University of South-Eastern Norway

www.usn.no

FM4017 Project 2018

Beer Production on a Pilot Plant Using the Emerson DeltaV Control System

MP-04-18

Faculty of Technology, Natural sciences and Maritime Sciences
Campus Porsgrunn

University of South-Eastern Norway

www.usn.no

Course:FM4017 Project, 2018

Title: Beer Production on a Pilot Plant Using the Emerson DeltaV Control System

This report forms part of the basis for assessing the student's performance in the course.

Project group: MP-04-18 **Availability:** Open

Group participants: Dhinesh Kallupatti Kannan
Itsaso Menchacatorre
Saso Vozlic

Supervisor: Carlos F. Pfeiffer, Hans Peter Halvorsen, Per Kristian Fylkesnes

Project partner: **Rune Andersen, Emerson at Porsgrunn**

Summary:

Beer productions is broken down into, wort brewing, fermenting and conditioning. The ingredients used in the process are grains, hops and yeast according to the recipe for Porter beer. In order to produce mentioned beer, DeltaV has been used to develop the control system suitable to the pilot plant. PWM and PID have been included as control strategies for better control during beer production. In addition, fermentation at 3 bars has been carried out. The resulting batch of Porter beer produced displays signs of extraordinary quality.

Preface

This report has been written to aid the user of the beer pilot plant. It contains a detailed description of the plant, the beer brewing process, the DeltaV control system and a preliminary method of cost estimation.

Porsgrunn, 19.11.2018

Dhinesh Kannan

Itsaso Menchacatorre

Sašo Vozlič

Contents

1 Introduction 7
1.1 Background 7
1.2 Objectives 7
1.3 Schedule 7
1.4 Report structure info 7
2 Brewing Process 8
2.1 Preparation 8
2.1.1 Removal of solids 8
2.1.2 Caustic wash 9
2.1.3 Sanitizer wash 9
2.1.4 Testing 9
2.2 Brewing 9
2.2.1 Mashing 9
2.2.2 Extraction 9
2.2.3 Boiling 10
2.2.4 Cooling 10
2.2.5 Fermentation 10
2.2.6 Cold crash 10
2.2.7 Conditioning 10
3 Beer Pilot Plant 11
3.1 Instrumentation and Equipment 11
3.1.1 Valves 11
3.1.2 Pumps 12
3.1.3 Agitators 12
3.1.4 Sensors and Indicators 12
3.1.5 Heat exchanger 12
3.1.6 Heaters 12
3.1.7 Auxiliaries 12
3.1.8 P&ID 12
3.2 Working principle 12
3.2.1 Input/Output Signals 16
4 DeltaV Control System 20
4.1 Setup 20
4.2 Programming process challenges 21
4.3 The program 22
4.3.1 Input and Output 23
4.3.2 Pulse width modulation (PWM) 24
4.3.3 PID 24
4.3.4 Hysteresis 25
4.4 Cleaning sequence 25
4.4.1 DeltaV sequence 25
4.5 HMI 26
4.6 Datalogging 28
5 Cost Estimation 29

5.1 Heating power calculation 29
5.2 Pumping power calculation 29
5.3 Material cost 29
5.4 Cooling cost 29

6 Conclusion 32

Nomenclature

Hops: It is the flower of the plant Humulus lupulu. It gives the bitter taste to the beer.

PID: A proportional-integral-derivative controller is a control loop feedback mechanism widely used in industrial control systems.

PWM: Pulse width modulation is a form of pulse modulation in which variation in the signal amplitude are represented by variations in the width(duration) of the pulses.

Yeast: A type of fungus which converts sugars into alcohol and produces carbon dioxide as a byproduct.

Wort: The sugary liquid before that is extracted from the mashing process.

1 Introduction

Beer brewing has a long tradition in Norway. The process consists of several steps, and these steps determine the characteristic of the end product. Apart from raw materials and cleanliness, accuracy and repeatability of the process conditions are very important to create a good beer. DeltaV is a leading industrial automation system with many options for monitoring and controlling processes. There is a great practical learning potential and professional curriculum value on developing and testing automation strategies using the DeltaV control system.

1.1 Background

At USN there is a full pilot-size plant to produce beer. The plant equipment performs the different unit operations required, including heating, fast cooling, solids separation, material transport among equipment units, and fermentation.

The pilot plant was used to produce two batches of beer (60 liters each) before this project, both being an ale type of recipe. The lab was equipped with a Siemens PLC control system and a Lab view control system which uses NI USB-6008 hardware, to which we replaced by the DeltaV control system. The fermentation was only carried out in buckets and the tanks were never used. This project will be the first to use continuous temperature-controlled fermentation in the tanks.

1.2 Objectives

The main objective of the project is to design a control system using DeltaV for the beer pilot plant. In addition, a batch of beer will be produced using the control system designed to test all the equipment and functionality.

1.3 Schedule

The project schedule can be found in the appendix A. Because of the changing nature of the project, the schedule was updated every week.

1.4 Report structure info

After the project introduction in chapter 1, the focus on chapter 2 will be on explaining beer brewing process at USN. Then, chapter 3 will describe the plant with P&ID and wiring diagrams. Next, in chapter 4, the control system using DeltaV will be discussed and there will be a detailed cost estimation presented in chapter 5. Finally, the conclusions will be offered in chapter 6.

2 Brewing Process

The production of beer requires several steps such us; cleaning, brewing, fermenting and bottling. In addition, each type of beer has a different recipe to be followed for its production. Thus, process conditions such as temperature, specific gravity greatly influence the production process.

2.1 Preparation

The most important part of beer production is maintaining proper cleanliness in all the equipment and the production area. In the pilot plant, the sanitation was ensured in a four-step cleaning procedure. Hence, it is also important to perform proper cleaning before and after the brewing.

2.1.1 Removal of solids

The first part of cleaning is to remove all the left-over solids in the tanks and piping. The reason for this, is that solids left inside the pipes can cause clogging and infect the wort in the next production cycle. For example, after filtration in the lauter, the solids take a cake like shape, which is removed using a shovel and the filter is also cleaned physically. The solids in the pipes, especially between mashing and lautering are also cleaned physically, in Figure 2.1 the result from the beer brewing can be seen. The leftover smaller particles are cleaned in the next steps.

Figure 2.1 Solids in the lauter tun

2.1.2 Caustic wash

Bleach or caustic soda is typically used in the industry to sanitize all the process equipment. In the pilot plant a sodium hydroxide solution at 75 °C was used to clean all the equipment. The solution is cycled in each tank for 30 minutes to ensure that all tank related pipes and valves are completely clean. In fact, the caustic nature of the solution also dissolves any left-over small solid particles in the pipes and crevices. Finally, once the cleaning process is finished, the caustic solution is safely discarded through the drain.

2.1.3 Sanitizer wash

After the caustic wash, the pilot plant is washed with water until the pH is normalized. Then, a special sanitizer solution (Star san HB) is mixed with water and run through all the tanks and piping. Note that the solution also sterilizes the tanks and pipes ensuring maximum cleanliness.

2.1.4 Testing

Before starting the brewing process, the whole plant should be cycled with water and the pH should be tested for every cycle until it matches drinking water standards. Then a sample should be drawn from the bottom of the last tank and physical tasting test should be performed to make sure it is drinkable.

2.2 Brewing

Brewing is the part where sugars are extracted from the grains, mixed with various additives and concentrated to a liquid called wort. During the brewing process, temperature and specific gravity of the liquid should be monitored [1]. Grains are sourced from dealers according to the type of beer that is produced. Typically, the grains are germinated and ground to a coarse powder before the brewing process starts. As a matter of fact, an ale type of beer was chosen for this project and the malted barley was sourced from the local supplier the day before the brewing was performed.

2.2.1 Mashing

In this phase, the carbohydrates and proteins in the malted grains are converted to fermentable sugars (sucrose, fructose, dextrose, maltose, etc.) by activating the enzymes in the grains. The enzymes are active between 65 to 70 °C. The mashing is typically performed for an hour at 65 °C. Once the mashing ends, the mixture should be heated to 75 °C to deactivate the enzymes.

2.2.2 Extraction

Next, the liquid wort is filtered out from the mash and additional process water is added to wash off all the sugars in the malt solids. The additional adding of water is called sparging. This process is slow and generally performed with gravity separation using a fine filter. Nevertheless, in large scale plants, press filters and centrifuges are used.

2.2.3 Boiling

The extracted liquid wort is quickly heated to boiling point and then, boiled gently with constant heat addition to reduce the liquid to about 20%-30%. In order to influence the final alcohol content, the specific gravity of the wort before boiling is noted. After, the wort is boiled to reach a desired specific gravity, typically from 1.040 to 1.080. During the boiling process, additives such as hops, and other flavorings are added. Lastly, a final filtration is performed once the boiling process is completed.

2.2.4 Cooling

Once the wort is boiled and filtered, it should be quickly cooled down to room temperature. Cooling down is achieved by passing the wort through a heat exchanger, to remove the heat from it using cold water or some refrigerant.

2.2.5 Fermentation

The most important part of beer making is the fermentation. First, yeast is added to the wort in the fermentation tank. Because, the yeast gets activated when it gets in contact with the wort and starts converting the sugars into alcohol and carbon-dioxide. Moreover, the modern way is to do fermentation under pressure to avoid formation of fruity esters [3] in the liquid. Typically, fermentation take anywhere between 10 days to 5 weeks to complete. Likewise, the specific gravity of the liquid is tested periodically and when it reaches 1.005 the fermentation process is complete. Nonetheless, note that different types of beer require different temperatures for fermentation. A hydrometer and a refractometer are used to measure the specific gravity. Appendix B shows the relation between specific gravity and alcohol percentage of beer.

