl.[5(pp11-12)] The total concentration of diacetyl is used to judge the maturity of the beer.[3]

This work aims to reduce the product loss during the fermentation and maturation process through the implementation of new equipment/procedures.

2. Materials and Methods

2.1 Temperature measurement analysis

Presently, to measure the temperature of lager beer in fermentation vessels, beer losses had to occur, by purging. Beer samples were extracted from a pipe connected to the medium height of the fermentation vessel, and the temperature was therefore measured using an analog thermometer.

When the thermometer showed a constant temperature, that temperature was recorded in the temperature registry sheets. The volume withdrawn from the purge, necessary to measure the temperature, was recovered in a volumetric cylinder and then also written down in the temperature registry sheet.

Comparison of the impact of thermometers selection

Two types of thermometers and three thermometers were studied in order to verify if it was a possibility to reduce the volume of lager beer necessary to measure the temperature.

An analog thermometer, from VLB BERLIM reference 2-1600-35, was used to measure the temperature of wort/HGB in the fermentation vessel before this study begun. The impact of using this thermometer on the losses of beer started in the 11th of March and went until the 10^{th} of April of 2019, using the procedure explained above for the temperature measurement.

The next step was the introduction of a digital thermometer, HERTER reference 010204004, which was kindly borrowed by the University of Madeira. A second digital thermometer was then used, this time acquired by the Empresa de Cervejas da Madeira and supplied by TFA, reference 010204017.

In order to evaluate how much high gravity beer volume would be saved with the substitution of the thermometer, all the liters used daily for the measurement were summed with the different thermometers. This analysis was extended to all the fermentation vessels in usage each day. The average volume of beer lost daily with each thermometer was then calculated. All these volumes will have a cost associated, evaluated by multiplying the volumes per the unit production cost price of the product.

Impact of thermal insulation of the purging tube

Regarding the subject of this study, the influence of the thermal of insulation of the pipe from where the beer was recovered was analysed. The fermentation vessels to which purging pipe was insulated were numbered 9 and 30. Like in the procedure performed in the study referred before the volume of beer was recovered to the volumetric cylinder which provided the volume necessary to measure the temperature. The thermometer used for this analysis was the analog thermometer for which had more data from the period without thermal insulation.

2.2 Examination of HGB and yeast purge

Due to the high concentration of suspended solids in the HGB, separation of phases through sedimentation was necessary. Therefore, high gravity beer remained an undetermined amount of time so that it could occur. Then all the sedimented yeast was removed from the CCV due to its negative effects on the beer, purging it from a pipe in the bottom of the fermentation vessel and purging it to an agitation tank through a hose-pipe.

The purged feeds recovered were introduced in a tank of 1200 liters with agitation (2700 rpm with agitator from SEW-EURODRIVE type RF40DT71D2Z) and kept for one hour aiming to obtain a representative sample of all the recovered purge. It is possible to know the volume purged using the level indicator of the tank. The sample was then undergone to the procedure explained in the 2.2.1 Centrifugation.

2.2.1 Centrifugation

Aiming to determine the quantity of yeast and HGB that was recovered from the purges a separation process, more precisely a laboratorial centrifugation, was used. The laboratorial centrifuge used is from Selecta, model Mixtasel-BLT.

Firstly, the empty centrifugation flask was weighed. The same flask was filled with 100 mL of water and the operator marked the meniscus. Then the tube was filled with the sample, homogenous solution of the collected purges, until the marked meniscus and weighed. Next, the sample underwent a centrifugation with the duration of 12 minutes at 4000 rpm. Once the centrifugation is finished the supernatant is withdrawn from the tube. The tube was again weighed, this time with the remaining solids, allowing to obtain the fraction of yeast and HGB in the studied sample.

