Keur-Keg

Senior Design Project

Senior Design II
EEL 4915L
Fall 2019

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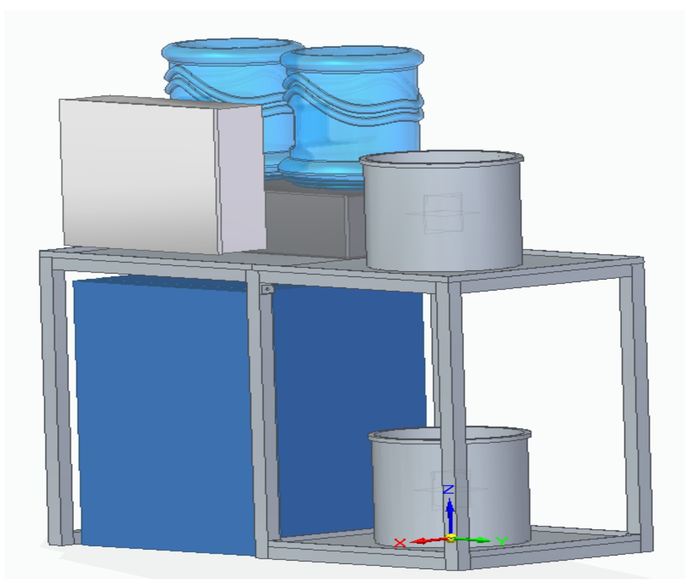

Due:
December 4, 2019

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1. Keur-Keg Brewing Description

1.1. Executive Summary

The process of brewing beer can be tedious and take a lot of time tending to the process which allows room for error and inconsistency of the product. A perfect brew of a certain recipe can be difficult to achieve because the timing, temperature, and processes need to be precise. Big companies can get all these aspects precise with huge and expensive equipment that automate the entire process to achieve perfection in bulk of every batch. On the other hand, the home brewer has to purchase all the individual equipment and can get the temperatures close but will find it difficult to get it perfect. The brew process typically takes around 3 hours to complete followed by the fermentation process which takes between 2 to 6 weeks to complete and still requires some tending throughout this process. The consumer then has the option to either bottle or keg their beer for the final carbonation step. The bottling process can take 2 hours whereas kegging can be done in as little as 15 minutes. We are proposing an auto-brewing system (Keur-Keg), after the user loads all of the ingredients into the correct dispensing units, the system will complete most of the brewing and fermentation process with the push of a button and minimal user interaction saving hours of time and making it so the user can achieve a consistent product every time they brew beer.

A person that brews their own beer can spoil their product or have an undesirable flavor by having too much or too little heat at certain steps, adding ingredients at the wrong times, having the wrong ratio of water to ingredients, and not achieving certain temperatures for a specific amount of time. Boil overs can also occur if heat is too high or the product is not stirred correctly causing a huge mess that is difficult to clean. This system will monitor temperature at every step, control the heat for the malting and brewing process and control the cool temperature needed throughout the fermentation process. It will also add ingredients at specific times and automatically transfer the product from stage to stage when complete. The user will be notified of any steps that require human interaction such as having to bottle or keg the final product. The Keur-Keg will be easily disassembled for the user to clean. Our objective is to build this auto-brewing system (Keur-Keg) to brew a maximum of 5 gallons of product using a standard 120 VAC wall outlet.

The control panel for this design will consist of contactors and relays that control the pumps, motors, heating element, dispensing units, cooling unit, refrigeration system, and supply power to the input or control components. These components consist of temperature sensors, fluid level sensors, and a user input display. The user input will allow different recipe inputs to be achieved and along with the temperature sensors and fluid level sensors will communicate with a microcontroller which will control the pumps, motors, heating elements, cooling unit, refrigeration system, and dispensing units. The microcontroller will consist of the timers so each step can operate with precise timing. This system can also be connected to wi-fi in order to send notification to the user when something is complete, an error occurred, or perform an extra step which was not automated. This report will give details such as project guidelines, requirements, specifications, research on other similar products, research on different systems and the parts that make them up, and the process of choosing and building the Keur-Keg.

1.2. Motivation and Goals

Home brewing has become significantly more popular as craft brewers have introduced people to the different flavors that can be achieved with beer brewing. Although this has allowed the consumer to narrow down and understand what specific flavors they may enjoy from their beer, the beer may not be easily repeatable at home. By having an automated beer brewing system, the user would then be able to make more of their favorite batches to keep it readily available for themselves and loved ones. The automation of the brewing processes also allows the user to still enjoy the brewing process but spend that time on something else. Currently there are similar products on the market for small scale personal brewing systems that can achieve proper consistency and temperature throughout the entirety of the process for the steps previously described that we would like to replicate and improve upon.