2.2.6 Cold crash

Once the fermentation is complete, the beer is cooled down to 4 °C to settle all the solids and inactivate the yeast [2]. This process also carbonates the beer more and creates a crispy flavor.

2.2.7 Conditioning

Nearing the final stage, the beer from the fermentation is transferred to bottles and a small amount of priming sugar is added. Obviously, the bottles are sealed right away. Often, a filtration step might be required before bottling to remove solids and yeast from the beer. Finally, sealed bottles are stored in a dark room for about 2-3 weeks before the beer is ready to be chilled and consumed.

3 Beer Pilot Plant

In this chapter the beer producing pilot plant at USN will be described. There are seven vessels: hot water tank, mash tun, lauter tun, whirlpool kettle, fermenter tank, bright beer tank and ice water tank, an overview is given by Figure 3.1. The order matches with the steps in which the beer is produced. First, the instrumentation will be described and right after the working principle of the pilot plant to produce beer.

Figure 3.1 Pilot Beer Plant

3.1 Instrumentation and Equipment

The set up consists of pneumatic and manual valves, pumps, agitators, temperature sensors, pressure indicators, heaters and other auxiliaries. This section briefly describes about all the equipment in the beer lab and its functions.

3.1.1 Valves

The plant consists of 14 manual butterfly valves, 12 pneumatic butterfly valves, 4 magnetic valves, 2 pressure relief valves and a ball valve. The automatic valves are operated through the control system and relevant manual valves are operated manually at each step. The manual valves are marked with the name HV and the automatic valves are marked by the name XV.

3.1.2 Pumps

There are 3 pumps in the plant, each serving a different purpose. The Process pump (P-001) handles the pumping of the liquids during the brewing and cleaning process. The waste water pump (P-002) is used to assist the draining of waste liquids and the cooling water pump (P-003) is used to circulate the coolant to the fermenter and bright beer tank.

3.1.3 Agitators

There are two agitators, one in the mash tun and one in the fermenter. They are switched on when the liquids need to be stirred.

3.1.4 Sensors and Indicators

All the tanks except the lauter tun has a PT100 temperature sensor and the fermenter also has a temperature gauge. There is also a temperature gauge on the outlet of the heat exchanger. The fermenter and the bright beer tank have pressure indicators and a pressure sensor is also installed on the fermenter. The mash tun, kettle and bright beer tank has level gauges installed in the sides.

3.1.5 Heat exchanger

A counter current plate type heat exchanger is used to cool the hot wort down to fermentation temperature using cold tap water or coolant.

3.1.6 Heaters

The hot water tank, mash tun and the kettle are equipped with two coil heaters each. The coil heaters are rated at 3000 W.

3.1.7 Auxiliaries

The plant auxiliaries include a compressor for instrument air and a chiller for cooling the coolant liquid.

3.1.8 P&ID

A fresh Piping and Instrumentation diagram was drawn in AutoCad since there was no older editable versions available at the start of the project. It can be found in the appendix C.

3.2 Working principle

Having the description of the instrumentation and equipment in mind, we will attempt to describe how is it used, and what purpose does it fulfill in general terms, for the porter beer recipe used. The details of the recipe can be found in appendix F. Detailed process terminology is explained in sec 2.2. In Table 3.2.1 brewing conditions are displayed.

Table 3.2.1 Brewing condition

S.no	Item	Value
1	Mashing water	50 liters
2	Sparging water	34 liters
3	Pre-boil gravity	1.065
4	Post-boil gravity	1.070
5	Final wort quantity	60 liters
6	Brewing efficiency	85%
7	Post-fermentation gravity	1.014
8	ABV	7.35%

First, the **hot water tank** is filled with tap water and heated by the two heaters in the tank. However, there is a manual valve in the tank that needs to be opened for the water to flow in. In fact, mentioned hot water is used both in the cleaning process and for beer brewing. Nevertheless, 67ºC are required for the brewing process while, 75ºC are used for cleaning. In the absence of a level sensor, ocular inspection is required to stop the tap water flow when inflow orifice is reached and close the valve. By contrast, the temperature is given out by the temperature sensor located in the tank.

Once intended temperature and volume are reached, the hot water is ready to be used in the next step. For the beer process, this means to pump it to the **mash tank**. For this purpose, relevant pneumatic valves are opened, the process pump is started, the relief valve on top of the tank is kept opened and the water is re-heated to 73ºC. The chosen grains are added, mashed and kept at 67 ºC for one hour using the PID. After an hour the temperature was increased to 76ºC to stop the mash process. In order, for the mixture to be more homogenously mixed, the mixer on top of the tank is used. Additionally, more water is added to the hot water tank, and heated accordingly to store it as the occasion for its use arises. In the mash tank, there is a temperature sensor and a gauge level to monitor the wort. Obviously, valves, heaters and pump should be stopped/closed accordingly. Note that once 73ºC are reached heaters can be turned off.

By the same token, when the wort is ready, it is pumped to the **lauter tank**. Likewise, relevant valves are opened, process pump started, and the wort pumped slowly as separation of solids from the wort take place. The reason for the slow pumping method, is that the filtering happens by gravity, so the wort has to go through the solids layer. About 40min where used for this process. Typically, once the transfer from mash tank to lauter is completed, the mash tank and piping involved need to be flushed before the brewing process is continued. Flushing the tank and pipes at this stage prevents the smell from the grains from sticking in the laboratory. Furthermore, the grains form a giant cake inside the tanks, which has a rather strong smell and thick consistency. The grains need to be taken out and disposed of. Because of the nature of the mixture, pipes are clogged requiring somewhat intensive manual labor and various forward and back flushing methods.

Assuming the wort is lautered and the mash tank flushed, the wort is pumped to the **kettle/whirlpool tank** together with the sparged water. Identically, relevant valves are opened, and the process pump started. The addition of water is to extract as much as possible from the solids. At this point, the level gauge at the kettle will display a rather full tank. Boiling process is started by setting the heaters to reach a 99ºC temperature and pouring the hops required by the beer recipe. This tank is equipped, with temperature transmitters in addition to mentioned level gauge and heaters. Consequently, the wort is boiled until about 30% of the level is reduced, the steam created in the process is directed to the mash tank for quenching trough appropriate route. Note that the percentage to be evaporated is based on the beer chosen. Also, some hops were added in the last 15min or so of the boiling process to extract good flavor. Pulse width modulation (PWM) was used to keep the temperature at boiling point and control the quenching. In this case the boiling process took 4.5 hours to be finalized. Moreover, to constrain the boiling process to the specified time, cold tap water was supplied continuously for continuous quenching. Then, the wort is whirl pooled to remove the solids. The result is shown in Figure 3.2.

Figure 3.2 Whirlpooling result

Next, the wort is transferred to the **fermenter tank** via the heat exchanger by opening relevant valves for cooling purpose. The wort must be cooled down quickly, which is what the heat exchanger does. In other words, the wort can come in at about 99ºC to the heat exchanger and can go out from the heat exchanger at about 35ºC.

Finally, the wort is transferred to the **bright beer tank** for fermentation and relevant yeast added. Again, appropriate valves are opened and coolant from the chiller flows around the jacket inside the tank. The ice water tank temperature can be set to 10ºC and the bright beer tank temperature to 19ºC, these temperatures are also dependent on the beer chosen. In these conditions, the beer is left to ferment around 12 days. During which, pressure and temperature are monitored through the temperature transmitter and pressure indicator. In this case 3 bars were reached, as shown in Figure 3.3. Generally, fermentation is done below 1.5 bars, but the equipment in the plant is capable of reaching 3. The importance of the monitoring is linked to the yeast, as they need specific conditions to be kept alive and working optimally.

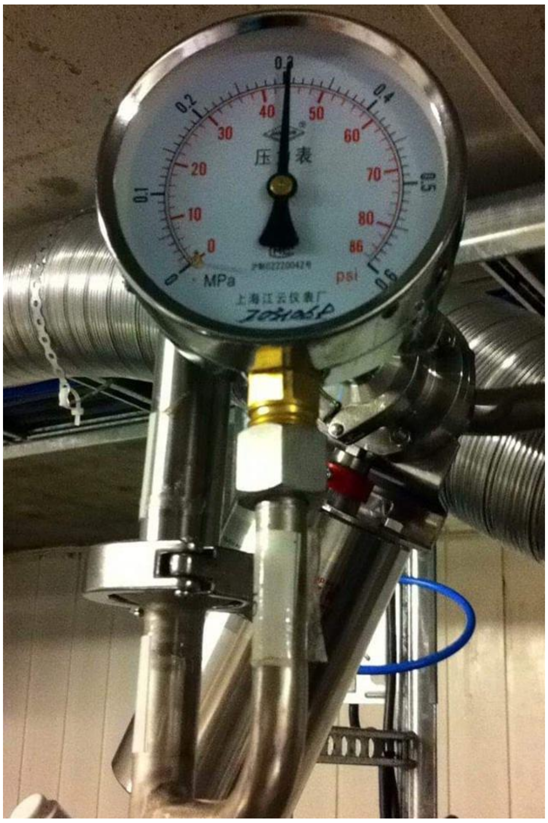


Figure 3.3 Pressure during fermentation

There is a pressure relief valve at the top of the tank. Once the wort is in this tank, the fermenter and kettle together with the heat exchanger and relevant pipes need to be flushed to free them of solids. After, the 12 days, a cold crash is conducted for the solids to settle before bottling. Such a procedure means to drop the temperature until 4ºC and carbonate the beer. After the cold crash, the pressure in the tank is slowly relieved and the beer is bottled, an example of the bottling result is shown in Figure 3.4. The bottles are stored in a dark room at room temperature for 30 days to facilitate conditioning of the beer. After that they can be chilled and consumed.

