Designing a Temperature Control System for a Craft Beer Fermenter Unit Using Arduino Uno and Simulink- a Budding Entrepreneurs Perspective

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Abstract: Craft beer brewing is an up and coming entrepreneurship venture in South Africa. The emphasis on craft beer brewingis such that, financial institutions in South Africa predict a 35% growth in this sector in 2016 and a contribution of 18 million litres by 2017. This can be seen as an opportunity for budding entrepreneurs to enter the market. There are two major challenges for a budding craft beer brewer, firstly, ensuring precision temperature control of the wort during the fermentation process. Secondly, getting the right balance between cost of the brewing process and the quality of the product. This paper explores how to design a precision and flexible temperature control for the fermenter unit utilizing Arduino hardware and MATLAB/Simulink model. Results show that the using the technique described in this paper, the first of the challenges facing the budding brewer, that is controlling the temperature of the fermenter, was precision controlled. The model described in this paper was used in brewing a Speciality Monk Ale and came in 3rd place for best ale in the 2016 SAB Intervarsity-Brewing challenge. This paper, unfortunately does not do a cost analysis, but rather proposes a solution which can be deployed by any budding entrepreneur without the high initial investments usually needed for purchasing brewing equipment.

Keywords: *MATLAB, Simulink model, Arduino, craft beer, fermentation, entrepreneur*

1. Introduction

Craft beer brewing is in its infancy stages in South Africa The market for craft beer grew by 30% in 2014. (Hedley, 2014). It is touted to grow by a further 35% by the end of 2016 reaching such growth from a mere 0.3% in 2011(Corne & Reyneke, 2013; Hedley, 2014)(Corne & Reyneke, 2013; Hedley, 2014)(Corne & Reyneke, 2013; Hedley, 2014)(Corne & Reyneke, 2013; Hedley, 2014)(Corne & Reyneke, 2013; Hedley, 2014)(Corne & Reyneke, 2013; Hedley, 2014)(Corne & Reyneke, 2013; Hedley, 2014)(Corne & Reyneke, 2013). According to a global sector team from a local bank in South Africa it will occupy another 2.1 % of the beer market by the end of 2017(Rogerson & Keagan, 2015). Experts say that this rapid growth in the craft beer market is due to the increased demand from consumers for originality and authenticity in food and beverages they ingest(Neall, 2015). In the case of craft beer, to maintain the high standards in manufacturing process, it is important to control the temperature of the fermenter at a specific temperature at all times. This paper explores how to construct a fermenter which can firstly regulate the temperature of the fermentation process and secondly ensure flexibility in the temperature range of the fermenter.The paper does this by first outlining why temperature control is essential in the brewing of craft beer. Secondly, the paper details the hardware setup and software used in setting up the fermenter. Thirdly it focuses on the methodology used in designing the MATLAB model. Next, the paper details a series of experiments that were setup to test the working of the model and finally a discussion is done on the actual results of the experimental process. The limitation of the paper is that it stops short of doing a cost analysis of the existing brewing process visa vie the process described in this paper.

2. Literature Review

The quality and consistency of craft beer brewed is directly related to the amount of control and monitoring taking place during the fermentation stage of craft beer brewing(Boulton & Quain, 2001).The type of beer being brewed will determine the specific yeast strain to be pitched in the wort. Wort refers to the resulting liquid once the mashing of malt, addition of the malt extracts, adjuncts and hobs is completed. The temperature range required, for optimal fermentation to take place is yeast strain specific. Low temperatures might stall the fermentation process, while high fermentation temperatures can encourage the yeast to create unwanted flavours and aromas due to increased metabolic activity(Jason, 2012).This increase in metabolic reaction also increases the overall temperature of the wort. This heightened temperature(Jason, 2012) may cause important proteins, which are necessary for fermentation, to unfold within the yeast cell. To prevent this, the cell expresses a protein called heat shock(Kerr & Schulz, 2016) proteins. What these proteins do is control the proper protein folding after translation. DNA damage(Adamczyk et al., 2016) will occur as a result of higher than recommended temperatures. To prevent this DNA damage from occurring, there needs to be temperature control. Depending on the type of craft beer being brewed, and the specific yeast strain used, the temperature of the wort has to be maintained between specific temperatures, usually between 7°C and 29°C(Brewer, n.d.)-(Styles, 2015). In this specific case, for the brewing the speciality Monk ale, the temperature of the wort had to be kept between 14°C and 17° C. As the temperature range of the wort needs to be between 7°C and 29°C for the different types of craft beer, it is important that temperature control unit of the fermenter is flexible and not hardwired to a specific temperature. In order to design the flexible temperature control unit certain hardware and software compents are needed. These components are described in the following discussion

