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STATISTICAL PROCESS CONTROL OF THE WORT FOR BEER PRODUCTION OF “PEJA BEER”

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Abstract. This study evaluates the process of production wort for beer production of “Peja Beer”. Samples of wort were taken for the period of ten days for measurable characteristics: original extract, pH and color. The process was conducted under real production conditions, where every four hours 315 hl of wort was produced. The Shewhart Control Graph for Individual Measurements was taken to determine if the process was with respect to each quality characteristic statistically under control. Based on the obtained results, we came to the conclusions that the process was under control. The upper and lower control limit for the original extract and pH were within the specifications while the color must be corrected.

Keywords: Wort, beer, pH, original extract, color, control graphs

Introduction

Wort Production

Beer is a fermented aqueous drink based on starch and flavoured by hops. The basic ingredients of beer are water; starch source such as malted barley able to be fermented (converted into alcohol): a brewer’s yeast to produce the fermentation; and a flavouring, such as hops, to offset the sweetness of the malt.[9]

The fundamental processes of brewing are malting, mashing, lautering, boiling, fermentation, maturation, filtration and packaging.
Malting is the process where barley grain is made ready for brewing, converting barley to malt. Malting is broken down into three steps in order to help to release the starches in the barley. First, during steeping, the grain is added to a vat with water and allowed to soak for approximately 40 hours. During germination, the grain is spread out on the floor of the germination room for around 5 days.[5]

The final part of malting is kilning when the malt goes through a very high temperature drying in a kiln; with gradual temperature increase over several hours. When kilning is complete, the grains are now termed malt, and they will be milled or crushed to break apart the kernels and expose the cotyledon, which contains the majority of the carbohydrates and sugars; this makes it easier to extract the sugars during mashing.[7]

Mashing is the process in which malt grist, solid adjuncts, and water are mixed together at a suitable temperature for the malt enzymes to convert the various cereal components into fermentable sugars and other nutrients. Mashing converts the starches released during the malting stage into sugars that can be fermented. The milled grain is mixed with hot water in a large vessel
known as a mash tun. In this vessel, the grain and water are mixed together to create a cereal mash. During the mash, naturally occurring enzymes present in the malt convert the starches (long chain carbohydrates) in the grain into smaller molecules or simple sugars (mono-, di-, and tri-saccharides). The principal enzymes responsible for starch conversion are β and α-amylases but also proteases, leading to a mixture of sugars and peptides or amino acids, producing wort of the desired composition.[3],[6]

This conversion is called saccharification which occurs between the temperatures 60–70°C. The result of the mashing process is a sugar-rich liquid or “wort”, which is then strained through the bottom of the mash tun in a process known as lautering. Prior to lautering, the mash temperature may be raised to about 75–78°C (known as a mashout) to free up more starch and reduce mash viscosity. Additional water may be sprinkled on the grains to extract additional sugars (a process known as sparging).

After mashing, when all the starch has been broken down, it is necessary to separate the liquid extract (the wort) from the solids. Wort separation is important because the solids contain large amounts of protein, fatty material, silicates and polyphenols (tannins). This insoluble, undergraded part of the malted barley grain is allowed to settle to form a bed in the mash tun and the sweet wort is filtered through it (lautering). The filtered wort is used as the fermentation medium to produce beer. The residual solid fraction obtained after this stage is known as brewer’s spent grains.[3]

Following extraction of the carbohydrates, proteins, and yeast nutrients from the mash, the clear wort must be conditioned by boiling in the kettle. After filtration, the wort is transferred to the brewing kettle, where it is boiled during at least one hour with the addition of hops. Boiling is needed to isomerize the hop alpha acids, to strip out unwanted malt and hop volatiles, to denature proteins and coagulate proteins/polyphenols as hot break, and to fix the wort composition by terminating all enzymic and microbiological activity surviving the mashing process. The purpose of wort boiling is to stabilize the wort and extract the desirable components from the hops, which will confer typical beer qualities, such as bitter taste, flavor, and foam stability. At the end of the boiling period, the hopped wort is transferred to a vessel known as a whirlpool, where further separation of hop residues (spent hops) and the trubaceous matter (hot break) takes place.[3],[6], [8] The hop residues, which are then useless, are dumped directly as being of no further value.