Figure 3.4. Bottling produced beer

3.2.1 Input/Output Signals

In this section a description of the I/O signals will be carried out by two figures and three tables. First in Figure 3.5 and Figure 3.6 the physical wiring setup is shown. The analog inputs are connected to the negative (-) terminal of the transmitters, which are supplied by a common 24VDC. The current signal range of the sensor outputs is 4-20mA, which is also the input range of the DeltaV analog module. Thus, scaling was not required.

Figure 3.5 DeltaV cards view.

Figure 3.6 I/O cabinet view.

Next, the current description of the I/O signals from the cabinet to DeltaV cards can be seen from Table 3.2.2, Table 3.2.3and Table 3.2.4.

Table 3.2.2 A1 I/O Signals

A1

Signal	Delta V Channel	Instrument	Tag
Digital Out	C3.1	Mash Tun Stirrer	M-01
Digital Out	C3.2	Fermenter Stirrer	M-02
Digital Out	C3.3	Hot Water Pump	P001
Digital Out	C3.4	Waste Water Pump	P002
Digital Out	C3.5	Ice Water Pump	P003
Digital Out	C3.6	Compressor	-

Digital Out	C3.7	Chiller	-
Digital Out	C3.8	Heat Element1 Mash Tun	HE-01
Digital Out	C3.9	Heat Element2 Mash Tun	HE-02
Digital Out	C3.10	Heat Element1 Whirlpool	HE-03
Digital Out	C3.11	Heat Element2 Whirlpool	HE-04
Digital Out	C3.12	Heat Element1 Hot Water	HE-05
Analog In	C1.2	PT 100 Ice Water Tank	TT-01
Analog In	C1.4	PT 100 Bright Beer Tank	TT-02
Analog In	C1.6	PT 100 Fermenter	TT-03
Analog In	C1.8	PT 100 Whirlpool	TT-04

Table 3.2.3 A2 I/O Signals

A2

Signal	Delta V Channel	Instrument	Tag
Digital Out	C3.13	Pneumatic Valve	XV-02
Digital Out	C3.14	Pneumatic Valve	XV-04
Digital Out	C3.15	Pneumatic Valve	XV-11
Digital Out	C3.16	Pneumatic Valve	XV-12
Digital Out	C3.17	Pneumatic Valve	XV-05
Digital Out	C3.18	Pneumatic Valve	XV-16
Digital Out	C3.19	Pneumatic Valve	XV-06
Digital Out	C3.20	Pneumatic Valve	XV-10
Digital Out	C3.21	Pneumatic Valve	XV-01
Digital Out	C3.22	Pneumatic Valve	XV-03
Digital Out	C3.23	Pneumatic Valve	XV-07
Digital Out	C3.24	Pneumatic Valve	XV-08

Table 3.2.4 A3 I/O Signals

A3

Signal	Delta V Channel	Instrument	Tag
Digital Out	C3.25	Heat Element2 Hot Water	HE-06
Digital Out	C3.26	Magnetic Valve	XV-14
Digital Out	C3.27	Magnetic Valve	XV-09
Digital Out	C3.28	Magnetic Valve	XV-13
Digital In	C2.1	Pressure instrument	PI01
Digital In	C2.3	Pressure instrument	PI01
Digital Out	C3.29	Magnetic Valve	XV-15
Analog In	C1.10	Magnetic Valve	TT-05
Analog In	C1.12	Magnetic Valve	TT-06

4 DeltaV Control System

This chapter will give an overview of the coded program as well as a description of the process behind it. The programming software used was DeltaV, which is a digital automation system software for designing and operating process control applications. The PLC logic was coded in Control Studio subprogram, while the HMI was designed in Operate Configure subprogram. Additionally, the Database Administrator subprogram was used to handle initial database creation and the Explorer subprogram for the overall view.

4.1 Setup

The hardware provided consisted on a workstation PC located in the process hall and DeltaV modules provided by Emerson. The PC workstation already had DeltaV installed with the appropriate licenses. Regarding the DeltaV modules, a single controller was used in conjunction with four I/O cards and a single DC/DC System Power Supply. The I/O cards comprise one Analog In, one Discrete In, one Discrete Out, as well as a Discrete Out. Specifically, all mentioned cards have 8 channels except for the Discrete out, which has 32 channels. Correspondingly, the PC is linked to the PLC through Ethernet.

During the wiring process, it was discovered, that the number of required Digital Output channels exceeded the number of supplied ones. As a result, Emerson was immediately contacted and two 8 channel Digital Out cards, that were initially provided, were switched for the Discrete out 32 channel card.

After the controller had been set up, a simple Digital Output block was used to verify the installation. However, the outcome of the test brought an error, and troubleshooting was required to determine the cause of it. Having no prior knowledge of DeltaV, manuals were consulted to clarify the source of the error. Nonetheless, after some trial and error, it was concluded that the issue was a version mismatch between the DeltaV software and the controller firmware, as shown in Figure 4.1. It was resolved with the help of Emerson personnel.

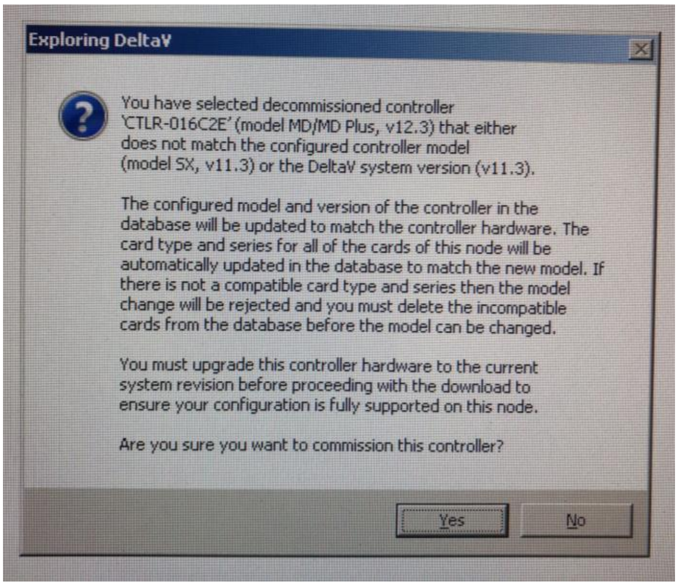


Figure 4.1 Firmware version mistmatch

4.2 Programming process challenges

The DeltaV manual [4] and university documented projects were used as a support for the biggest part of the set up and programming. In addition, Emerson provided a training session on the use of DeltaV.

While programming, several setbacks occurred. First, there was a version mismatch, as previously mentioned in the setup section. The initial thought to find a possible solution was to start from a new, clean database. Initially, a copy of an existing specific database was taken and renamed as per the instructions of the university manuals. The assumption behind this clean database creation, was that maybe something got corrupted in the existing template.

At the same time, when Emerson personnel came to fix the error, they brought a library containing different prebuilt modules and they imported it into the new database. Unfortunately, it was later discovered that the new database did not contain the required licenses. It was incorrectly assumed that licenses were system wide. Thus, it became apparent that as per instructions, it was imperative to use a copy of specified database template. Posing the next challenge of importing the library from the clean database to the copied one. This led to a small issue with the import-export, that was solved when original files from Emerson were imported.

During the database switching a glitch appeared, where the decommissioned controller would not appear in DeltaV Explorer structure. At this point, again, troubleshooting was required. Firstly, the cards were removed one by one, secondly switching between the databases followed. Nevertheless, the error persisted. Ultimately, Emerson was contacted, and as per their advice the main controller was unplugged for just a couple of seconds and plug back in. Happily, the error was solved, and the controller was recognized and selectable.

Moving forward, the HMI for running the plant was created. But, after running the HMI, we were confronted by a Startup error, which, at first glance, did not seem to have any impact on the process. However, Emerson was informed of the presence of the error, while programming work was continued in the lab.

Unfortunately, the Startup error reappeared when trying to use PID-PWM module that was provided by Emerson. Mentioned modules, required parameter configuration through own faceplates, which did not work properly. A faceplate is the interface were a block can be configured. A work around was pursued by trying to configure the module in Control Studio, but to no avail. Even using the default, inbuild PID, did not work, as seen in Figure 4.2. After trying to configure the PID module through Control Studio and extensive trial and error, with no more options to explore Emerson was contacted. Emerson personnel visited the lab at their convenience and resolved the error.

Figure 4.2: An instance of the faceplate error

4.3 The program

The program for beer brewing is stored in the Industrial Beer Lab database. The HMI picture used is also called Industrial Beer Lab. The program is structured under a single area called «beer plant». The area contains unit modules corresponding to the physical tanks of the system, i.e. «Mash tun», «Whirlpool», etc. Each of these contain the appropriate submodules for reading and controlling the unit. These usually include Analog Input and Digital Output modules. In some cases, extra modules are used to output the desired logic. The whole structure is shown in Figure 4.3.

