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ENERGY ANALYSIS OF BEER BREWING UNDER BATCH PROCESS.

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***Keywords**: This paper reports an energy assessment of an actual brewing process. A step by step description of the most relevant stages of the process is presented, performed in a laboratory scale facility. The hot stage of the cooking process is performed on three 304 stainless steel tanks, with an individual capacity of 65 liters, assembled on a vertical metal frame platform. The hot part of the process is driven by electric heaters and the cold one is performed on a domestic refrigerator, dedicated to the fermentation control. A 50 liters batch run required 7 hours and 30 minutes for the hot stage, followed by an additional 14 days for fermentation and maturation. The total energy consumed along the process was estimated to be around 197 MJ, resulting in an average consumption of 3.94 MJ/l. This energy is divided into 96% for electricity, of which 74% corresponds to cold processes and 22% to hot processes, and the remaining energy expenditure concerns the manual processes. Compared to data from literature, for large scale continuous production breweries, results from the present study displayed a much higher value of energy per volume. Although differences were quite big, that was expected for batch based processes.*

***Keywords**: Microbrewery, Small scale brewing process, Malt drink, Batch process.*

1. INTRODUCTION

Beer is the 5th most consumed beverage in the world, behind tea, soda, milk and coffee (OCDC, 2005). Its worldwide production in 2015 was higher than 1.9 billion hectoliters, maintaining an economically strategic position in the food industry (KBU, 2015).

Beer market continues booming, allowing for the emergence of microbreweries, which ends up sharing a slice of the large breweries' market. Microbreweries strategy is based on high quality raw materials and special brewing processes. Competitiveness and environmental impact reduction become issues, and energy consumption came as a key concern.

According to Fadare et al., 2010, the main alternatives to reduce the environmental impact and energy consumption in the beverage industry may come from the increase in energy conversion efficiency by using cogeneration systems, process intensification and choice of renewable energy sources. Studies on that direction were carried out on "green breweries" by Muster-Slawitch at al., 2010, and on storage of hot water by Majozi et al., 2009.

Microbreweries have an advantage in respect to big ones when it comes to possibilities of energy consumption reduction, due to their complexity and flexibility. Fadare et al., 2010, studied a 1,700,000.00 hl/year southwestern Nigeria brewery , whose main energy sources were electricity, heat and human labor. Main processes were reported as: a) grain weighing, charging, cleaning and milling; b) wort boiling, enzymatic conversion, grain filtering, cooling and decantation; c) wort finishing by filtering, density correction and carbonation; and d) bottle washing and inspection, beer filling and packaging, pasteurization, label placement, boxing and palletizing. The study referred to a 9.8 ton malted grain batch, producing 563 hectoliters of beer, with a specific energy consumption of 261.63 MJ/hl.

Muster-Slawitsch et al., 2011, in their "Green Brewery" project, collected data from continuous productions breweries (2 medium sized and 1 small facility), using the heat exchangers network method. This method only concerns flow and thermal processes, such as wort pre-heating and cooking, water filtering, grain washing, bottle washing and packaging, water heating, steam generation and condensing, and flue gas exchangers. Medium sized breweries displayed a specific energy consumption of 60.0 MJ/hl for a range of 800,000.00 to 1,000,000.00 hl annual production, while the small brewery displayed a specific energy consumption of 104.7 MJ/hl for a range of 20,000.00 to 50,000.00 hl annual production.

Scheller et al., 2008, reported an average specific energy consumption of 72 MJ/hl for a few large size German breweries with annual production higher than 500,000.00 hl. Their brewing processes recompress vapor during wort boiling, adding high electrical power consumption. In order to reduce overall consumption, authors reported the use of a wort kettle with internal boiler combined to a heat recovery system based on vapor condensing and an energy storage system.

Kubule et al., 2016, conducted a 3 years long study on the key opportunities to increase energy efficiency in a small brewery with annual production between 15,000.00 and 17,000.00 hl. Collected data showed an average specific consumption of 317.3 MJ/hl for the 1st year, 313.4 MJ/hl for the 2nd year and 300.46 MJ/hl for the 3rd year. The reduction in the annual energy consumption was due to equipment refit.

The growing concern on energy consumption in small breweries associated to the scattering of available data motivated the present study. A 0.5 hl laboratory workbench was designed and built in order to allow for energy assessment.

2. BREWING PROCESS AND WORKBENCH

The workbench design searched to reduce human labor and to rationalize energy expenditure with reduced overall brewing time.