2.2.1.1 Ratio of HGB on the purges

Firstly, it was obtained the weight of HGB present in 100 millilitres of sample. For that, after the centrifugation the mass of the flask with the remaining solids was subtracted from the initial mass of the flask plus the one hundred millilitres of sample; the calculus explained is represented in the equation 1.

$$M_{supernatant}(g) = M_{Flask + 100mL\ sample}(g) - M_{Flask+Remaining\ solids}(g) \quad (1)$$

Once the quantity (grams) of HGB in 100 mL was determined, then, it was multiplied by a factor of ten to calculate the recovered HGB per unit volume of purge, as is it possible to see in the equation 2.

$$C_{HGB}\left(\frac{g}{L}\right) = M_{supernatant}\left(\frac{g}{100mL}\right) * 10 \quad (2)$$

2.2.1.2 Quantity of beer and yeast extracted in the purges

The next step was to realise the quantity of HGB present in the overall purges and, with that purpose, the total mass of HGB was calculated using the HGB ratio of the sample, obtained from above equation 2, and the total volume recovered from the purges, as represented in the equation 3.

$$M_{HGB}(kg) = \frac{C_{HGB}\ (g/L) * V_{Purged}\ (L)}{1000} \quad (3)$$

One needs to know the volume of purged high gravity beer instead of its mass, given that the production cost price value is given as euros per litre. For that reason, the equation 4 was used to convert the mass of purged HGB into volume.

$$V_{HGB\ purged}(L) = \frac{M_{HGB}\ (kg)}{SG_{HGB}} \quad (4)$$

Were SG is the volumic mass (also known as 'specific gravity') of HGB.

The beer recovered during the purge is high gravity beer meaning that is denser, i.e., more concentrated than the commercial product. Since the production cost price is given according with the commercialized beer price, one needs to verify how much of this will be obtained after dilution of the HGB. For that reason, the equation 5 was used.

$$V_{Commercial\ beer\ purged}(L) = V_{HGB\ purged}(L) * \frac{E_{Wort}}{E_{Final\ product}} \quad (5)$$

Were the variable E_{Wort} and $E_{Final\ product}$ represents the original extract from the HGB and original extract of the commercialized beer, respectively.

2.2.1.3 Pitching and cropping

Also, to take in consideration is the HGB that was lost due to dragging during the separation of the yeast. This quantity of HGB and yeast collected in the yeast cropping, is not truly wasted, since in the pitching process both the HGB and yeast are introduced in CCVs for a new fermentation. To account for the true loss of HGB, it is firstly necessary to obtain the correct mass of suspension of yeast and HGB that exit the fermentation vessel. The latter is obtained by subtracting the quantity that enters to the quantity that exits. (equation 6).

$$M_{Truly\ purged}(kg) = M_{Total\ yeast\ recovered}(kg) - M_{Introduced\ in\ pitching}(kg) \quad (6)$$

The calculated mass was then transformed into volume using the density of the purge, equation 7.

$$V_{Truly\ purged}(L) = \frac{M_{Truly\ purged}(kg)}{\rho_{yeast\&HGB\ cropped}\left(\frac{kg}{L}\right)} \quad (7)$$

After obtaining this volume, the same calculations/procedures were carried as above (centrifugation and equation 1 to equation 5) to obtain an equivalent estimated total volume of beer with the commercialized original extract wasted due to the dragging.

2.3 Fermentation sheet analyses

2.3.1 Fermentation and maturation days determination

Through the analysis of the fermentation sheets, provided by the company, the average number of days which are needed so that the correct fermentation occurs through the different temperature stages was determined. Thereafter, the maturation followed during 4 days at around 0ºC.

2.3.2 Losses associated with the purges

The next information that was obtained through the treatment of data within the fermentation sheet was the quantity of beer that was lost to purges.