After boiling and clarification, the wort leaving the whirlpool has to be cooled in preparation for the addition of yeast and subsequent fermentation. Wort is usually cooled through plate heat exchangers. The principal changes that occur during wort cooling are as follow: cooling the wort to yeast pitching temperature, formation and separation of cold break and oxygenation of the wort to support yeast growth.

**Shewhart Individuals Control Chart**

Individuals control charts are statistical tools used to evaluate the central tendency of process over time. Individuals control charts are used when it is not feasible to use averages for process control. Control charts for individuals are often used to monitor batch processes, such as chemical processes, where the within-batch variation is so small relative to between-batch variation that the control limits on standard X chart would be too close together. Range charts are used in conjunction with individuals charts to help monitor dispersion.[10]

Points outside of these control limits are signals indicating that the process is not operating as consistently as possible; that some assignable cause has resulted in a change in the process. Similarly, runs of points on one side of the average line should also be interpreted as a signal of some change in the process. When such signals exist, action should be taken to identify and eliminate them.[11]

**Calculation of moving range**

The difference between data point, \( x_i \), and its predecessor, \( x_{i-1} \), is calculated as \( MR_i = |x_i - x_{i-1}| \).
For “m” individual values, there are m-1 ranges. Next, the arithmetic mean of these values is calculated as 
\[
\bar{MR} = \frac{MR_1 + MR_2 + \ldots + MR_{m-1} + MR_m}{m-1}
\]
If the data are normally distributed with standard deviation \(\sigma\) then the expected value of \(\bar{MR}\) is
\[
d2\sigma = \frac{2\sigma}{\sqrt{\pi}}. [11]
\]
**Calculation of moving range control limit**

The upper control limit for the range (or upper range limit) is calculated by multiplying the average of the moving range by 3.267:

\[
UCL_r = 3.267 \bar{MR} \tag{1.1}
\]

The value 3.267 is taken from the sample size-specific D4 anti-biasing constant for \(n=2\), as given in most textbooks on statistical process control. [4]

**Calculation of individuals control limits**

First, the average of the individual values is calculated:

\[
\bar{x} = \frac{x_1 + x_2 + \ldots + x_{n-1} + x_n}{m} \tag{1.2}
\]

Next, the upper control limit (UCL) and lower control limit (LCL) for the individual values (or upper and lower natural process limits) are calculated by adding or subtracting 2.66 times the average moving range to the process average:

\[
\text{UCL} = \bar{x} + 2.66 \bar{MR} \tag{1.3}
\]
\[
\text{LCL} = \bar{x} - 2.66 \bar{MR} \tag{1.4}
\]

The value 2.66 is obtained by dividing 3 by the sample size-specific \(d_2\) anti-biasing constant for \(n=2\), as given in most textbooks on statistical process control. [4]

**Materials and Methods**

The statistical process control of the wort for beer production was performed at Beer Factory “Peja Beer”. The chemical analyses were done at the Factory Laboratory.

**Raw Materials**

Water for the mush production is used from the spring of White Drini. For mush production was used malted barley produced from Scarlet type two row barley in Croatia Nova Gradishka. Lupulo (Humulus Lupolus): Germany – CO2- Hop Extract Hallertauer magnum, Hop Styrian Aurora and Hallertau Perle PELET TYPE 90, Slovenia.

**Mash Preparation**

For mash production was used 100% malted barley. Malt is milled with conditioning milling in ratio of: malt with water, 1: 3. Grindling of malt was done at 45°C. The process of mashing production is done by infusion, figure 2.1. The breaks and temperatures used for Phytase was 45°C, Protein rest 52°C, Maltose rest 63°C and Saccharification rest 72°C. The whole mass was then heated to 76 °C and held for 10 minutes. At the end of the heat treatment, all the mass is transferred to the drain to remove the filtrate. After withdrawing the whole mush and removing the trub, the obtained mush was boiled for 60
minutes at 95 °C, with addition of hops in three doses. The first dose of hops was of 50%, the second dose of 30% and the third dose of 20%.

![Temperature vs Time](image)

Fig. 2.1. Temperature vs Time in infusion method

### Methods of Analysis

#### Original Extract

The determination of original extract was made according to the method (EBC Method: 8.5). By Beer-analyzer was determined the wort original extract expressed in percentage (%).