According to BJCP (Wolfe at al., 2015), the simplest mashing process is performed by single infusion, which has the advantage of requiring a minimum of human labor, equipment, energy and time. It prohibits, as a disadvantage, the use of undermodified malt or adjuncts. Some minor modifications allow for the process to become more flexible, with a customized sequence of operation, also called as step-infusion mash. This method was chosen as it avoids grain to be in contact with the heat source, which could roast malted grain, bringing astringency to beer.

The method required a hot liquor tank, dedicated to heat the infusion water, a mash tun tank, for the water to grain mixture, and a boiling kettle, to perform the final hot step. All tanks in the workbench were made on 304 stainless steal, and the first and third tanks were powered with 6 kW electrical resistances, horizontally placed at 30 mm from the tank bottom (Calegari, 2013). Following that same order, tanks were placed on a metal stand at different heights, allowing for a sequential transfer of water and wort, through proper food grade hoses. A plastic flat bottom tank was used for wort fermenting, installed inside a domestic refrigerator with an auxiliary temperature controller. Fig. 1 presents the workbench brewing flowchart that correlates processes to their equipment.

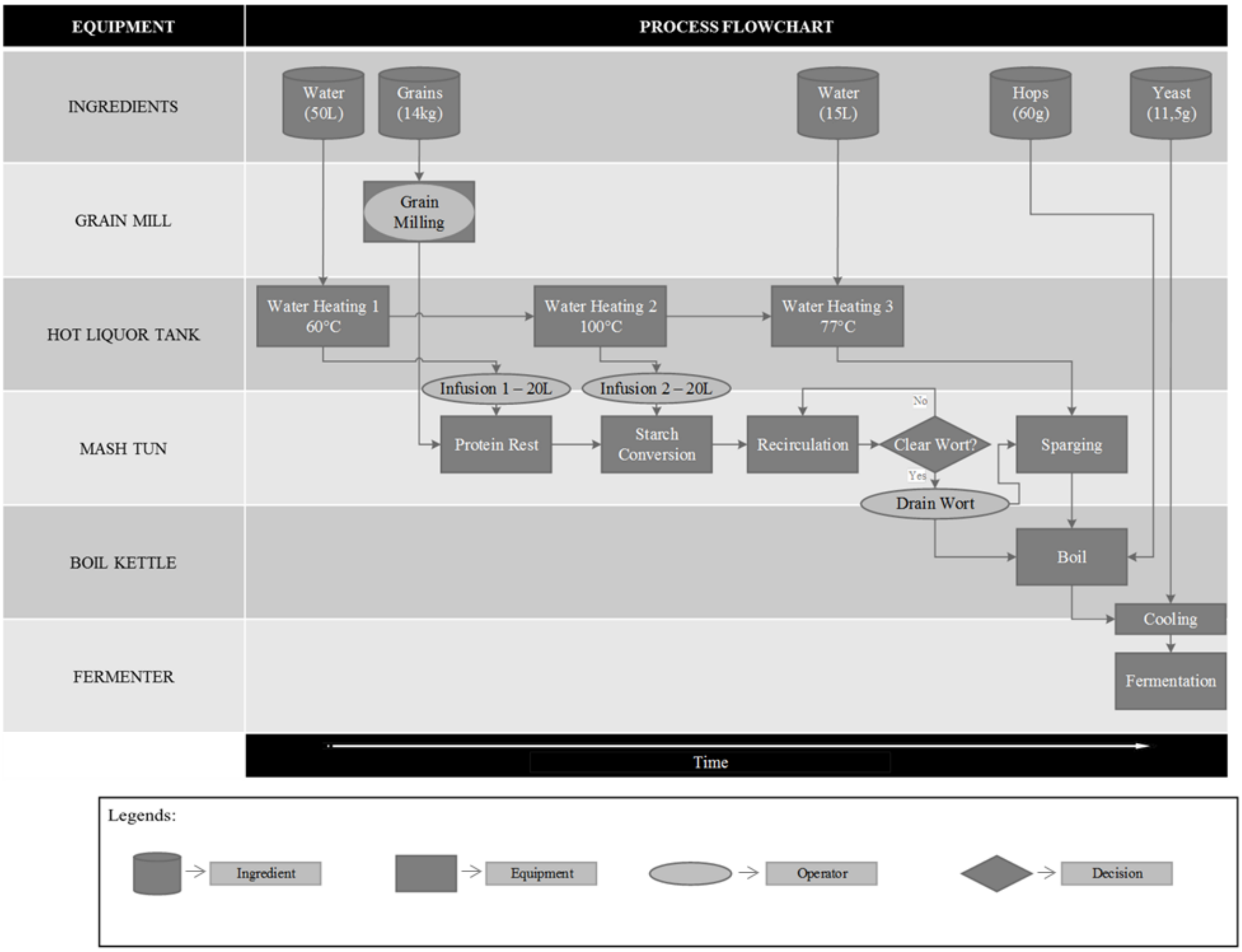

Figure 1. Brewing flowchart with equipment and processes.