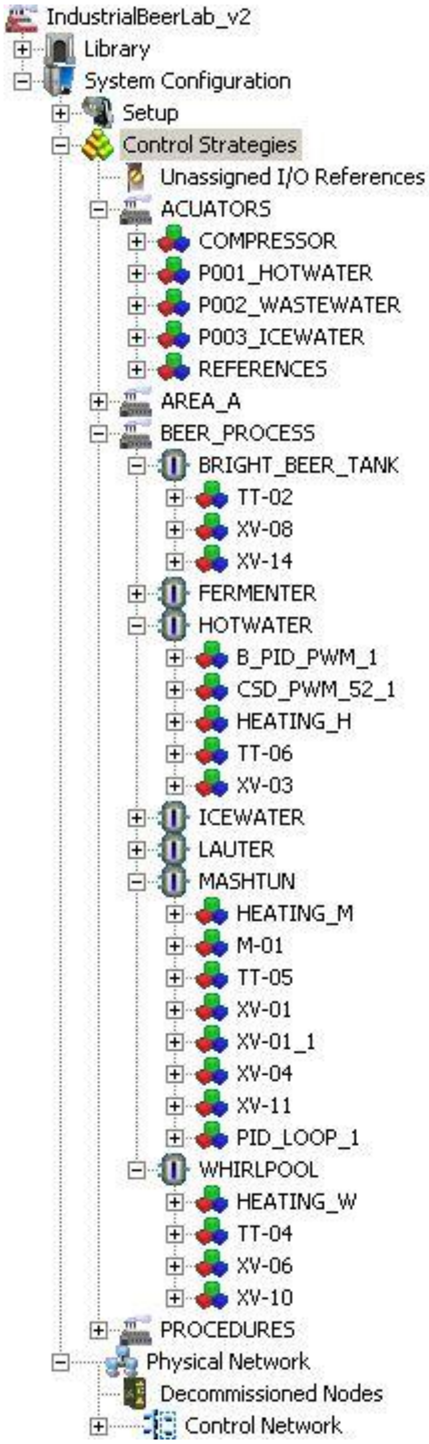


Figure 4.3: The structure of the program

4.3.1 Input and Output

Internal references are used throughout the program to connect the HMI supplied user inputs with the correct modules. While the connection could have been done directly, it was concluded that the usage of the internal parameters provided better modularity. This approach proved to be useful for both testing and programming later.

Because of the On/Off operability of the whole system, a simple digital output module is sufficient for controlling most of the actuators, while analog input modules provide the temperature measurements.

4.3.2 Pulse width modulation (PWM)

A PWM module is used to control the power output of the heaters, as shown in Figure 4.4. It is a modified version of the one found in the library. The code for calculating the PWM cycle is shown in appendix E. The user is expected to input the duty cycle and the cycle time. In short, it reduces the energy by having on time and off time. For the beer pilot plant process a cycle time of 10s was chosen, which is appropriate given the extremely slow response of the system. The duty cycle was changed to fit the need of the current operation. The heating of cold water uses the full power, which is reduced to about 50% when the temperature is approximately 10 °C from the desired setpoint. At 5°C it is reduced to about 10%, since there is enough residual heat left to raise the temperature to the setpoint. A duty cycle of around 2-5% is sufficient to maintain the a relatively stable temperature. These values vary slightly for each tank.

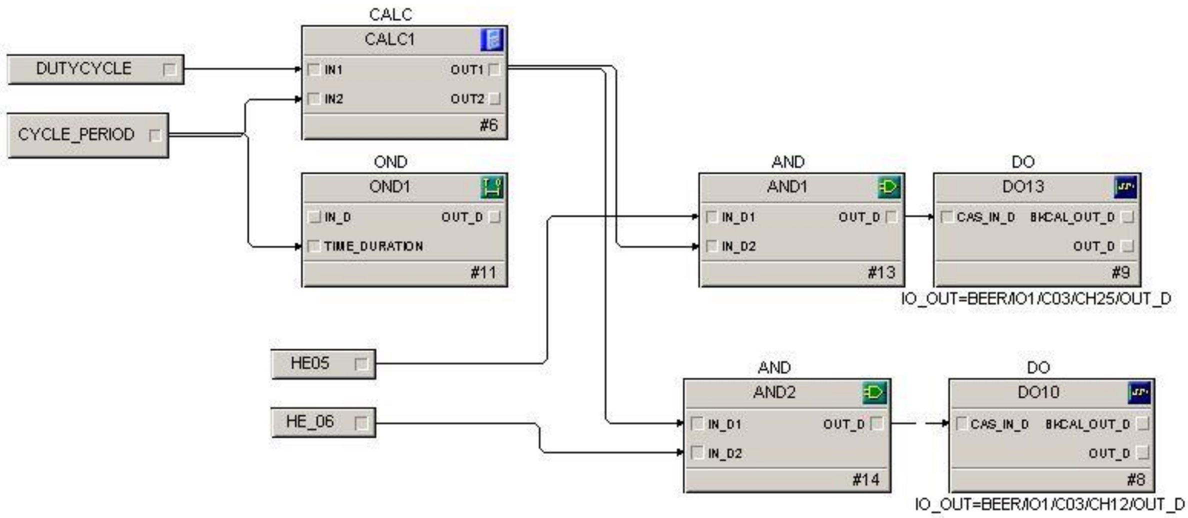


Figure 4.4: The PWM module

4.3.3 PID

Since the mashing process requires good temperature, a PID module implemented. It controls the duty cycle, which is supplied to the PWM module of the “Mash tank”. The PID was tuned according to the procedure for non-self-regulating processes, as described in [7] and [8]. The mash tun was filled with 60l of water and heated with a 10% duty cycle at 10s cycle time. After some time, the heating was turned off and the system was cooled down. The whole process was monitored with the use of datalogging and the graphs were used to determine the rising and falling slopes, K_1 and K_2 of the process, as well as the deadtime θ. They were used to calculate the integrator gain:

$$K_p = \frac{K_2 - K_1}{duty_{10\%} - duty_{0\%}} = 2.238 \quad (4.1)$$

The value of the closed loop time constant τ_c was set to triple that of the deadtime, $\tau_c = 3 * \theta = 540\text{s}$.

Using these values, we calculated the controller gains using the following formulas:

$$K_c = \frac{1}{Kp} * \frac{2 * \tau_c + \theta}{(\tau_c + \theta)^2} = 0.335 \quad (4.2)$$

$$T_i = 2 * \tau_c + \theta = 540 \quad (4.3)$$

The calculated parameters were a good starting point, since the process reached and stabilized at the setpoint, but it was too slow for practical purposes. After some trial an error, the value of K_c was set to one, which was good for setpoint tracking.

The values were used to control the process, after the temperature was manually adjusted to around 90-95% of the desired setpoint.

4.3.4 Hysteresis

The temperature in the chiller and the bright beer tank is controlled by an On/Off controller. The user inputs the desired setpoint and hysteresis and the controller will chill the system until it reached the lower limit. It will turn on again when the temperature exceeds the upper band limit. This provides good control, because the temperature loses are small and the controller only need to switch on after several hours.

4.4 Cleaning sequence

While making a cleaning sequence we were, in a large part, constrained because of the semi-manual nature of the system as well as the lack of proper instrumentation (namely level sensors). Because of this and the time constraints of the project, we implemented a simple sequence for the cleaning of the Mash and Lauter tuns with water and caustic soda, as shown in Figure 4.5.

While the execution of the sequence remains problematic, as of the time of writing, the underlying logic is sound and should provide appropriate cleanliness of the tanks when fixed.

4.4.1 DeltaV sequence

The sequence should execute in the following manner. First it turns off every valve and pump. This is the neutral position. The user should input the cycle time and the number of cycles through the HMI faceplate. Then he should select the which sequence to run. If there is no currently running sequence and if the stop button is not active, then the sequence will progress into the next step.

The appropriate valves are opened, then the sequence waits for a couple of seconds (3-5 seconds) for the liquid to fill the pipes. This prevents cavitation. Then we start the pump and run it for the specified cycle time. The first set of valves is closed and second set it opened. The pump runs for the specified time again. The process is repeated for the specified number of cycles for all of loops in each tank.

A transitional condition is used to ensure that the sequence will not continue, unless the user confirms that any manual valves present are in the correct position.

The status of the stop button is checked at each step. If its activated, then all the valves and pumps are stopped, and any active sequence will terminate.

The code for the sequence is appendix D.

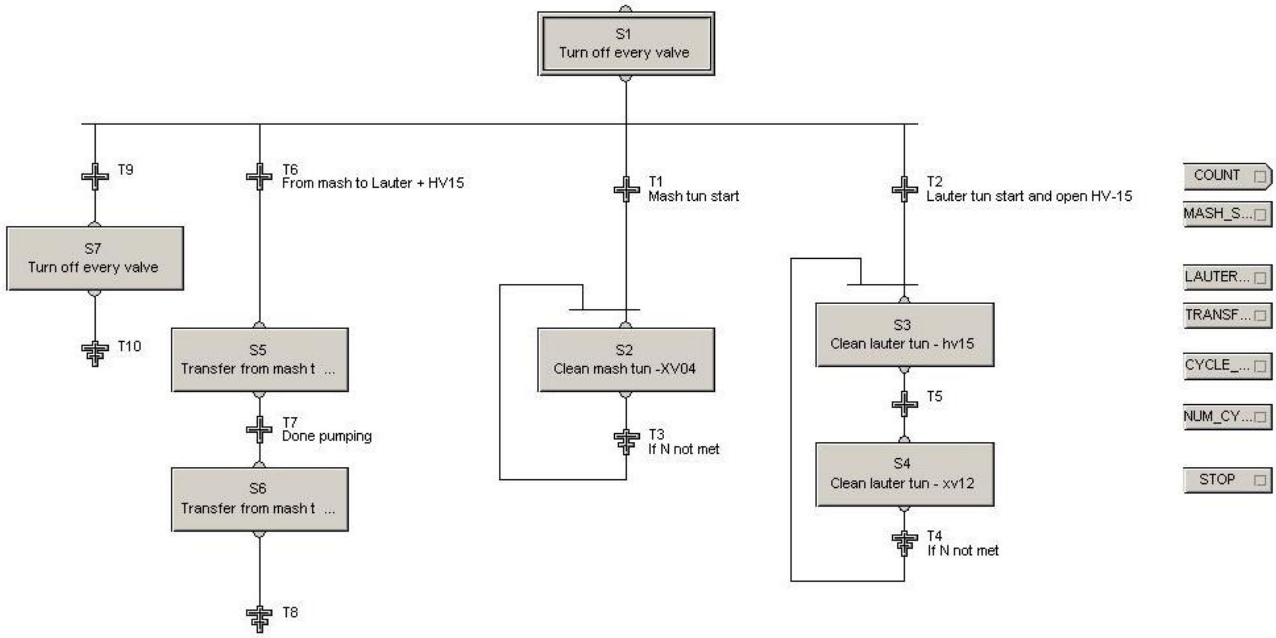


Figure 4.5: The cleaning sequence

4.5 HMI

In the beginning, the relevant faceplates for the control modules were not working properly and the symbols for several units weren't available. So, a preliminary HMI, shown in the Figure 4.7, was created with the available symbols and animations. Once the errors with faceplates and compiler were fixed and more standardized final HMI, visible in Figure 4.6, with faceplates for the heaters were created.