Vapour-compression refrigerator: The vapour compression refrigerator is a hardware component in which the wort is placed for the fermentation process. It consists of a cooling element. The vapour-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from one space to another(Rao, 2003).Vapour-compression refrigeration is when refrigerant undergoes phase changes is widely used method for cooling(Godden, 2015). The vapour compression refrigerator developed for this experiment is shown in Figure 1.

Halogen bulb heater: The Halogen bulb heater is placed within the vapour compression refrigerator. A halogen bulb gives light and heat. This acts as a heat source which is not too intense to create hot spots, but bring up the temperature if necessary for the fermentation process. The light heaters have a rapid heat up and cool down time in comparison with a standard heating element.

Temperature sensor: The vapour compression refrigerator, where the fermentation is done, needs to measure the temperature inside the unit to control and monitor. The LM35 is a sensor used for measuring temperature. The LM35 is a precision integrated circuit temperature sensing device with an output voltage linearly proportional to temperature in centigrade(Chattoraj, 2015). It has three pins including a data pin. The LM35 is rated for operation within the range of -55°C to 155°C. with an accuracy of 0.5°C from 0°C to 25°C(Texas Instruments, 2016).

Arduino UNO: Arduino UNO is an economical a microcontroller board that can be utilized with Simulink. Arduino UNO is based on the ATmega 328(Munoz, 2015). It has 14 digital input/output pins, six of which can be used for Pulse Width Modulation (PWM) applications, 6 analogue inputs and a USB connection. This is a physical option to connect a Simulink program to real world input and output peripherals.

Relays: Relays are electromechanical switches. Relays can be used as a separation between low and high voltages. Due to the Arduino UNO having low operating voltages, relays have to be used to make a switching connection between the fermenter and the Arduino UNO. This is because the fermenter operates on much a much higher voltage. This in turn then isolates the Arduino UNO from the fermenter, preventing any possible high voltage noise interference("How relays work," n.d.). The relay used in this setup has a 250VAC at a current rating of 10Amps(SRD, 2016).

Insulation: Insulation is essential in this process as the temperature within the fermenter had to stay constant to achieve the best results. Furthermore, insulation lowers energy cost of the fermenter, increases operating efficiency and reduces noise.