The brewing process (3rd line) starts by filling the hot liquor tank with 50 liters of filtered tap water and heating it to 60°C. Meanwhile, grain mill is set up on the bench and malted grains are crushed (1st line) and stored in the mash tun tank .Whenever water from that hot liquor tank reaches the desired infusion temperature, a 20 liters volume is transferred to the mash tun tank, allowing for the protein to rest. This is a 20 minutes process with the purpose of breaking the malt proteins, and is referred as infusion 1 at line 4.

The remaining water at hot liquor tank is heated to 100°C, and another 20 liters volume is again transferred from that tank into the mash tun tank to perform infusion 2. That step of the process raises the mixture temperature to 70°C, starting the enzymatic conversion process which lasts for 40 minutes. This process is also called saccharification because at this temperature some enzymes are activated converting the starch into fermentable sugars. At the end of that step, mixture temperature falls to about 63 °C, and the performed range is known to be optimal for Alfa and Beta Amylases enzymatic conversion.

At the end of the enzymatic conversion step, wort filtering is performed by recirculating it on the mash tun tank (line 4). First of all, the wort is withdrawn from the tank bottom valve and discharged back on its top, in order to promote grain bed stabilization and build a filter medium to retain protein and particles of crushed grains. Simultaneously, extra 15 liters of tap water is added to the hot liquor tank and heated to 77°C.

Whenever wort is considered clear (line 4, logical operator), it is drained into the boil kettle tank (line 5) and the remaining hot water from the hot tank is again transferred into the mash tun tank to extract the wort withheld in grains bed. This process is also called lautering and is responsible to separate the wort from the grains as well as to increase the yield of the mashing process.

Whenever the lautering is finished, an approximate 56 liters of wort is boiled on boil kettle tank for 60 minutes, after hops addition. It takes 35 minutes to achieve the boiling temperature, and the overall process takes 95 minutes. Once the process is ready, wort is cooled down to room temperature and poured into the fermenter (line 6). Yeast is added, and the fermentation process should be carried out at controlled temperature. A domestic refrigerator is used to keep the fermenter temperature at 17°C and this process usually ranges from 7 to 10 days, depending on beer style. Some special yeasts can be added at that moment.

At the end of that period, the final mixture can be considered as beer, ready to be bottled. A proper filling tube is connected to the fermenter to fill the bottles, preventing the beer from oxidizing. As the filling is performed, a little amount of sugar is added to allow yeast to convert it into carbon dioxide, and give extra carbonation. Bottles are kept under refrigeration (17 °C) for an extra 7 days period, and the final product is a ready to drink beer at 3 bar internal pressure.

3. ENERGY ASSESSMENT

3.1 Main Energy Demands

The main energy sources identified in the case studied were electrical and human. Electrical consumption came from the resistors that drove the mashing and boiling processes and run the refrigerator on the fermenting period. Human physical expenditure was also assessed, as small scale brewing depends on physical labor.

Electrical energy consumption E_P (Wh) was calculated by

$$E_P = Pt \tag{1}$$

with t as time (h) and P (W) the apparent power of all devices, given by

$$P = UI \tag{2}$$

U and I are electrical tension (V) and current (A), respectively.

According to Farinatti, 2003, the human physical expenditure is calculated in accordance to the body's activity, usually expressed in kcalories, but easily converted into joule. The expression to estimates the human physical expenditure E_H is

$$E_H = \frac{4.186\, MET\ m\ t}{1000} \tag{3}$$

where MET stands for the Metabolic Equivalence of Task (Tab. 1), equivalent to 58.2 W/m^2, m is the body mass (kg) and t is the time (h)

Table 1. Metabolic equivalent activity MET by activity level (Ainsworth et al., 2000)

Physical Activity	MET
Sitting – typing or writing	1.5
Standing – light effort	2.3
Standing – moderate to light effort	3.0
Standing – moderate effort	3.5
Standing – moderate to heavy effort	4.0

3.2 Instrumentation

Acquired data to evaluate the energy consumption was made by the following equipment.