All the valves were drawn as automatic valves since the manual valves are expected to be replaced very soon. This was done to minimize the work needed to redraw the HMI.

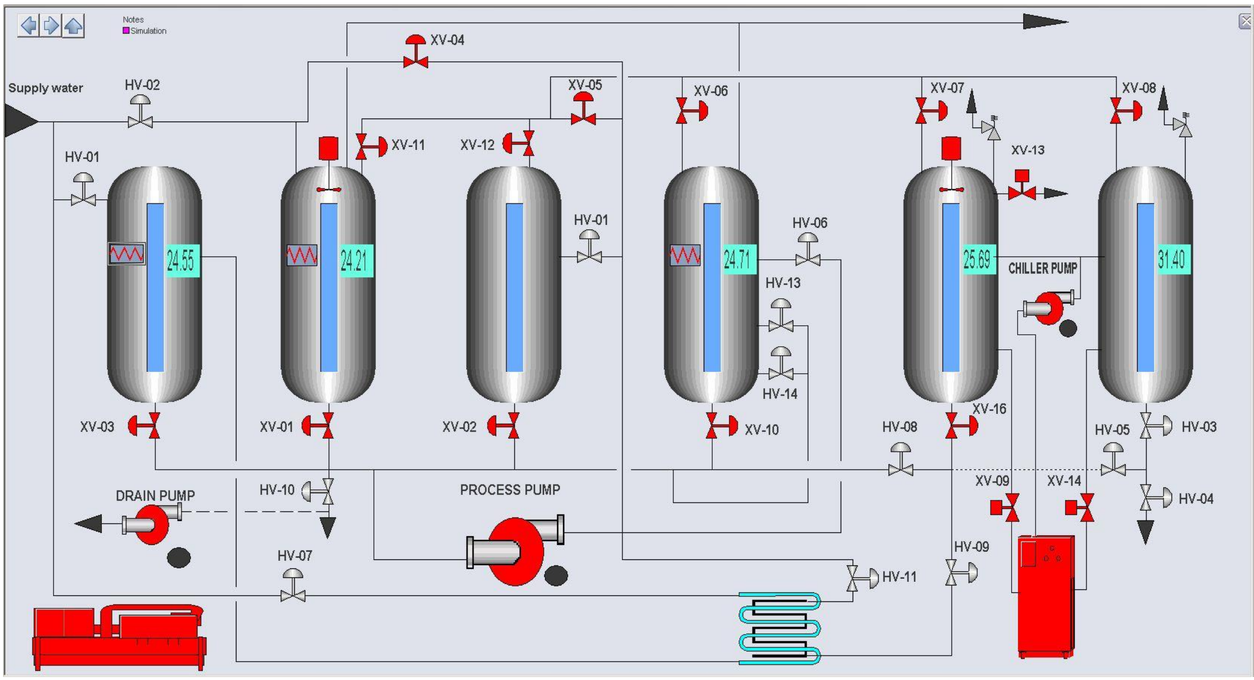


Figure 4.6: The final HMI

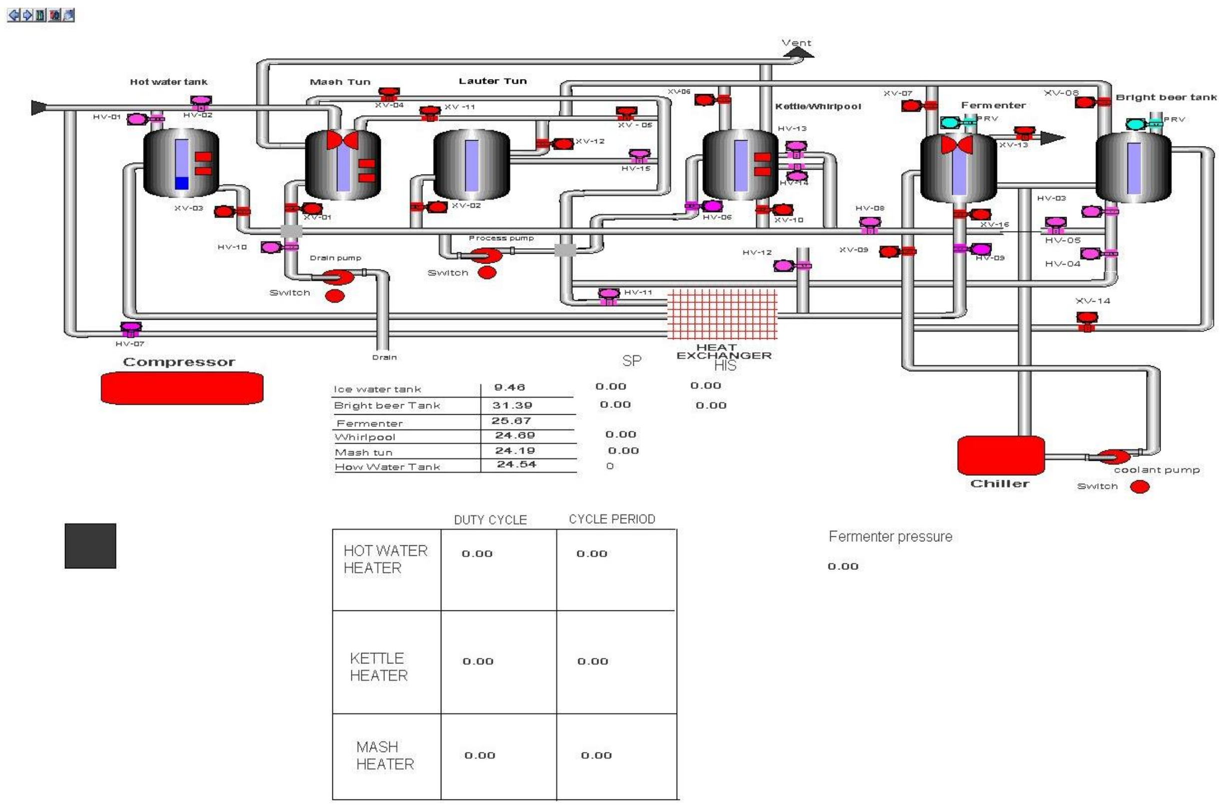


Figure 4.7: The initial HMI

4.6 Datalogging

A data logging system was set up for logging the temperatures relevant to the brewing process and fermenting. The reason for this was to account for possible changes or anomalies during the process and to use gathered data for the cost estimate. Unfortunately, at the time of writing this report, it was discovered that the data was not retrievable. Moreover, logged data files were saved but upon opening them, the graphs seemed to be empty. Diligently, Emerson was contacted as to how to proceed. Anyway, during the brewing and fermenting process the graphs shown in the datalogging subprogram were important to make a decision on how to best handle the hysteresis for the bright beer temperature set point.

5 Cost Estimation

The estimated cost of production of beer per liter is calculated in two parts, brewing and cleaning as shown in Table 5.4.1. In each part cost of power and material is taken for calculation. The cost of process water, instrument air and labor is assumed to be zero. The power cost is taken as 1 kr/Kwh.

5.1 Heating power calculation

The process liquid is mostly water and hence the heating calculation was based the water heat capacity. A heating calculation tool [5] was used to find out the time required for the 6000 W heaters in the tank to raise the heat of a certain volume of liquid to a set temperature. The calculated time is then multiplied with the power to arrive at a final value in kilowatt-hours (Kwh).

5.2 Pumping power calculation

From the specifications of the pump, it was known that the pump capacity was 40 liters/minute and power rating of 100 W. Based on these values, the pump on time for each step was calculated and multiplied with the power rating to arrive at a final value in Kwh.

5.3 Material cost

All the ingredients required for the porter beer recipe was sourced as a package from the local supplier and the materials used for cleaning and sanitation was accounted separately.

5.4 Cooling cost

In order to maintain the beer at a stable 19 °C temperature, continuous cooling was required. In this section we calculate the heat penetration into the tank in watts and use that value to arrive at a power usage value in Kwh, assuming a 60% refrigerator efficiency.