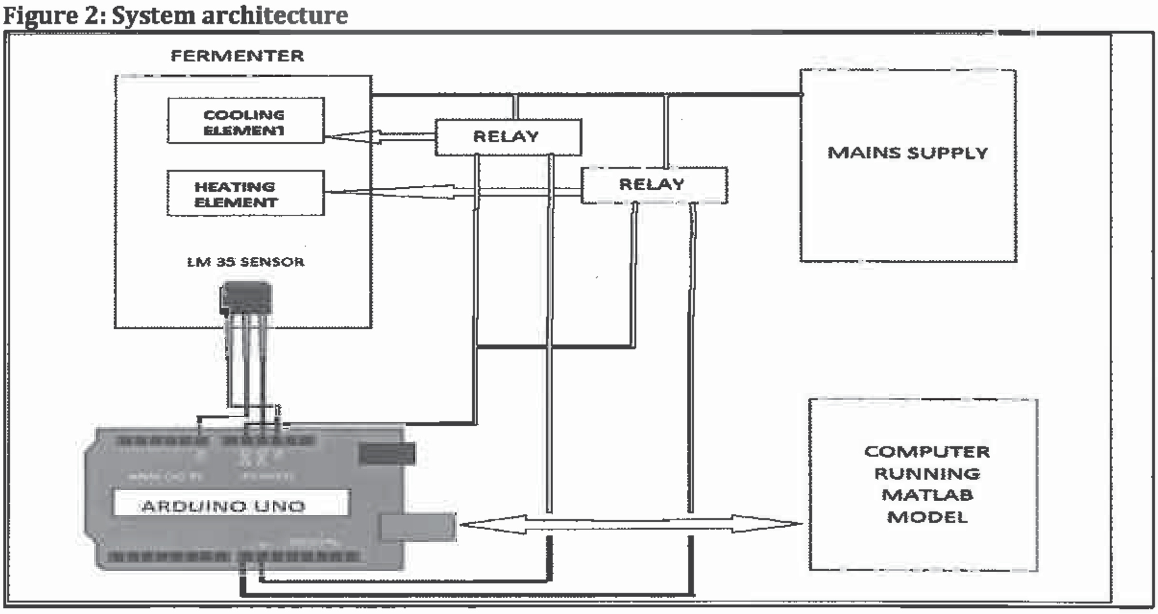
MATLAB and Simulink: MATLAB stands for MATrix LABoratory. It is a software pack that is built up around vectors and matrices. It is typically used for linear algebra but MATLAB is also a used for solving algebraic and differential equations and for numerical integration(Moore, 2014).This is a viable option to program the model in. Simulink is a tool found within MATLAB. It is a graphical programming environment for modelling, simulating and analysing multi-domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries developed by MathWorks(Nise, 2011),Simulink could thus prove to be a platform to take the model to a real world control system.

Figure 1: The vapour compression refrigerator used in the fermenting process

3. Methodology

The necessity for a customized fermenter with a precision and flexible temperature control unit was established in the literature review. The aim of this paper is to demonstrate the designof the customized fermenter. The fermenter consists of an insulated box with the cooling and heating elements switched using relays. The relays are controlled with a temperate sensor and user defined model utilising the MATLAB/Simulink and Arduino UNO combination. The process of fermentation needs to be controlled and monitored at predetermined and specified temperatures. As mentioned before, in this scenario the temperature of the wort had to be kept between 14°C and 17° C. This temperature range is very close to ambient temperature and therefore temperature regulation is challenging as will be demonstrated in the results. The system architecture describing the setup of the project is depicted in Figure 2.

Figure 2: System architecture



The system architecture, depicted in Figure 2, has a hardware and software section. The hardware section is made up of the cooling element, heating element, relays, temperature sensor, the Arduino and a host computer. The host computer is connected to the Arduino via USB. The Arduino has a LM35 sensor temperature sensor connected to itsanalogue input.The relays to the cooling and heating elements are connected to the digital output of the Arduino. The software component consists of the MATLAB software and Arduino firmware that is running on the host computer. MATLAB has a support package for Arduino that include the firmware that map the input output peripherals as well as setting up the communication protocols for Simulink interfacing. This needs to be installed so as to create a communication bridge between the Arduino and MATLAB software. Once the communication has been setup, a model is created in Simulink to design the control model.