For this study, one considered that all the losses of product in the purges, performed after the fermentation and maturation processes were completed, were due to an insufficient sedimentation process and analyses to the fermentation sheets were performed for acquiring the total volume of HGB purged. The difference between the liters of fermentation wort that enter the fermentation vessel and the liters of clarified HGB that are recovered from the vessel were then multiplied by the ratio of extract value of the wort to the extract value intended for the final beer product, to originate the volume that is lost due to all the purges (equation 8).

$$V_{Loss\ during\ purges} = (V_{Entered\ in\ the\ tank} - V_{Recovered\ from\ the\ tank}) * \frac{E_{Wort}}{E_{Final\ product}} \quad (8)$$

With the extract value of the wort and the extract value intended in the final product, is possible to determine the volume of commercialized beer that is supposed to be produced from each tank, by multiplying the total volume entered in the fermentation vessel by the above ratio of the extract values (equation 9).

$$V_{Supposed\ to\ be\ recovered} = V_{Entered\ in\ the\ tank} * \frac{E_{Wort}}{E_{Final\ product}} \quad (9)$$

Calculating the difference between the beer volume that was supposed to obtain for each fermentation vessel and the volume that was actually recovered, one can determine the total volume of beer lost during the sedimentation and filtration processes (equation 10).

$$V_{Loss\ during\ purges\ and\ filtration} = V_{Supposed\ to\ be\ recovered} - V_{Recovered\ after\ dilution} \quad (10)$$

From industrial data in fermentation sheets, the fraction of lost beer was estimated and the value compared with the company prediction to confirm the veracity of the calculus. For this purpose, the volume of beer that was lost in the purges and filtration was divided by the total volume that was supposed to be recovered, as described in the equation 11.

$$\eta_{Loss} = \frac{V_{Loss\ during\ purges\ and\ filtration}}{V_{Supposed\ to\ be\ recovered}} \quad (11)$$

2.4 Evaluation of the gains with the centrifuge

To know which portion of beer would be reused with the introduction of an industrial centrifuge, the total volume that would be purged from CCVs till the day of the correct fermentation and maturation processes cycles was calculate. The process to find the average number of days that are need for these processes is explained in the 2.3.1. Once this value is known, the purges that occurred during and before the range of these days, necessary for the fermentation/maturation cycles, were recovered and analysed through the procedures described in the section 2.2 and 2.2.1, respectively. Then, with the values of the fermentation sheet from the respective fermentation vessel the total volume that was lost in the purges was calculated as indicated in section 2.3.2.

As described in equation 12, the volume lost in the purges before the average days of fermentation and maturation, the volume of beer sold to a local company (directly recovered from the fermentation vessel) and the volume of beer dragged during the sedimentation, were subtracted to the total volume lost in the purges. This made possible the verification of how many liters would be saved using the industrial centrifuge; since all the remaining volume lost in the purges was due to excessive purging, otherwise unnecessary if the referred equipment after the maturation process was in use.

$$V_{Beer\ gain} = V_{Loss\ during\ purges} - V_{Beer\ purged\ before\ complete\ maturation} - V_{Sold\ to\ local\ company} - V_{Beer\ lost\ by\ dragging} \quad (12)$$

Aiming to extrapolate the results obtained from the fermentation vessels studied, urged to find a factor which would be able to apply to all the productions of the company even for those from which no purges were recovered. Due to that need, the yield of recuperation that would be achieved with the use of an industrial centrifuge was calculated (equation 13).

$$\eta_{Centrifuge} = \frac{V_{Beer\ gain}}{V_{Loss\ during\ purges}} \quad (13)$$

2.4.1 Annual loss production of beer

With the purpose of discovering the quantity of the beer that is purged annually and could be reused with the centrifuge, leading to a monetary saving to the company, the procedure explained in section 2.3.2 it was performed for all the fermentation sheet of a determined year. The total volume that was lost due to the purges. The some performed is explained in equation 14.

$$V_{Total\ loss\ in\ the\ purges} = \sum_{Vessel\ 1}^{Vessel\ n} V_{Loss\ during\ purges} \quad (14)$$

Then, the volume that would be possible to recover due to the introduction of the centrifugation equipment was obtained by multiplying the yield of recuperation by the centrifuge with the total volume lost during the purges (equation 15).

$$V_{Gained\ with\ centrifuge} = V_{Total\ loss\ in\ the\ purges} * \eta_{Centrifuge} \quad (15)$$