From the bright beer tank specifications,

Outer radius, $r_0 = 0.45m$

Inner radius, $r_i = 0.39m$

Liquid height, $h = 1m$

Thermal conductivity of the insulation, $k = 0.033\ W/mK$

Liquid temperature, $T_i = 292\ K$

Outside temperature, $T_\propto = 299\ K$

Surface area of the tank,

A = area of cylinder surface until the liquid level + bottom plate

$$A = (2 * \pi * r_0 * h) + (\pi * r_0^2) \tag{5.1}$$

$$A = 1.9645\ m^2$$

Total thermal resistance [6],

$$R'_{tot} = \frac{\ln(\frac{r_o}{r_i})}{2\pi k} + \frac{1}{2\pi r_o h} \tag{5.2}$$

$$R'_{tot} = 1.2692\ m^2/WK$$

Heat transfer per unit length,

$$q' = \frac{T_\propto - T_i}{R'_{tot}} \tag{5.3}$$

$$q' = 5.515\ W$$

Total heat loss, $q = q' * A$

$$q = 10.835\ W$$

The cooling circuit was operating for 12 days and assuming 60% efficiency,

Total power required = 5 Kwh

Table 5.4.1 Project cost estimation

Project Cost Estimation								
Project Name		***HARRY PORTER***				Project Number		1
Clent Name		***BEER LAB***				Start Date		31/10/2018
Project Manager		***SASO/ITSASO/DHINESH***				End Date		15/11/2018
Remarks						Total Production in Liters		60
Project Phase		**Estimated Hours**	**Power**		**Material**		**Other**	**Total Cost**
			Price /Kwh	**Cost**	**Price per Kg**	**Cost**	**Cost**	
1	**Cleaning**							
1.1	Heating	*2.61*	*1*	*kr 15.66*				*kr 40.87*
1.2	Caustic soda	*8*				*kr 69.90*		*kr 559.20*
1.3	Cycling	*2.5*	*1*	*kr 0.25*				*kr 0.25*
1.4	Sanitizer					*kr 10.00*		*kr 10.00*
2	**Hot Water**							
2.1	Heating	*0.75*	*1*	*kr 4.50*				*kr 4.50*
3	**Mashing**							
3.1	Grains				*kr 45.30*	*kr 770.00*		*kr 770.00*
3.2	Heating	*1*	*1*	*kr 0.12*				*kr 0.12*
3.3	Pumping	*0.025*	*1*	*kr 0.00*				*kr 0.00*
3.4	Agitation	*1*	*1*	*kr 0.10*				*kr 0.10*
4	**Lautering**							
4.1	Pumping	*2*	*1*	*kr 0.20*				*kr 0.20*
5	**Boiling**							
5.1	Heating	*4.5*	*1*	*kr 27.00*				*kr 27.00*
5.2	Pumping	*0.03*	*1*	*kr 0.00*				*kr 0.00*
5.3	Whirpooling	*0.16*	*1*	*kr 0.02*				*kr 0.02*
6	**Cooling**							
6.1	Pumping	*0.25*	*1*	*kr 0.03*				*kr 0.03*
7	**Fermentation**							
7.1	Cooling	*5*	*1*	*kr 5.00*				*kr 5.00*
8	**Bottling**							
8.1	Bottle caps					*kr 50.00*		*kr 50.00*
Total		27.825	0		kr -		*kr -*	*kr 1,467.29*
	Total Cost	*kr 1,467.29*						
	Cost per liter	kr 24.45						

6 Conclusion

At the time of report hand in, a batch of porter beer was produced, using DeltaV hardware and software. Also, all the instruments and equipment at the pilot plant were tested in the brewing, fermenting and bottling process.

Described errors in section 4.2 turned out to be a significant drain of time and energy. The general assumption was that, since none of the group members were familiar with DeltaV, the errors were caused by a mistake in our programming or DeltaV handling. As a result, significant amount of time was spent reading the manuals and trying to debug the program. In hindsight, we should not have been so reserved in asking Emerson for help and advice. Anyhow, while trying to solve errors a deeper knowledge on DeltaV was acquired, and thus, creating a second interface with custom faceplates or own PWM block became a reality.

The usage of PWM for controlling the heaters proved to be instrumental for controlling the temperature and preventing energy waste. Moreover, the quenching solution developed during brewing to transfer the steam from the kettle to the mash continuously reduced remarkably the labor hours.

On the bottling day, after the cold crash, pressure needed to be relief in order to get the beer into the bottles. The pressure relief valve was used to relief the pressure from the bright beer tank, because there was no other way to relief pressure slowly. Unfortunately, this option turned out to be an important mistake. In short, by letting pressure out, the screw holding the valve in place loosened, and at 1 bar it blew to the ceiling. Consequently, the beer inside the bright beer tank was pushed upward coming out from the hole the valve had left. Although, the possibility of such an accident was considered, the implication was not fully understood, leading to the accident. However, the lab was quickly cleaned, and bottling proceeded. Fortunately, a rather small amount of beer was lost. But it was an important lesson learned for the future handling of pressure.

The importance of following a good sanitation procedure in food was tested when cleaning the plant with caustic soda, water flush and sanitizer usage. After all, the group members tested the water before brewing and were aware that contamination could ruin all the beer. Furthermore, the bottles were meticulously cleaned and sanitized before bottling.

Fermenting at high pressure was carried out to improve the flavor in the beer, as it became apparent how temperature, pressure and grains timing could have big effect on the taste.

References

[1] John J. Palmer, How to Brew: Everything you need to know to brew beer right the first time. Brewers Publications, 2006.

[2] Landaud, S., Latrille, E., & Corrieu, G. (2001). Top Pressure and Temperature Control the Fusel Alcohol/Ester Ratio through Yeast Growth in Beer Fermentation. Journal of the Institute of Brewing, 107(2), 107-117.

[3] Pires, E. J., Teixeira, J. A., Brányik, T., & Vicente, A. A. (2014). Yeast: The soul of beer's aroma—a review of flavour-active esters and higher alcohols produced by the brewing yeast. Appl Microbiol Biotechnol Applied Microbiology and Biotechnology, 98(5), 1937-1949.

[4] Emerson Process Management (2010). Getting started With Your DeltaV Digital Automation System

[5] Process heating services ltd. For industrial electric heaters. "Water heating time calculator", November 2018. [Online]. Available: www.processheatingservices.com/water-heating-time-calculato [Accessed: Nov. 10, 2018]

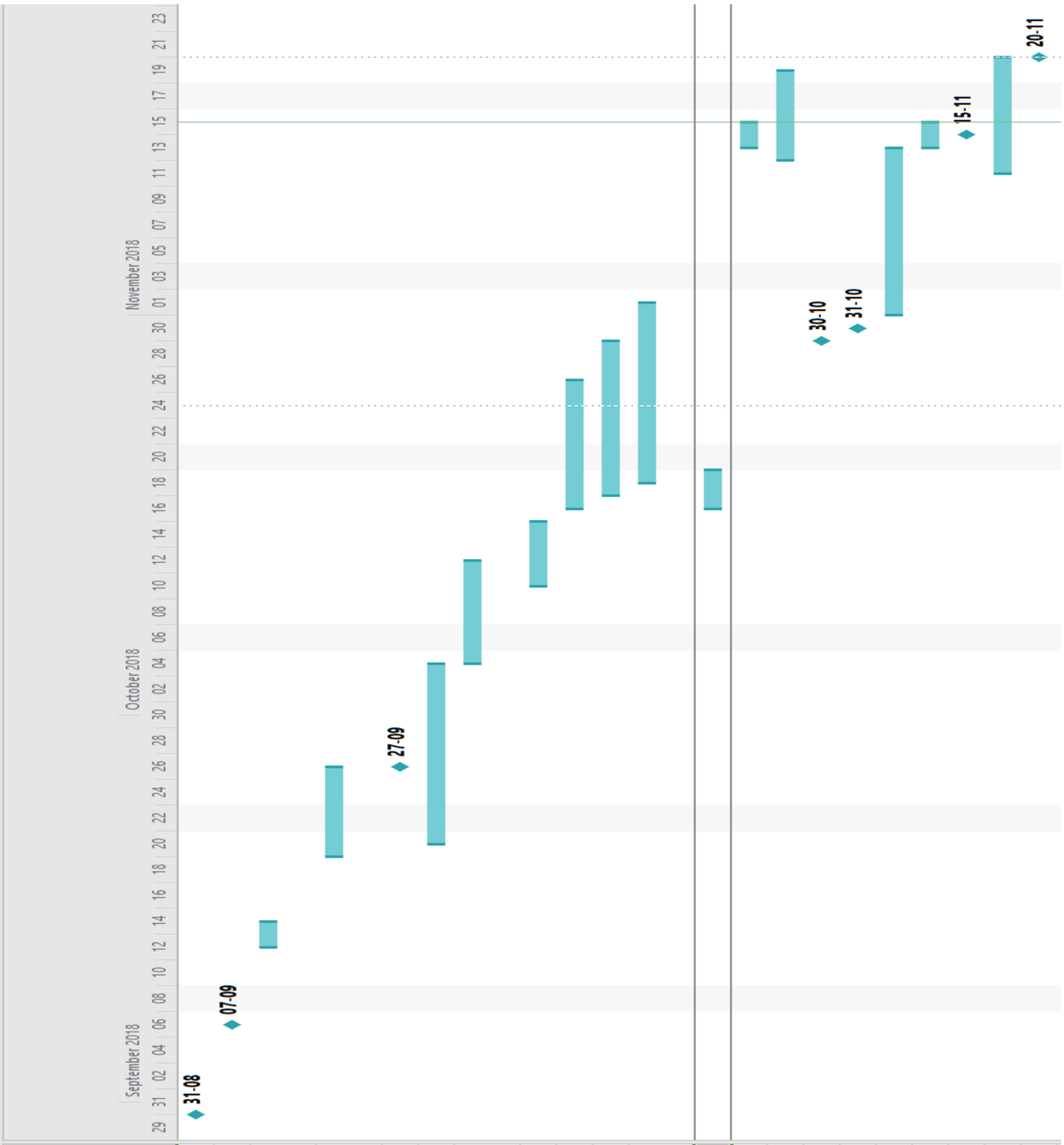
[6] F. P. Incropera, D. P. DeWitt, T. L. Bergman, A. S. Lavine, Fundamentals of heat and mass transfer, 7th ed., John Wiley & Sons, 2013, 116-120.