Figure 3: Simulink model for regulating the fermenter unit

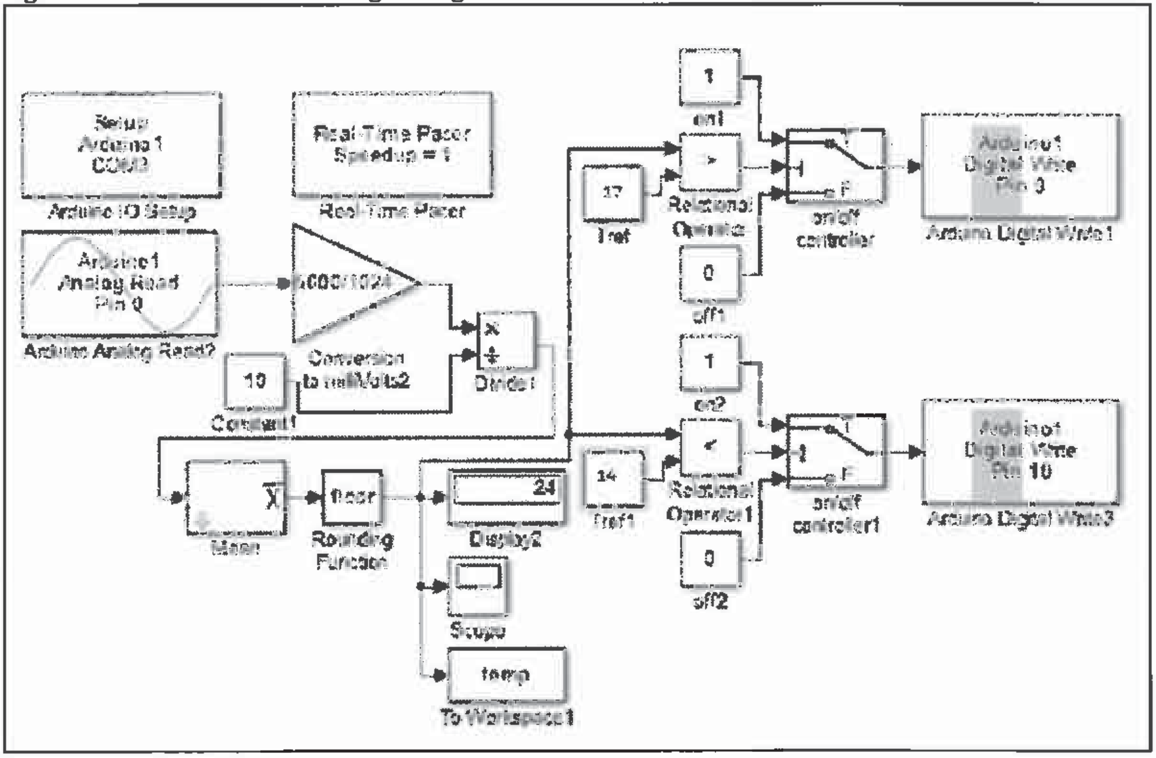


Figure 3 shows the Simulink model used to control the temperature of the fermenter unit. The model initially inserts a communication port selection block. This is to read raw data from the temperature sensors of the Arduino into the software model. This is firstly converted to voltage and then to degree Celsius by multiplying it with the value of 5000/1024. This is done with a gain block seen after the analogue read block. This temperature is in turn then converted into voltage by using a division block and dividing by 10. By doing so, the output value will be the temperature that is sensed by the LM35 that is connected to the Arduino. By using the mean block, one can filter out any noise. This block takes the average of a set number of values that is fed into the block over a specified amount of time. Both the time span and the amount of values can be user defined. The mean is then rounded off.

This rounded temperature value is then connected to the controlling part of the program. The temperature is fed into comparator blocks that will test whether or not the temperature is above or below the user defined temperatures, in this case study they were set to 14°C and 17°C. This then outputs a Boolean answer then outputs a signal to the digital output pin. These output pins are thus connected physically to the relays which will then turn either the cooling or heating element, thereby controlling the temperature to with a user defined bandwidth.