Multiplying the volume gained with the centrifuge by the production cost price of the beer gives the amount of money that won't be wasted by the purges (equation 16).

$$Cost\ price * V_{Gained\ with\ centrifuge} = Money\ recovered \quad (16)$$

Due to different causes, not all fermentation sheets that permitted the procedure described in the section 2.3.2, which lead to an incorrect quantity of liters that would be reused with the introduction of the equipment. For that reason, a correction factor was introduced which was obtained through the division of the total volume of beer accounted in the study for the total volume of beer that was produced in the timeline of the study, as represented in the equation 17.

$$f_{Correction\ factor} = \frac{V_{Beer\ accounted}}{V_{Beer\ produced}} \quad (17)$$

That correction factor was then applied to the amount of money that was previously determined as the total money that would be saved in a determined timeline (equation 18).

$$Money\ recovered\ (total) = \frac{Money\ recovered\ (accounted)}{f_{Correction\ factor}} \quad (18)$$

2.5 Dilution factor

Since all the volume of beer recovered was HGB it was necessary to convert all HGB volumes to volumes of beer with the commercial original extract (11,25 g/100mL). With this purpose, a dilution factor was applied to the volume of high gravity beer, as described in equation 5.

All the values of extract provided from the fermentation sheets are indicated in Plato degree (˚P) units. However, the original extract of beer should be indicated in g/100mL. To convert the Plato degree (g/100g) to g/100 mL, the specific gravity (SG) of the respective wort must be known. The specific gravity can be estimated from the Plato degree through equation 19.[6(p140)]

$$SG_{Wort\ or\ HGB} = \frac{°P}{258{,}6 - [\frac{°P}{258{,}2} * 227.1]} + 1 \quad (19)$$

Thought the equation 20 it is possible to obtain the desired value of original extract to use in the equation 5.

$$E_{Wort}(\frac{g}{100}mL) = SG_{Wort} * °P \quad (20)$$

3. Results and discussion

3.1 Daily temperature measurement

There are two lines of thought about which factors influence, negatively, the quantity of beer needed for a correct daily measurement of the temperature of the working fermentation vessels. The first one is that the waste is due to the slow time of response from the analog thermometer. The other one is that waste is due to the lack of insulation in the pipe, from which the sample is collected to read the temperature. In the present study, both hypotheses were studied. For both studies, the production cost price of the product was assumed to be 0,15 euros per litre, according to the company.

3.1.1 Thermometer study: analog thermometer comparison with the digital thermometer

The first issue tackled in this thesis, the daily amount of money (in euros) needed in order to perform a correct measurement of the fermentation vessels temperature for each one of the thermometers, was compared. Firstly, was tested the saccharimeter for beer wort (thermometer A), secondly the thermometer borrowed by the University of Madeira (thermometer B) and finally the thermometer acquired by the ECM (thermometer C).

One can see that there was an improvement with the introduction of the thermometer B as the volume of waste had a significant decrease, around 18%, from 12.78 to 10.56 €/day (which is directly proportional to the volume wasted). After verifying that the introduction of a digital thermometer in the process allowed to decrease the waste associated with the procedure, then, thermometer C was purchased and the tests were repeated to see if the results corroborated the first analysis. There was still a decrease in the daily waste of beer when compared with the thermometer A, this time of around 12%, from 12.78 to 11.23 €/day. The reason why the thermometer B was not purchased, was that the thermometer C is more precise and accurate.

The breakeven point of the thermometer bought by the company was then calculated. For that, the amount of money that would be possible to save daily with the new thermometer was then estimated, by comparison with the use of thermometer A. The money saved daily would be around

1,55 € and the cost of the thermometer C was 26,40 €, meaning that it was possible to achieve the breakeven point 17 days after the thermometer was introduced.

3.1.2 Impact of thermal insulation of the purging tube

The next step was to verify if the insulation of the pipe, from which the beer is withdrawn to measure its temperature, would influence the quantity of beer needed for the daily temperature measurement.