Table 2. Workbench instrumentation and characteristics

ID	Equipment	Model	Resolution	Uncertainty
1	Digital Multimeter	Politerm - POL-777	0,01 V	±(1,5% + 30d)
2	Digital Clamp Meter	ICEL - AD-6900	0,01 A	±(2,0% + 5d)
3	Electronic Precision Scale	Marte - AC10k	0,1 g	±1,1 g
4	Thermocouples	J type	68 µV/°C (Sensibility)	±0,75%
5	Data Logger	Agilent – 34970A	22 bits	±0,004%
6	Digital Stopwatch	Oregon Scientific	1/100 s	±0.041 s

A digital multimeter (1) and a clamp ammeter (2) were selected to calculate the real power of the heating elements and the refrigerator compressor, and consumption was obtained after time integration, measured by a digital timer (6). Malted grains mass was previously known as they were delivered on 1 kg bags, but they were verified by a digital balance (3).

The hot process temperature profiles were followed by thermocouples (4) installed inside the 3 tanks, connected to the data logger (5). A chronometer (6) measured the process periods and its uncertainty was evaluated based on Trillo et al, 2004. That same instrument was used to monitor the compressor running time over 2 hours. That measured sequence was extrapolated to a 24-hour period, in accordance to the study of Lorenzini et al., 2007.

4. RESULTS

Results refers to a 50 liters beer brewing batch that took approximately 6 hours and 30 minutes, 14 days of fermentation and carbonation and extra 60 minutes for the bottle filling process. Energy sources were mainly electrical and human expenditure.

4.1 Mashing temperature profile

Figure 2 shows the mashing and boiling temperature profiles, acquired on the 3 workbench tanks for an overall period of 3 hours

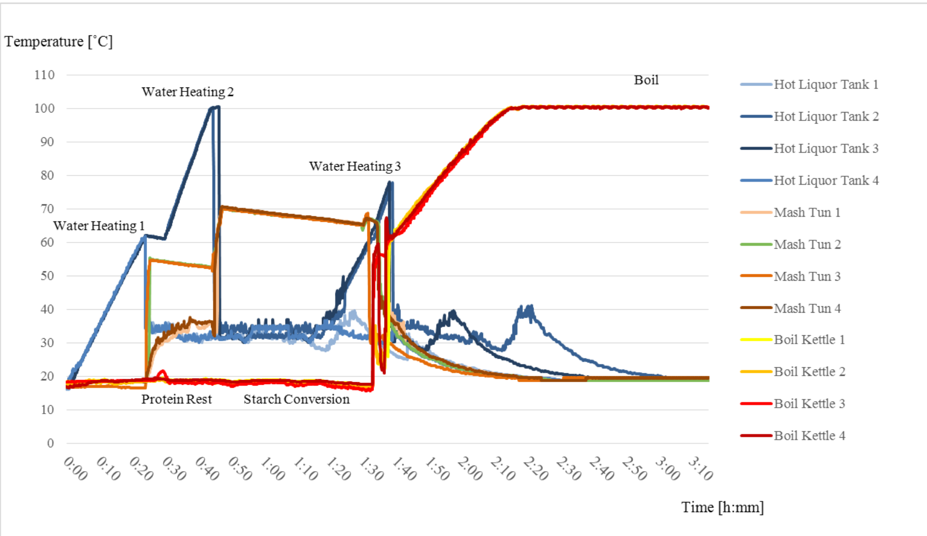

Figure 2. Brewing process temperature profile.

It can be seen that the fluid temperature in the hot liquor tank was the first one to respond, followed by the one in the mash tun tank, and finally closed by the boiling kettle tank. An overall analysis of the temperature curves shows that they performed in a quite coherent way with the expected process behavior. Water temperature was raised from environmental conditions till 100 °C on the step called water heating 1, only as a short episode, and it was kept at that level as a baseline along the boiling process.

4.2 Equipment Energy Consumption

Table 3 shows the energy inventory according to each of the brewing processes

Table 3. Equipment Energy Inventory.

Operation	Equipment	Electric Power (W)	Time (h)	Energy (MJ [kWh])	Uncertainty (MJ [kWh])
Water Heat 1	Hot Liquor Tank	5358.99	0.42	8.04 [2.24]	0.22 [0.06]
Grain Mill	Grain Mill	655.32	0.30	0.71 [0.20]	0.02 [0.01]
Water Heat 2	Hot Liquor Tank	5358.99	0.25	4.82 [1.34]	0.13 [0.04]
Water Heat 3	Hot Liquor Tank	5264.00	0.37	6.95 [1.93]	0.20 [0.05]
Boil	Boil Kettle	5358.99	1.60	30.88 [8.57]	0.84 [0.23]
Fermentation	Refrigerator	209.43	95.20	71.78 [19.94]	3.67 [1.06]
Carbonation	Refrigerator	209.43	99.20	74.79 [20.78]	3.82 [1.06]
		Total Energy:		189.91 [52.75]	5.38 [1.49]