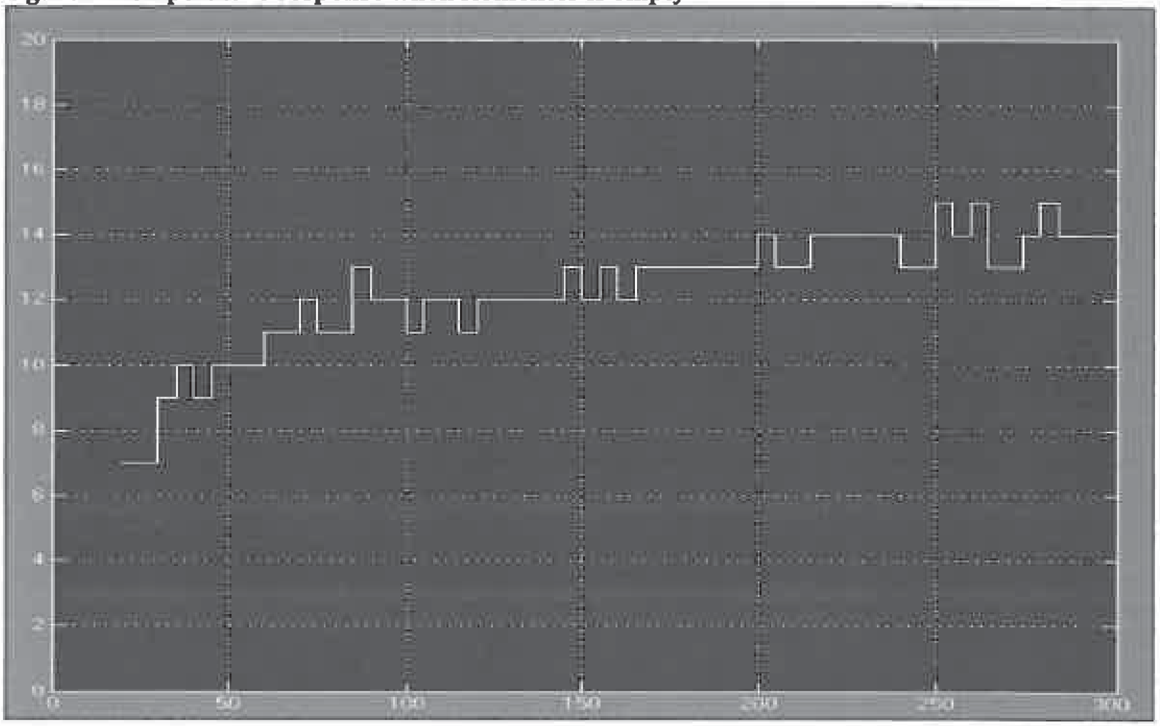
Experimental setup: This experiment, as stated previously, needed temperature of the wort to be kept between 14°C and 17°C. In order to test the working of the model, three different types of tests were done. In the first test, the fermenter was emptied and the temperature of the fermenter brought down to 8°C. This experiment was done to test two specific situations Firstly, how fast can the temperature of an empty fridge be raised from 8°C to the required range and secondly how effectively the temperature will be maintained within the required range given that the fermenter is empty. The assumption here is that if regulation is possible in a vacuum created by the empty fermenter, then it will work for a fermenter with wort inside it. The second test required the fermenter be emptied and heated up to20°C before the controller model was switched on.This experiment would again determine the speed with which the temperature was regulated to the required level and effectiveness of the control given that the fermenter is empty. The thirdexperiment is done using 15 litres of warm liquid within the fermenter. The temperature of the warm liquid when it was placed in the fermenter was approximately 25°C. This test would resemble a real case scenario when the wort is placed in the fermenter and would give good idea of the control process.

4. Results and Discussion

The results are split into three as per the experimental setup described in the previous section.