Was possible to conclude that the thermal insulation of beer withdrawal pipes does not represent a decrease in the volume necessary to obtain the precise temperature of the fermentation wort/beer in the vessels.

3.2 Centrifugation study for suspended solids reduction

One of the major challenges verified in the brewery, where the study was performed, was the excessive high concentration of suspended solids left in the 'green' beer after gravital sedimentation, which led to an earlier clogging in the posterior filtration. This problem might be solved by introducing a centrifuge between the maturation and filtration processes.

The utilization of the centrifuge has a main goal - the reduction of the suspended solids in the feed stream of the kieselguhr filtration, leading to a significant decrease in the operation time and to a decrease in the diatomaceous earth usage per volume of filtrated beer. Because quantifying the benefits of such additional operation would be difficult, an economic analysis regarding the introduction of the centrifuge was performed.

Another prospective benefit linked to the introduction of a centrifuge would be the reduction of the utilities cost in the fermentation area, since it would not be needed to keep the 'green' beer in the fermentation vessels at low temperatures for so long waiting to reach an acceptable concentration of the suspended solids to proceed to filtration.

In the present study, as in the previous one, the production cost price of the beer was considered to be 0,15 euros per litre.

3.2.1 Fermentation and maturation days

The first step to comprehend how much beer was wasted due to the excessive purges was to discover how much of the purges was necessary, to obtain a beer which had undergone both fermentation and maturation processes correctly and then was ready to undergo filtration, packaging and commercialization, according to the procedure in section 2.3.1.

Aiming to achieve this goal, all the fermentations sheets from the year 2018 were studied so as to get to know the average number of days used so that the fermentation and maturation processes occurred correctly. This would allow to estimate the number of production days gained if the 'green' beer would be sent to the centrifugation, prior to filtration, without compromising the beer quality.

The average number of days needed so that the beer would be ready for filtration by interposing a centrifuge ranged between 18 and 21 days. In order to ease the calculus and the recovery of the samples, all the purges performed after the 21st day are considered excessive, meaning that the fermentation and maturation processes had proceeded correctly until the referred day.

3.2.2 Total purges

The volume of total purges carried out correspond both to the purges done aiming to measure the temperature daily and the purges performed to collect the sedimented yeast. The volume of product used to daily measure the temperature from each fermentation vessel, previous to the period of the study, could not be recovered and this portion was neglected. The accounted volume lost in the total purges was only due to the purges done to collect the sedimented yeast. This was possible since the total volume of product lost in the temperature measurements is significantly lower than the total volume of product lost in the other purges.

The next step was to determine the total volume of beer that was wasted in the purges, the necessary and the unnecessary if there was a centrifuge, during each fermentation in the diverse fermentation vessels. The example which will be presented is the analysis performed to the fermentation vessel 28 which started the fermentation in the 28th of March of 2019.

Firstly, the specific gravity, in Plato degrees (g/100g) was measured and then equations 19 and 20 were used to convert those units into g/100mL.

This analysis was carried out throughout the fermentation and registered in the respective sheet by the company operators. There, one can acquire important data such as the numbers of batches of wort that entered the fermentation vessel, the quantity of HGB liters from each batch and the respective extract. It was also possible to know the liters that exit the fermentation vessel, the original extract and the liters of beer that were obtained after the dilution.

Using equation 8, and the information from the fermentation sheet, the total volume of commercial beer lost during the purges was obtained.

The percentual production loss was also analysed in order to verify if the respective results obtained through the calculus coincide with the information provided by the company. This worked as a confirmation that calculation procedures were correct. For that purpose, equations 9, 10 and 11 were used. In the case of CCV28, the percentual product loss reached 9,46%, which was a similar value when compared with the company's predictions.

3.2.3 Volume reused with centrifuge

After knowing the total volume of HGB that was being purged, it was necessary to discover which portion wouldn't be purged if there was a centrifuge. This means that all the liters of beer purged after the 21st are considered a gain that would be achieved with the equipment introduction.