The following devices were used: Alkoolizerbeer, Anton Paar DMA 4500, densitymeter, Sp-1m Sample changer (Anton Paar GmbH, Germany) and cuvette.

In the beer-analyzer, the cuvette were placed in the following order: the first cuvette with distilled water, the second cuvette with alcohol, the third cuvette with mush, the fourth cuvette with NaOH and the other four cuvette are filled with distilled hot water at 60 °C, while the number of cuvette were taken according to the number of samples we analyzed.

Wort samples were filtered through filter paper. The filtered wort was poured into the cuvette, placed in a beer analyzer where measurements were made and the results read.

The Original Extract (EO) was calculated by Balling formula:

\[
OE(\%) = \frac{(2.0665 \times A) + E_R}{100 + (1.0665 \times A)} \cdot 100
\]

where are: \(OE = \) original extract of wort in percentage, Plato, \(A = \) content of alcohol by mass (% m/m), \(E_R = \) real extract of beer in percentage, Plato.

#### Wort Color

The wort color is determined by spectrophotometer (EBC Method: 8.5). The absorbance of wort was measured at a wavelength of 430 nm in a 10 mm cuvette. The color in EBC (European Brewing Convention) units was obtained by multiplying the absorbance by a given factor. The color measurement was performed by Agilent 8453 spectrophotometer (Agilent Technologies, Santa Clara, California), cuvette dimension of 10 mm, membrane filter holder, membrane filters porosity of 0.45 micron. The spectrophotometer was adjusted to 430 nm wavelength, having a precision of ± 0.5 nm. The sample was not diluted so that we have absorbance at 430 nm, within the linearity of the spectrophotometer. Measurements were made in the room of 10 mm. The sample was filtered through a membrane filter to which 1 g/liter of
kiselgur was added for clarification of the sample. The calibration of the spectrophotometer was done by setting the wavelength at 430 nm.

The cuvette was filled with distilled water and the apparatus was calibrated at absorbance of 0.00. The cuvette was filled with wort from the sample, and then read the absorbance.

The colour of the undiluted sample was calculated using the formula:

\[
\text{Color (EBC unit)} = A \times f \times 25 \tag{3.2}
\]

where \(A\) = absorbance at 430 nm in a 10 mm cuvette and \(f\) = dilution factor and the result was expressed in units of EBC in two significant digits.

**Wort pH**

The wort pH was determined by the Method (EBC Method: 8.17.)

**Working tools:**
- pH meter, HACH HQ430d flexi,
- standard solution for calibration of the apparatus,
- test tubes and
- distilled water.

**Sample preparation:**
An Erlenmeyer flask is obtained in which the wort is heated till 20°C the sample is filtered then we have determined the properties of wort.

**Working procedure:**
After calibration of the pH-meter with buffer solution, the electrode is rinsed with distilled water and dried thoroughly then immersed in the sample, mixing the solution with the electrode and allowing it to stand slightly (until the pH value does not changes in pH-meter), then we read the pH value. Much standard pH values ranged from 5.2-5.6.

**Results and Discussion**

Calculations of the different control cutoff points are exhibited as follows.

**For original extract:**

\[\bar{x} = \frac{13.29 + 13.18 + 13.05 + \cdots + 13.01 + 13.1 + 13.22}{60} = 13.10483\]

\[\bar{x} = 13.10483/\text{(CL: Control Limit or Central Line)}\]

\[MR_1 = |x_2 - x_3| = |13.18 - 13.29| = 0.11\]

\[MR_{59} = |x_{50} - x_{51}| = |13.22 - 13.10| = 0.12\]

\[MR = \frac{0.11 + 0.13 + 0.03 + \cdots + 0.04 + 0.09 + 0.012}{59} = 0.07949\]

\[MR = 0.07949\]

\[UCL = \bar{x} + 3 \frac{MR}{d_2} = 13.10483 + 3 \frac{0.07949}{1.128} = 13.3162\]

\[LCL = \bar{x} - 3 \frac{MR}{d_2} = 13.10483 - 3 \frac{0.07949}{1.128} = 12.8934\]
Figure 4.1. Control charts for individual observations of original extract and for the moving range

For pH:
For the average of the individual values
\[
\bar{x} = \frac{5.27 + 5.30 + 5.35 + \ldots + 5.32 + 5.22}{60} = 5.2555
\]