[7] B.Rice and D.Cooper, "Integrating (Non Self Regulating) Processes: Analyzing Pumped Tak Dynamics with a FOPDT Integrating Model" November,2018. [Online]. Available: https://www.controlguru.com/analyzing-pumped-tank-dynamics-with-a-fopdt-integrating-model/ [Accessed: Nov. 16, 2018].

[8] B.Rice and D.Cooper, "Integrating (Non Self Regulating) Processes: A Design and Tuning Recipe for Integrating Processes" November,2018. [Online]. Available: https://controlguru.com/a-design-and-tuning-recipe-for-integrating-processes/ [Accessed: Nov. 16, 2018].

Appendices

Appendix A <Project Schedule>



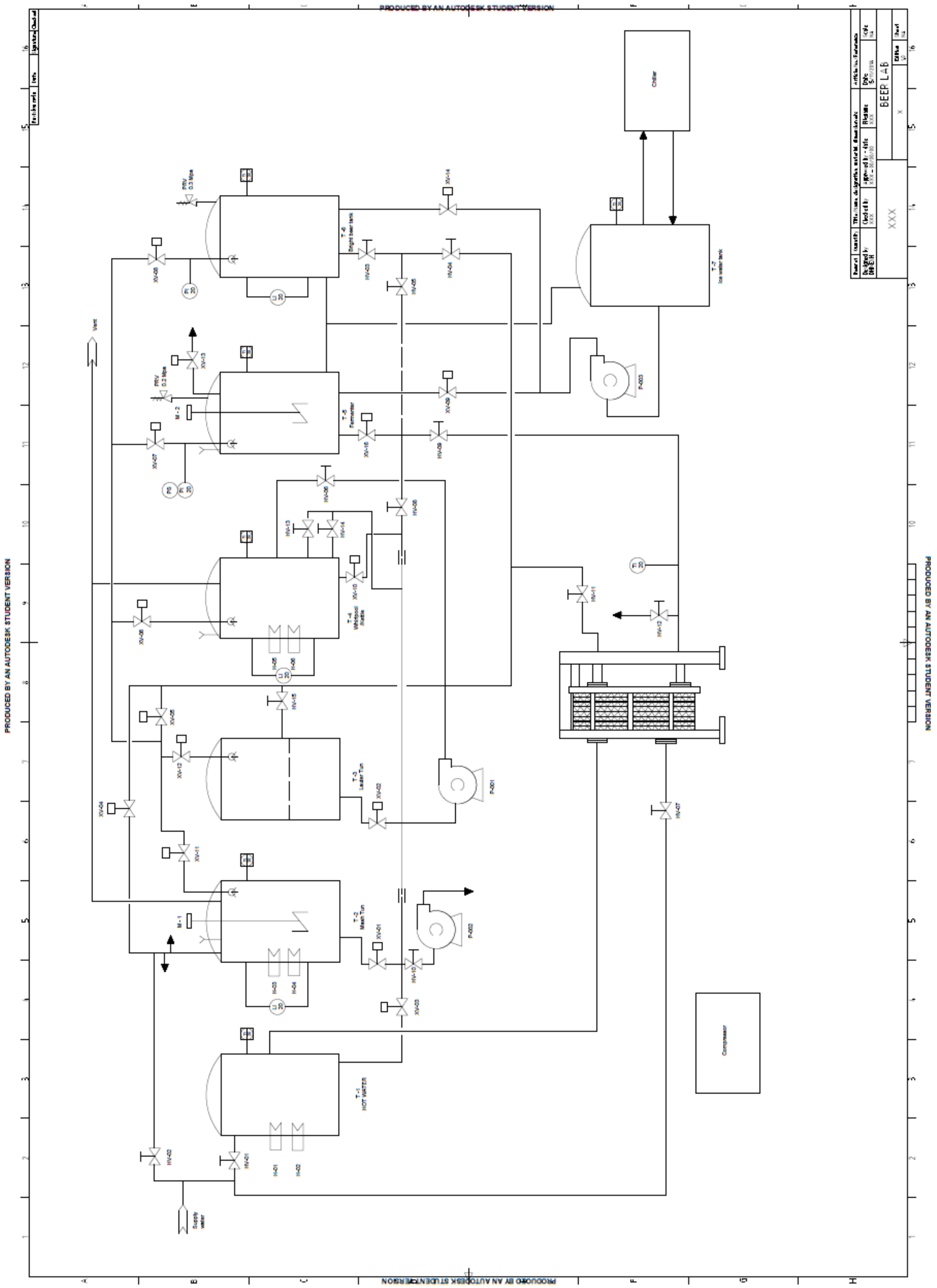
Name	Duration	Start	Finish
Project Start	0 days	Fri 31-08-18	Fri 31-08-18
Project meeting	0 days	Fri 07-09-18	Fri 07-09-18
Equipment installation	2 days	Thu 13-09-18	Fri 14-09-18
Documentation Review	5 days	Thu 20-09-18	Wed 26-09-18
DeltaV training	0 days	Thu 27-09-18	Thu 27-09-18
Cabling +Labelling	10 days	Fri 21-09-18	Thu 04-10-18
Initial Logic creation	6 days	Fri 05-10-18	Fri 12-10-18
HMI creation	3 days	Thu 11-10-18	Mon 15-10-18
Testing	8 days	Wed 17-10-18	Fri 26-10-18
Troubleshooting	8 days	Thu 18-10-18	Mon 29-10-18
Logic update(controller)	10 days	Fri 19-10-18	Thu 01-11-18
Cleaning	3 days	Wed 17-10-18	Fri 19-10-18
HMI update	2 days	Wed 14-11-18	Thu 15-11-18
Sequence creation	5 days	Tue 13-11-18	Mon 19-11-18
Sanitising	0 days	Tue 30-10-18	Tue 30-10-18
Brewing	0 days	Wed 31-10-18	Wed 31-10-18
Fermenting	9 days	Thu 01-11-18	Tue 13-11-18
Cold Crash	2 days	Wed 14-11-18	Thu 15-11-18
Bottling	0 days	Thu 15-11-18	Thu 15-11-18
Report writing	7 days	Mon 12-11-18	Tue 20-11-18
Report Hand-in	0 days	Tue 20-11-18	Tue 20-11-18

Appendix B <Specific gravity to ABV% calculator>

Reference temperature 20 °C

Specific gravity	**Alcohol by volume (ABV) %**
1.010	0.4
1.015	1.2
1.020	2.0
1.025	2.8
1.030	3.6
1.035	4.3
1.040	5.1
1.045	5.8
1.050	6.5
1.055	7.2
1.060	7.9
1.065	8.6
1.070	9.3
1.075	10.0
1.080	10.6
1.085	11.3
1.090	12.0
1.095	12.7
1.100	13.4
1.105	14.2

Appendix C <Piping and Instrumentation diagram (P&ID)>



Appendix D <Sequence code>

S1:

```
'//XV-01/XV_01.ST'  := 0;
'//XV-02/XV_02.ST'  := 0;
'//XV-03/XV_03.ST'  := 0;
'//XV-04/XV_04.ST'  := 0;
'//XV-05/XV_05.ST'  := 0;
'//XV-06/XV_06.ST'  := 0;
'//XV-07/XV_07.ST'  := 0;
'//XV-08/XV_08.ST'  := 0;
'//XV-09/XV_09.ST'  := 0;
'//XV-10/XV_10.ST'  := 0;
'//XV-11/XV_11.ST'  := 0;
'//XV-12/XV_12.ST'  := 0;
'//XV-13/XV_13.ST'  := 0;
'//XV-14/XV_14.ST'  := 0;
'//XV-15/XV_15.ST'  := 0;
'//XV-16/XV_16.ST'  := 0;
'//P001_HOTWATER/P001.CV' := 0;
'//P002_WASTEWATER/P002.CV' := 0;
'//P003_ICEWATER/P003.CV' := 0;
```

T1:

```
'COUNT.CV'= 0  AND 'MASH_START.CV' AND NOT 'STOP.CV';
```

S2:

A1:

```
IF (NOT 'STOP.CV') THEN
    '//XV-04/XV_04.CV' := TRUE;
    '//XV-01/XV_01.CV' := TRUE;
END_IF;
```

A2: DELAY 3s

```
IF (NOT 'STOP.CV') THEN
    '//P001_HOTWATER/P001.CV' := TRUE;
```

```
END_IF;

A3:     DELAY CYCLE_TIME
IF (NOT 'STOP.CV') THEN
        '//P001_HOTWATER/P001.CV' := FALSE;
        '//XV-04/XV_04.CV' := FALSE;
        '//XV-01/XV_01.CV' := FALSE;
END_IF;

A4:
IF (NOT 'STOP.CV') THEN
        '//XV-05/XV_05.CV' := TRUE;
        '//XV-11/XV_11.CV' := TRUE;
        '//XV-01/XV_01.CV' := TRUE;
END_IF;

A5:     DELAY 3s
IF (NOT 'STOP.CV') THEN
        '//P001_HOTWATER/P001.CV' := TRUE;
END_IF;

A6:     DELAY CYCLE_TIME
'//P001_HOTWATER/P001.CV' := FALSE;
'//XV-05/XV_05.CV' := FALSE;
'//XV-01/XV_01.CV' := FALSE;
'//XV-11/XV_11.CV' := FALSE;
IF (NOT 'STOP.CV') THEN
        'COUNT.CV':='COUNT.CV'+1;
ELSE
        'COUNT.CV':='NUM_CYCLES.CV'+1;
END_IF;

IF ('NUM_CYCLES.CV'  >  'COUNT.CV') THEN
        'T3/CV.CV':=True;
ELSE
```

```
        'T3/CV.CV':=False;
        'COUNT.CV' := 0;
    END_IF;
```