So, the next object of study was to know the exact quantity of beer that was being wasted in the purges performed after the 21st day. Since the production sector works 24 hours a day, and the purges can occur in any shift, it was not feasible to be present in all the purges done. For that reason, this problem was approached from a different angle.

3.2.3.1 Beer lost in the purges before the fermentation and maturation processes were concluded

Because the purges carried out before the 21st day are more monitored than the subsequent, the approach chosen was to recover all the purges done in the different fermentation vessels before the 21st day, since the respective worts entered the fermentation vessels, and then proceed with the analysis of the sample. The purges were collected to a tank, as explained in section 2.2. Then, a sample was recovered from the tank and the composition of HGB and yeast were analysed after laboratorial centrifugation, as explained in 2.2.1.

The procedure will be explained making use of the same example of the fermentation vessel 28 which started the fermentation in the 28th of March of 2019.

Firstly, for the present problem two main pieces of information about the purges were needed: the volume collected in the purge and the number of days from start of fermentation until the referred purge was done in the fermentation vessel. The measurement of the volume was conducted with the recovering tank and the counting of the fermentation days was realised on account of the fermentation sheet, the values for the parameters of the example referred above were 560 liters and 19^{th} day, respectively.

Secondly, the necessary data was the mass fraction of beer and yeast present in the purge collected, and for that reason the recovered sample underwent a centrifugation, as explained in section 2.2.1.

The results of the HGB ratio in the purge from of the fermentation vessel 28 on the 19th day was 473,2 g/L. obtain through the procedure of centrifugation and equations 1 and 2.

Knowing the HGB ratio in the purge and the volume that was recovered, one can estimate the mass of HGB purged, as explained in equation 3. In the present example, the mass obtained was 265 kg, from which was then obtained the volume of high gravity beer through equation 4.

The HGB specific gravity used for the current investigation was equal in all the purges. The aforementioned was possible given that all the purges were only performed after the extract had achieved a stable value in and around 2.5 P˚, which was then converted in specific gravity using the equation 19. The value of the latter parameter is 1.01 g/cm^3. The volume of HGB collected in the purge in the referred example was 262,4 L and, finally, to achieve the wasted volume of beer with the commercial original extract, which in this case was 315.9 L, equation 5 was used, where the original extract of the wort and original extract of the commercial beer were 13.54 and 11.25 g/100mL, respectively.

The volume of commercialized beer that is purged before the complete maturation, before the 21th day, is then subtracted from the total volume lost in the purges.

3.2.3.1.1 Beer lost due to the yeast cropping

The next parameter that was studied was the volume of beer that was dragged with the first purge, where the goal is to extract the majority of the sedimented yeast after the ‘cold shock’.

A centrifugation procedure was performed to a sample from such purge, as explained in the section 2.2.1, and equations 1 to 2 used to achieve the HGB ratio, which was 371.44 g/L.

Given that the first purge recovered from the fermentation vessel was weighted with the scale incorporated in the recovering tank for yeast, this weight had to be converted in volume, in order for equations 3, 4 and 5 from the previous section to be used.

Therefore, it was necessary to obtain the density of the first purge. For that purpose, it was recovered a specific volume and weighted, allowing for the value of the parameter to be determined, which was 0.92. In order to facilitate the calculus, the density for all the first purges executed, with the purpose of extracting most of the yeast, were considered constant. It was then possible to know the volume of the purge using the mass of the recovered purge and the density of the respective purge on account of equation 7. This allowed one to obtain the volume of beer that could be commercialized but was dragged with the yeast during the sedimentation.

It was taken in considered that the introduced yeast (pitching) contained also beer. So, aiming to ease the calculus, it was considered that the yeast introduced and the one purged had the same composition of beer and yeast, changing only the volume. This was only possible to assume since the yeast introduced in one fermentation vessel was in fact a yeast that was purged from another fermentation vessel. Taking this into account, the mass of yeast and high gravity beer that effectively exit the vessel are obtained through equation 6.