The overall electrical energy consumption was experimentally measured as 189.91±5.38 MJ [52.75±1.49 kWh]. All heating processes were responsible for 43.34 MJ, or 22.8% of the total energy expenditure. Among then, boiling was the most energy consuming. It becomes obvious that the cooling energy, almost 78%, must be the focus for energy efficiency on breweries. The power consumption per operation depends mainly on the beer style, size and age of the equipment, and especially of the scale of production

The specific energy consumption for this workbench was of 3.79±1.05 MJ/L, or expressed in 379.82±105.27 MJ/hl for future comparisons to values reported by breweries

4.3 Human Physical Expenditure

Table 4 brings the human physical expenditure for this particular brewing process.

Table 4. Energy inventory of physical activities expenditure for the brewing workbench

Operation	Number of People	Activity	Time (h)	Energy MJ [kWh]
Equipment Cleaning	1	Standing – moderate to heavy effort	0.83	1.12 [0.31]
Hot Liquor Tank Filling	1	Standing – light effort	0.12	0.09 [0.02]
Grain Milling	1	Standing – moderate to light effort	0.33	0.33 [0.09]
Infusion 1	1	Standing – light effort	0.05	0.04 [0.01]
Milled Grain Addition	1	Standing – moderate to heavy effort	0.17	0.22 [0.06]
Infusion 2	1	Standing – light effort	0.07	0.05 [0.01]
Hot Liquor Tank Filling	1	Standing – light effort	0.08	0.06 [0.02]
Recirculation	1	Standing – moderate effort	0.67	0.78 [0.22]
Sparging	1	Standing – light effort	0.08	0.06 [0.02]
Wort Drain	1	Standing – light effort	0.25	0.19 [0.05]
Wort Cooling	1	Standing – moderate to heavy effort	0.50	0.67 [0.19]
Pitching the Yeast	1	Standing – moderate to light effort	0.25	0.25 [0.07]
Equipment Washing	1	Standing – moderate to heavy effort	1.00	1.34 [0.37]
Bottle Filling	1	Standing – moderate to light effort	0.67	0.67 [0.19]
Idle / No Activity	1	Sitting – typing or writing	2.60	1.31 [0.36]
	Total Energy			7.86 [1.82]

The overall physical expenditure on the workbench was estimated to be 7.86 MJ, or 15.78 MJ/hl. The most energy demanding activities were identified to be equipment washing, at the first place, followed by its cleaning. The majority of the remaining activities are less demanding as they are mainly monitoring ones.

This last value of 0.16 MJ/l must be added to the electrical energy of 3.79 MJ/l from Table 3 to complete the overall energy inventory. The estimated human expenditure represents about 10% of the uncertainty of the electrical energy (±1.05 MJ/l) and can therefore neglected.

The workbench specific consumption was estimated as 395.54 MJ/hl, witch is higher then the ones from literature. Kubule et al., 2016, reported 300.46 MJ/hl for a small size brewery, but still comparable, and Muster-Slawitsch et al, 2011, and Scheller et al., 2008, ranged their values from 60 to 72 MJ/hl, for large scale facilities.

5. CONCLUSIONS

The purpose of this paper was to work out an energy analysis of the brewing process performed on a small scale laboratory workbench. That workbench was conceived and designed to produce beer with low energy consumption and run by a single operator.

Data from actual electrical power measurements associated to the equipment elapsed times made it possible to estimate the amount of energy required to produce a batch of 50 liters of beer. The total or overall amount of energy accounted to be of 197.77 MJ, with 96% of it requested by electrical driven processes, and a minor part for human physical expenditure. Some of the 7.86 MJ of human expenditure could be reduced by introducing an auxiliary food grade centrifugal pump to enhance processes like cleaning and filtering. That shift on energy conversion would cause electrical energy to grow, but in the other hand would significantly increase the beer quality and reduce the human working time.

Refrigeration processes were the most demanding, as fermentation and carbonation, which corresponded to 78% of this kind of the electrical demand. For future work, it is essential to improve the efficiency of processes as fermentation, carbonation, filtering and cooling. Special attention should be given to new conceptions of temperature controlled fermenter and the use of food pumps for filtering and cooling processes.

Compared to data from literature, for large scale continuous production breweries, results from the present study displayed a much higher value of energy per volume. Although differences were quite big, that was expected for batch based processes.

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