1.3. Project Objectives

Our objectives for this project include having the total output current as minimal as possible, all parts to work in sequence with the MCU, to obtain a successful product output of 5 gallons using multiple different recipes, a battery backup for the MCU, design system in to any 120V, 20A outlet and have the system operate at full capacity. This objective was completed by performing careful research on the parts needed and then selecting the proper parts to build the system. To achieve the optimal output and proper consistency, we made sure that the MCU was coded properly allowing it to communicate between the timers, sensors, motors, and pumps. Consistent products every time relies mostly on proper coding of the MCU to ensure precise timing, temperature, and mechanical operations. A battery backup for the MCU is an important objective because if a power loss occurs at any time, a notification will be sent to the user so alternate measures can be performed so the batch can be saved instead of spoiled.

1.4. Budget

The parts listed in Table 1 are descriptions of the components that were needed to complete the project. The PCB and power supply consisted of many individual components and the cost of each item varied depending on the part we choose.

Table 1: Proposed Budget

Description	Quantity	Price
Heating element	2	50.00
Power supply components	1	100.00
PCB	2	100.00
Motor	1	50.00
Pumps	3	200.00
Stainless steel containers	2	200.00
Hoses and components	1	300.00
Cooling unit	1	50.00
Sanitation materials	1	50.00
Brewing material (Hops, malt)	2	100.00
Structure	1	200.00

The goal for estimated total cost was not expected to 1500 dollars, however the actual cost of the projected was double that at 2900 dollars as seen below in Table 2. This project was funded by the members of this senior design group.

Table 2: Actual Budget

Description	Quantity	Price
Water system	1	180.00
Fluid transfer system	1	350.00
Steeping system	1	250.00
Boiling system (including dispensing units)	1	500.00
Fermenting system	1	200.00
Control cabinet	1	100.00
Relays, amplifiers, and wires	1	120.00
Power supplies	1	100.00
PCB/MCU	1	100.00
Frame and brewing material (Hops, malt)	1	100.00
Miscellaneous	1	900.00
Total	2900.00	

1.5. Automatic Brewing Requirements and Specifications

Table 3 lists all the standards that the project met in the implementation process of the Keur-Keg. By meeting the parameter requirements for temperature sensing, brewing capacity, sanitation level, liquid volume, and timer accuracy, we ensured repeatability of recipes for every brew. A typical brewing capacity of 5 gallons with a 5% tolerance was chosen due to this being a typical brewing amount for home beer brewers. We built the Keur-Keg to meet a food sanitation level of C since it was attainable without having a 100% controlled general environment. For the liquid volume sensor and timer sensor, we ensured the accuracy to be within 5% so the brews of the same recipe are steady in flavors and consistency. For the system to be durable, all the sensors and miscellaneous equipment were able to withstand the environment of which it was placed. E.g. If a sensor is placed in the boil kettle then it was able to withstand boiling temperatures. We provided enough memory for at least 10 recipes sets a goal for the engineering team, but also makes it marketable.

Table 3: Market Standards and Requirements

Parameter	**Min**	**Typical**	**Max**	**Unit**
Temperature Sensor	-2	±1	+2	°F
Brewing Capacity	4.75	5	5.25	gal
Sanitation Level		C		n/a
Liquid Volume Sensor	0.95	1	1.05	gal
Timer Accuracy	-3		+3	secs
Equipment Temperature Endurance	-20	250	+20	°F
Recipes in Memory		10		n/a

Table 4 lists many of the constraints under which the Keur-Keg was designed. These constraints are the guidelines by which our design were inhibited by to provide a lower cost, durability, and quality product.

Table 4: General Design Constraints

Parameter	**Min**	**Typical**	**Max**	**Unit**
Containers	1		3	n/a
Power		2000	2400	W
Current Draw		16.67	20	A
Project Cost			1500	$
Power Supply Voltage	114	120	126	Vac
Power Supply Frequency		60		Hz
Power Supply Phase		1		n/a
Footprint		5x5		ft2
Height		5		ft
Weight		70		lbs
Battery Backup Time Period	4			weeks
Supported Brewing Process		Malt Extract/ Grain		n/a

1.5.1. Product Specification

1.5.1.1. Water specification

This project used a simple and in-expensive water that contained a good balance of minerals which balance the PH to an ideal level. This eliminated having to perform the chemistry to get the water perfect before each brew and still produce a tasteful and quality product. Distilled water and reverse osmosis water was not used since they lack the minerals required to produce a quality output. Bottled water is expensive when looking to get an output of 5 gallons. Tap water produced in Florida contains plenty of minerals and utility companies will try to keep the PH balanced between 6.5 and 8.5 which is acceptable for brewing beer other recipes in the future. The water chosen to be used in this project was spring water which was found in 5-gallon jugs and purchased at the local grocery store at a reasonable price.