To obtain all the other values was through the same equations used in the previous chapter. Regarding the example of the fermentation vessel 28 which started the fermentation in the 28th of March of 2019, the volume of beer with commercial original extract lost due to dragging was 471.87 liters.

The volume of beer with the commercialized original extract lost due to dragging in the first purge was also subtracted to the total volume lost in the purges Because the fermentation vessel in consideration is the same as the one referred in 3.2.2., the dilution factor will be the same.

3.2.3.2 Beer sold to a local company

Other parameters that would take part in the study of what would be the gain with the introduction of the centrifuge, was the volume of high gravity beer that was sold to a local company. This beer was collected directly from the fermentation vessel as a high gravity beer. So, in order to account the right volume of beer that appears in the losses as purges but are in fact beer that was sold to the local company, equation 8 is needed. Continuing with the example given in the previous section for the fermentation vessel 28, 30 barrels of 30 liters of HGB were collected from this fermentation vessel. Since the beer was high gravity beer, the dilution factor needed to be applied in order to obtain the total volume of beer with the commercial original extract.

In this case, the total volume that was sold to the local company was 1 083,4 liters which was also subtracted to the total volume of beer lost during the purges. Sicne the fermentation vessel was the same the dilution factor was the same as in the previous chapters.

3.2.3.3 Volume of beer gained with the centrifuge

After obtaining all the needed parameters - the total volume of beer that was wasted in the purges, the volume of commercialized beer that is collected before the 21th day, the volume of beer sold to the local company and the volume of beer that was dragged due to the sedimentation process - equation 12 could be used to acquire the volume that would be gained if there was a centrifuge prior to the kieselguhr filtration and after the maturation process of the ‘green’ beer.

$$V_{Beer\ gained} = 4\ 694{,}74 - 315.91 - 1\ 083{,}4 - 471.87 = 2\ 823.56\ L$$

In the case of the fermentation vessel 28, an amount of commercial beer of 2 823.56 liters would be saved with the introduction of the industrial centrifugation in the process to substitute the yeast sedimentation. Besides the benefits already referred, this will lead also to a more uniform product as the income stream of the filtration would always have approximately the same concentration of remaining suspended solids.

3.2.3.4 Yield of recuperation with the centrifuge

Once the quantity of product that would be saved for a singular fermentation vessel was discovered, it was necessary to find a viable way to extrapolate the gains with the centrifuge to all the other sedimentation processes in the factory. The industrial data was available and could be obtained through the fermentation sheets, but that has not been studied yet.

With that purpose, the fraction of lost beer that would not be purged out once a centrifuge had been introduced was calculated using equation 13. In the present example the yield of recovery was 60%.

Thereafter, all the procedures explained in sections 2.2 until 2.4 were performed to another 24 fermentations vessels operating in the facilities during the present study. The value of yield that was used to extrapolate to all the fermentation vessels was the average of the yields obtained from the 25 fermentation vessels, i.e. 62%

It was not possible to observe any tendency in the yield of beer recovery with the centrifuge since the process was mainly manual, leading to an enormous oscillation in the data.

3.2.4 Annual loss in the purges

Finally, all the 184 fermentation sheets from the year 2018 were studied in order to obtain the volume that was purged during the referred year from each fermentation vessel, aiming to apply the yield of centrifugation to all the beer purged so that the total volume that would be recovered in a specific timeline with the implementation of this operation could be obtained.

So, to obtain the total volume lost in the purges in 2018, equation 14 was used. After obtaining the total volume lost in the purges, equation 15 was applied with the goal of acquiring the total quantity of beer that would be recovered with the introduction of the centrifuge. Thereafter, equation 16 was used in order to achieve the exact amount of money that would be saved by the centrifuge. The price of beer recovered due to centrifuge would be 51 062. 49 €.

3.2.4.1 Correction factor

Due to various factors, a few parameters necessary for the computations were illegible in the fermentation sheets. Therefore, not all the fermentations that took place in 2018 were taken in consideration for a correct analysis of the fermentations. So, it was necessary to introduce a correction factor and, for that, equation 17 was used

With the correction factor from 2018 year (0.89) and using the equation 18, it was possible to estimate that the money that would be recovered in 2018 with the use of centrifuge would be 57 354.05€.