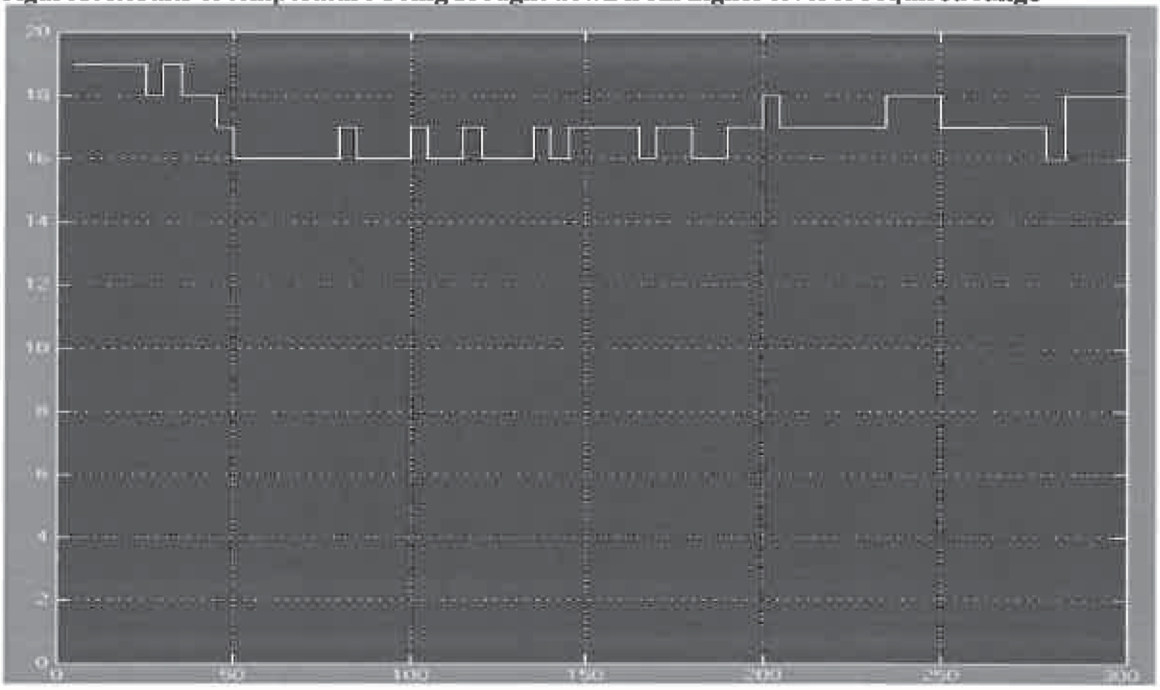
Results when applying the control model on an empty fermenter at 8°C: The evaluation begins with cooling the fermenter down to a temperature of 8°C then the controller model is turned on to test the speed and accuracy of the controller. The temperature sensors are logged in the Simulink program and the result is shown in Figure 4. Figure 4 is the graph obtained from the MATLAB/Simulink controller. The Y-axis represents the temperature in Degrees Celsius and the X-axis represents the time in Seconds. The fermenter's starting temperature was below 8°C before the control model was turned on. It achieved the desired minimum temperature of 14°C in less than 300 seconds. Furthermore, it did not overshoot its maximum defined temperature of 17°C indicating a good temperature regulation.

Figure 4: Temperature response when fermenter is empty



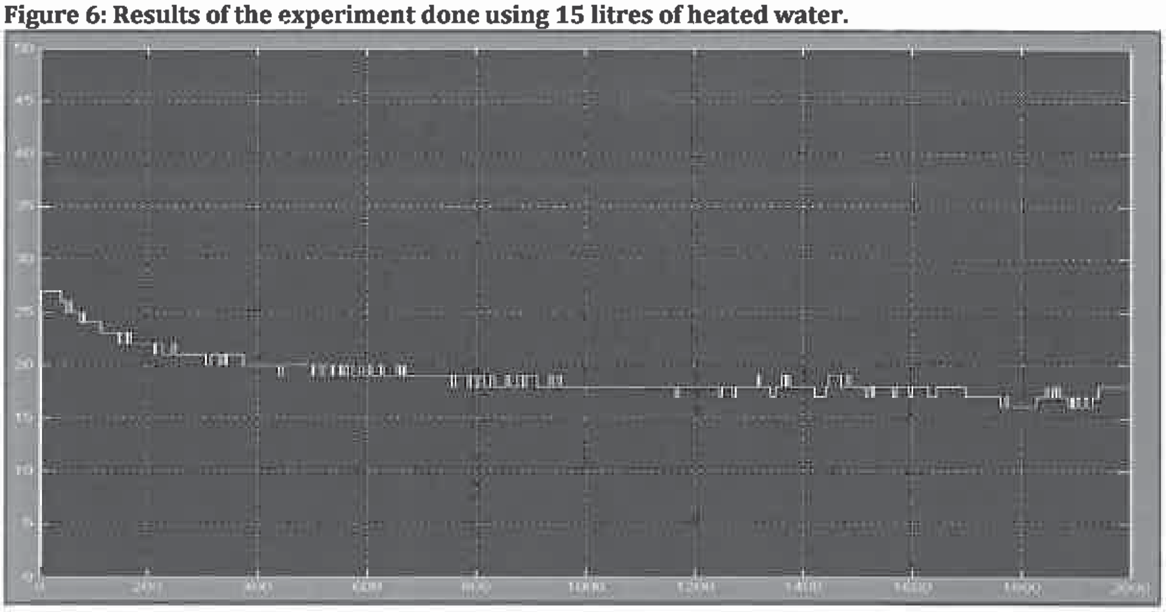
Results when applying the control model on an empty fermenter at 20°C: The second test is conducted with the fermenter being heated to 20°C and then the controller model was once again turned on to monitor the speed and accuracy of the controller. The temperature sensors are logged in the Simulink program and the result is shown in Figure 5. Figure 5 is the graph obtained from the MATLAB/ Simulink controller. The Y-axis represents the temperature in Degrees Celsius and the X-axis represents the time in Seconds. As seen in figure 5, the fermenter had an initial temperature of 19°C. At this point the controller model was turned on. The fermenter cooled down to the regulated range within 50 seconds and did not overshoot or go below the set minimum temperature demonstrating good temperature regulation.