T3:

True

T2:

'LAUTER_START.CV' AND 'COUNT.CV'=0 AND NOT 'STOP.CV';

S3:

A1:

```
IF (NOT 'STOP.CV') THEN
    '//XV-02/XV_02.CV' := TRUE;
END_IF;
```

A2: DELAY 3s

```
IF (NOT 'STOP.CV') THEN
    '//P001_HOTWATER/P001.CV' := TRUE;
END_IF;
```

A3: DELAY CYCLE_TIME

```
IF (NOT 'STOP.CV') THEN
    '//P001_HOTWATER/P001.CV' := FALSE;
    '//XV-02/XV_02.CV' := FALSE;
END_IF;
```

A4: DELAY 3s

```
IF (NOT 'STOP.CV') THEN
    '//XV-05/XV_05.CV' := TRUE;
    '//XV-11/XV_11.CV' := TRUE;
    '//XV-01/XV_01.CV' := TRUE;
END_IF;
```

A5: DELAY 3s

```
IF (NOT 'STOP.CV') THEN
    '//P001_HOTWATER/P001.CV' := TRUE;
END_IF;
```

A5: DELAY CYCLE_TIME

```
'//P001_HOTWATER/P001.CV' := FALSE;
'//XV-05/XV_05.CV' := FALSE;
'//XV-01/XV_01.CV' := FALSE;
'//XV-11/XV_11.CV' := FALSE;

IF (NOT 'STOP.CV') THEN
    'COUNT.CV':='COUNT.CV'+1;
ELSE
    'COUNT.CV':='NUM_CYCLES.CV'+1;
END_IF;

IF ('NUM_CYCLES.CV' > 'COUNT.CV') THEN
    'T5/CV.CV':=True;
ELSE
    'T5/CV.CV':=False;
END_IF;
```

T5:

```
'MANUAL_LAUTER.CV'
```

S4:

A1:

```
IF (NOT 'STOP.CV') THEN
    '//XV-05/XV_05.CV' := TRUE;
    '//XV-12/XV_12.CV' := TRUE;
    '//XV-02/XV_02.CV' := TRUE;
END_IF;
```

A2: DELAY 3s

```
IF (NOT 'STOP.CV') THEN
```

```
        '//P001_HOTWATER/P001.CV' := TRUE;
END_IF;
```

A3: DELAY CYCLE_TIME

```
'//P001_HOTWATER/P001.CV' := FALSE;
'//XV-05/XV_05.CV' := FALSE;
'//XV-02/XV_02.CV' := FALSE;
'//XV-12/XV_12.CV' := FALSE;

IF (NOT 'STOP.CV') THEN
        'COUNT.CV':='COUNT.CV'+1;
ELSE
        'COUNT.CV':='NUM_CYCLES.CV' +1;
END_IF;

IF ('NUM_CYCLES.CV' > 'COUNT.CV') THEN
        'T4/CV.CV':=True;
ELSE
        'T4/CV.CV':=False;
        'COUNT.CV'  := 0;
END_IF;
```

S5:

A1:

```
IF (NOT 'STOP.CV') THEN
        '//XV-02/XV_02.CV' := FALSE;
        '//XV-01/XV_01.CV' := TRUE;
END_IF;
```

A2: DELAY 3s

```
IF (NOT 'STOP.CV') THEN
        '//P001_HOTWATER/P001.CV' := TRUE;
END_IF;
```

T7:

```
'DONE_PUMPING.CV'
```

S6:

'//P001_HOTWATER/P001.CV' := FALSE;
'//XV-01/XV_01.CV' := FALSE;

T8:

False

T9:

'STOP.CV'

S7:

'//XV-01/XV_01.ST' := 0;
'//XV-02/XV_02.ST' := 0;
'//XV-03/XV_03.ST' := 0;
'//XV-04/XV_04.ST' := 0;
'//XV-05/XV_05.ST' := 0;
'//XV-06/XV_06.ST' := 0;
'//XV-07/XV_07.ST' := 0;
'//XV-08/XV_08.ST' := 0;
'//XV-09/XV_09.ST' := 0;
'//XV-10/XV_10.ST' := 0;
'//XV-11/XV_11.ST' := 0;
'//XV-12/XV_12.ST' := 0;
'//XV-13/XV_13.ST' := 0;
'//XV-14/XV_14.ST' := 0;
'//XV-15/XV_15.ST' := 0;
'//XV-16/XV_16.ST' := 0;
'//P001_HOTWATER/P001.CV' := 0;
'//P002_WASTEWATER/P002.CV' := 0;
'//P003_ICEWATER/P003.CV' := 0;

Appendix E <PWM code>

```
CALC1 Expression

DUTYCYCLE := IN1;
CYCLE_PERIOD := IN2;
DUTY_SCALE_EU100 := 100;
DUTY_SCALE_EU0 := 0;
DUTYRANGE := (DUTY_SCALE_EU100 - DUTY_SCALE_EU0);
ONTIME := (ROUND(ABS((DUTYCYCLE - DUTY_SCALE_EU0) / DUTYRANGE * CYCLE_PERIOD)));
OFFTIME := (CYCLE_PERIOD - ONTIME);
ONTIMEMIN := 0;
OFFTIMEMIN := 0;


IF
                ((ONTIME  > ONTIMEMIN) AND
                (OFFTIME  > OFFTIMEMIN))
THEN
                TIMERSTART := ('^/OND1/OUT_D.CV' = FALSE);
                ELAPSED := '^/OND1/ELAPSED_TIMER.CV';

                IF
                                (ELAPSED <= ONTIME) AND (ONCE = TRUE)
                THEN
                                PWM_OUT := 1;
                                ELSE
                                PWM_OUT := 0;
                                ONCE := FALSE;
                                ENDIF;
ELSE
                TIMERSTART := '^/OND1/OUT_D.CV' = TRUE ? FALSE : TIMERSTART ;
IF
                (OFFTIME <= OFFTIMEMIN) AND (ONCE = TRUE)
                THEN
                PWM_OUT := 1;
                ELSE
                PWM_OUT := 0;
                ONCE := FALSE;
                ENDIF;
ENDIF;
IF
                ('^/OND1/IN_D.CV' != TIMERSTART)
THEN
                '^/OND1/IN_D.CV' := TIMERSTART;
                ONCE := TRUE;
ENDIF;

OUT1 := PWM_OUT;
```

Appendix F <Harry Porter recipe>

Harry Porter — Page 1 of 2

Harry Porter

Baltic Porter (9 C)

Type: All Grain
Batch Size: 60,0 l
Boil Size: 64,4 l
Boil Time: 60 min
End of Boil Vol: 62,5 l
Final Bottling Vol: 60,0 l
Fermentation: Ale, Single Stage
Taste Notes:

Date: 24 Aug 2018
Brewer: MorraRi
Asst Brewer:
Equipment: Humle og malt
Efficiency: 75,00 %
Est Mash Efficiency: 75,0 %
Taste Rating: 30,0

Prepare for Brewing

- ○ Clean and Prepare Brewing Equipment
- ○ Total Water Needed: 81,4 l
- ○ Mash Water Acid:

Mash or Steep Grains

Mash Ingredients

Amt	Name	Type	#	%/IBU
13800 g	Pale Malt (2 Row) Bel (5,9 EBC)	Grain	1	81,2 %
1350 g	Caramunich II (Weyermann) (124,1 EBC)	Grain	2	7,9 %
850 g	Wheat Malt, Bel (3,9 EBC)	Grain	3	5,0 %
500 g	Chocolate Malt (689,5 EBC)	Grain	4	2,9 %
500 g	Roasted Barley (591,0 EBC)	Grain	5	2,9 %

Mash Steps

Name	Description	Step Temperature	Step Time
Saccharification	Add 50,4 l of water at 73 C	67 C	60 min
Mash Out	Heat to 76 C over 10 min	76 C	10 min

- ○ Sparge Water Acid:
- ○ Fly sparge with 31,1 l water at 76 C
- ○ Add water to achieve boil volume of 64,4 l
- ○ Estimated pre-boil gravity is 1,060 SG

Boil Ingredients

Amt	Name	Type	#	%/IBU
100 g	East Kent Goldings (EKG) [5,00 %] - Boil 60,0 min	Hop	6	19,3 IBUs
2,40 Items	Whirlfloc Tablet (Boil 15,0 mins)	Fining	7	-
50 g	Challenger [7,50 %] - Boil 15,0 min	Hop	8	7,2 IBUs

- ○ Estimated Post Boil Vol: 62,5 l and Est Post Boil Gravity: 1,064 SG

Cool and Transfer Wort

- ○ Cool wort to fermentation temperature
- ○ Transfer wort to fermenter
- ○ Add water if needed to achieve final volume of 60,0 l

Pitch Yeast and Measure Gravity and Volume

Fermentation Ingredients

Amt	Name	Type	#	%/IBU
4,0 pkg	Safale American (DCL/Fermentis #US-05) [50 ml]	Yeast	9	-

- ○ Measure Actual Original Gravity _______ (Target: 1,064 SG)
- ○ Measure Actual Batch Volume _______ (Target: 60,0 l)
- ○ Add water if needed to achieve final volume of 60,0 l

Fermentation

- ○ 24 Aug 2018 - Primary Fermentation (14,00 days at 19 C ending at 19 C)

Dry Hop and Bottle/Keg

- ○ Measure Final Gravity: ________ (Estimate: 1,014 SG)
- ○ Date Bottled/Kegged: 07 Sep 2018 - Carbonation: Bottle with 321,13 g Table Sugar
- ○ Age beer for 30,00 days at 18 C
- ○ 07 Oct 2018 - Drink and enjoy!

Notes