\( \bar{x} = 5.2555 \) (CL: Control Limit or Central Line)

\[
MR_1 = |x_2 - x_1| = |5.30 - 5.27| = 0.03
\]

\[
MR_{59} = |x_{60} - x_{59}| = |5.27 - 5.22| = 0.05
\]

\[
\overline{MR} = \frac{0.03 + 0.05 + 0.02 + \ldots + 0.12 + 0.10 + 0.05}{59} = 0.050169
\]

\( \overline{MR} = 0.050169 \)

UCL = Upper Control Limit
LCL = Lower Control Limit

\[
UCL = \bar{x} + 3 \left( \frac{\overline{MR}}{d_2} \right) = 5.2555 + 3 \left( \frac{0.050169}{1.128} \right) = 5.3889
\]

\[
LCL = \bar{x} - 3 \left( \frac{\overline{MR}}{d_2} \right) = 5.2555 - 3 \left( \frac{0.050169}{1.128} \right) = 5.1221
\]
Figure 4.2. Control charts for individual observations of pH and for the moving range
For Color:
For the average of the individual values
\[ \bar{x} = \frac{6.4 + 8.1 + 6.7 + \cdots + 8.1 + 7.1 + 7.7}{60} = 7.832 \]
\[ \bar{x} = 7.832 \text{(CL: Control Limit or Central Line)} \]

For the moving range
\[ MR_1 = |x_2 - x_1| = |6.4 - 8.1| = 1.70 \]
\[ MR_{59} = |x_{60} - x_{59}| = |7.7 - 7.1| = 0.6 \]
\[ \frac{MR}{MR} = \frac{1.70 + 1.40 + 0.80 + \cdots + 0.00 + 1.00 + 0.6}{59} = 0.9949 \]
\[ MR = 0.9949 \]
UCL = Upper Control Limit
LCL = Lower Control Limit
\[ UCL = \bar{x} + \frac{3 \cdot MR}{d_2} = 7.832 + 3 \cdot \frac{0.9949}{1.128} = 10.478 \]
\[ LCL = \bar{x} + \frac{3 \cdot MR}{d_2} = 7.832 - 3 \cdot \frac{0.9949}{1.128} = 5.186 \]
Based on obtained results of measurable characteristics of wort such as original extract, pH, and color, we came to the conclusion that the process of wort production is statistically under control. Range charts are used together with individual charts to observe the distribution of variables.

From the control charts for the original extract, we came to the conclusion that the process is under control and within specification given that we have an average value (center line) of 13.105%, the upper control limits, UCL is 13.32% and lower control limits, LCL is 12.89%, while the values set by the company for the specifications we have, the average value of 13%, while the lower specification limits, LSL is 12.7% and upper specification limits, USL is 13.3%.. Observation 53 points these are outside the moving range control limit.

From the control charts for pH we conclude that the process is under control and within specification given that we have an average value (center line) of 5.25, the upper control limits, UCL is 5.38 and the lower control limits, LCL is 5.12 while the values set by the company for the specifications we have for the lower specification limits, LSL the value of 5.2 and the upper specification limits, USL the value of 5.4. Observation 41 to 51 points are outside the individual control limits.

From the control charts for color we conclude that the process is under control and out of specification given that we have an average value (center line) of 7.83 EBC, upper control limits, UCL is 10.48 EBC and the lower control limits, LCL is 5.19 EBC while the values set by the company for the upper specification limits, USL the value of 9.5 EBC and for the lower specification limits, LSL the value of 6.5 EBC. Observation 47 points these are outside the moving range control limit.

**Conclusions**

1. According to control charts for individual observations of pH and for the moving range from 41 to 51 points are outside the individual control limits thus should be identified and eliminated in the process.
2. Specifications for wort color must be corrected.
3. The brewing company should apply the statistical process quality control, SPC method to improve and maintain the quality of its product by controlling the raw material and all stages of the brewing process such as the process of wort production, the process of fermentation and maturation, the process of filtration, filling and packaging.

4. The company should establish a Statistical Quality Control unit and employ trained personnel to monitor the progress of the processes and to ensure durable and reliable quality characteristics of their final products.

5. The company should maintain accurate statistical data on their production in order to help the statistical control unit to have access to improve the quality of subsequent products.

References