Figure5: Results of temperature being brought down from higher level to required range



Controlling the Fermenter with heated liquid placed inside the Fermenter: This experiment depicts a typical application of the fermenter. In a typical application the warm wort would be put into the fermenter. Thus this experiment uses 15 litres of liquid heated to 25°C is placed into the fermenter before the control model was switched ON. Figure 6 is the graph obtained from the MATLAB/Simulink controller. The Y-axis represents the temperature in Degrees Celsius and the X-axis represents the time in Seconds. It can be seen that the controller started cooling the liquid immediately. Furthermore, one can clearly observe the speed at which the temperature drops in the first 400 seconds and then slows down. Note the regulation of the temperature after 1000 seconds. These results illustrated the buffering effect of having a liquid within the fermenter during the fermentation process as well as the efficiency and accuracy of the fermenter.

Figure 6: Results of the experiment done using 15 litres of heated water.



Flexibility of software: This system is defined as flexible as the temperatures that are needed for the desired beer can be easily changed within the software. This is changed by changing the values in the constant blocks in the Simulink constant blocks labelled "Tref" and "Tref1". Thus the range is not hardware defined as long as it's in the limiting factor within which the fermenter operation, this being from 0°C to 50°C. Thus the end user can set the temperature band anywhere within this range.

5. Conclusion

This paper looks at how craft beer brewing can be done from a budding entrepreneur's perspective. The two main challenges facing the brewer is firstly, ensuring precision temperature control of the wort during the fermentation process. Secondly, getting the right balance between cost of the brewing process and the quality of the product. This paper started by examining the importance of temperature control in craft beer brewing. The paper then focussed on setting up the hardware and software for constructing the fermenter. Next, the paper described how the model was created on Simulink to control the temperature of the fermenter.The paper finally setup three experiments which would test the working of the model. The results showed that temperature control was obtained in all three scenarios, the first with an empty fermenter at 8°C, the second with an empty fermenter at 20°C and finally on a fermenter with 15 litres of warm liquid. The last of the experiments was as close to real test with the wort.The main reason for doing a test with and without mass in the fermenter was that the mass of the wort had a regulation buffering effect so it was decided to regulate an empty fermenter to demonstrate the quality and speed of the control model. This model is also flexible as it enables the brewer to change the required temperature range without altering hardware. This is especially useful when brewing a different type of craftbeer that might need a different temperature range to optimise the fermentation process. The one limitation of this paper is that it was not able to do a cost analysis of this technique with respect to using a state of the art craft beer brewing machine, the main reason being that this paper is focussing on a budding entrepreneur with limited capital.

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