Increase in the facilities' efficiency

The introduction of the centrifuge in the process would allow a reduction of product loss verified in the production sector. For that reason, the fermentation sheets of the year 2018 were analysed in order to obtain the percentage of product loss reduction with the new equipment.

It would be possible to reduce the total breakage of the production sector from 10.63% to 6.62%, representing a reduction of 37.74%, for the year 2018.

The same calculus was performed for the year 2017 and in that year, it would have been possible to reduce the percentage of total product loss from 10.1% to 6.93%, representing a reduction of 31.42%.

3.2.5 Centrifuge quotation

The first company that which was possible to approach was the Flottweg which redirected the question to the Sales Engineer Beverage, who provided an informal quotation through the email. The value proposed by the Flottweg was 205,000.00 € for the equipment, 2,500.00 € for the transport and 6,000.00 € for the operation start-up for one week with a process technician from Germany, having a total cost of 213,500.00 €.

The second company to which was possible to contact was GEA. From this one, the quotation delivered was more formal and is presented in annex C. The price for the centrifuge was 228,400.00€ and the costs of transport and start-up were similar (both companies are from Germany), performing a total cost of 236,900.00 €.

Although the quotation from the second company is more expensive, this was the one that was chosen for a breakeven point estimation. The choice was based in two factors: firstly, through the conversation/negotiation it was possible to see that this company could give a better support in Portugal in case of a needed backup; secondly, and even if the breakeven is done with the higher equipment cost, it would still be favourable if the cheaper equipment were to be acquired.

3.2.5.1 Breakeven point of the investment

So, supposing that the centrifuge from the company GEA would be chosen, the next step was the calculation of the breakeven point to verify how long it would take to get enough earning to pay off the investment.

Using the value of beer recovered in the year 2018 was used to calculate the breakeven. Accordingly, the investment would be paid off in a time span of 5 years. Was taken in consideration a security factor of 20% associated to the breakeven time.

4. Conclusion and Future work

During all the study performed, different approaches were discussed and studied which would lead to a reduction of product loss in the production sector in the brewery industry. Firstly, the main challenges that the company was facing in this sector were investigated. Production loss was essentially observed in the volume lost during the daily measurement of temperature from the fermentation vessels and in the volume that was being purged from the fermentation vessels to reduce the concentration of suspended solids. Then, the influence of the analog thermometer used and the thermal insulation of the purging pipe, from which was recovered the sample of beer to read the temperature, in the product loss verified during the temperature measurement was studied. Regarding the thermometer it was determined that the introduction of a digital thermometer provided a decrease of volume loss of approximately 12%, leading to a breakeven point of the investment of 17 days. The thermal insulation of pipe did not show any impact in the reduction of the volume lost.

Concerning the product loss due to the excessive purges, the necessary and unnecessary purges were discriminated. An alternative separation process to the current set-up plant (just sedimentation to separate the 'green' beer from, mainly, the yeast) was analysed. Introduction of an industrial centrifuge would be the most interesting equipment to proceed to the separation of 'green' beer and yeast prior to the kieselguhr filtration. An economic analysis confirmed that the gains with the introduction of the centrifuge would allow an achievement of the breakeven point of such investment in approximately 5 years with 20% of security factor, considering the beer recovered in the year 2018.

With the investment chosen, it was possible to estimate that once the equipment is installed and working, for production similar to those of the years 2018 and 2017 will be possible to reduce the percentage of production loss in the production sector by 37.74% and 31.42%, respectively.

As for future work that could be done, the financial and practical study of the introduction of the centrifuge is suggested. The alternatively proposed centrifuge, the one with the lower throughput, could also be analysed, regarding its ability to clarify the yeasty beer, to reduce the suspended solids concentration with lower efficiency and also extract the trub from the wort. Furthermore, the change of the wort kettle configuration could also be considered in order to enhance its efficiency.

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