1.5.1.2. Sanitizer Specification

It is important to sanitize all the equipment that comes into contact with the beer brewing process. For our design, we went with heat and Star San combination of sanitizing the equipment used during brewing. The brew kettles were able to heat water to boiling and then run that boiling water through the entire system during a cleaning program. Then, before brewing begins the was able to run a sanitation program. We chose Star San as the sanitizing chemical to be used during the sanitization program because it is an “acidic sanitizer” that was specifically “developed for sanitizing brewing equipment” (Palmer, Chapter 2: Sanitation, 2015). This sanitizer works best for our design because we will not have to worry about ensuring the complete rinsing out of the sanitizer. Star San is able to sanitize with as little as 30 seconds of contact and does not change the final beer products flavor or quality if any residue is left in a container or in the hoses. Users should follow the directions provided with Star San to determine the proper amount to use per unit of water.

1.5.2. User Preparation and Operation

The user is responsible to perform some tasks before starting the machine, after the brew cycle is complete, and when the fermenting is complete. These tasks would be difficult to fully automate due to the different recipes, the packaging items come in, and nature of the task. Larger breweries can automate these tasks because they focus more on certain recipes whereas our project was designed to brew multiple different recipes. The tasks the user must perform are very minimum compared to the brewing cycle and must be performed to ensure a good product. The steps that need to be completed before starting the system are as follows:

1. Turn the main circuit breaker on to power the main systems.
2. Set liquid malt in a tub of hot water for ease of removal.
3. Fill a 5-gallon jug with water and sanitizing formula and insert into the water reservoir and run the sanitize program to ensure the formula contacts all of

the hoses, connections, and kettles. Dump sanitizing fluid from the fermenter and set fermenting pot in the fermenting refrigerator.

4. Install 2 new 5-gallon jugs containing water used for the brewing process into the water reservoir.
5. Open grain, hops, dry malt, and liquid malt. Read the brew instructions and fill the dispensing unit with the applicable ingredient.
6. Enter information provided in the instructions into the user interface.
   - Initial water level
   - Initial temperature and steeping time
   - Boiling time
   - Times to dispense the liquid malt, dry malt, and hops
   - Fermenting temperature and time
   - Any optional steps in the recipe that can notify the user
7. Start the brew cycle

After the brew cycle is complete, the user will have to perform some cleaning and minor maintenance to get the system ready for another brew and eliminate any contaminants in the system. These steps are as follows:

1. Disconnect the hose from the fermenter and put into a 5-gallon bucket.
2. Remove grain screen, liquid malt container, steeping kettle, and boiling kettle. Clean sediment from steeping and boiling kettle and re-install.
3. Run the flush program.
4. (Optional) Remove and clean any hoses, hops containers, or solenoids if needed and clean. This may need to be done every five uses. System flush should adequately clean the plumbing equipment.
5. Dump the 5-gallon bucket and clean both the steeping and boiling kettles.
6. If user has a separate fermenting unit, system is ready to use. Repeat the above process. If user is finished, turn the main circuit breaker off.
7. User will receive notifications if any dry hops or special ingredients need to be added during the fermenting process.

After the fermenting is complete the user is responsible for bottling or kegging the final product. These steps could be 10 days to over a month after the brewing process is completed. These simple steps are listed below:

1. Remove the fermenting pot from the fermenting refrigerator.
2. Bottle or keg the final product in accordance with the instructions.
3. Clean the fermenting pot, stopper, and airlock. Replace airlock if needed.
4. Install fermenting pot into refrigerator and connect hose to fermenting unit.

At this point, the process is ready to repeat, and a new batch is ready to be made. This process can be repeated until any special maintenance or cleaning is needed.

1.6. Design Standards and Constraints

Standards and constraints made up the basis for the design of our automated brewing product. Standards are a set of guidelines for the product that was developed that considers existing national or international standards. These standards are already the minimum requirements necessary to not only a make a good product, but a product that conforms with existing safety levels and regulations. The intention for the Keur-Keg is to be used in the United States so it was built following the standards set forth by IPC-Association Connecting Electronics Industries (IPC), the Institute of Electrical and Electronics Engineers (IEE), and the International Electrotechnical Commission (IEC); all three are organizations and are respected throughout the world, comprised of professional and experienced engineers. Aside from standards, the Keur-Keg was also restricted by constraints of the environment it will be in, such as the physical environment, political environment, or social environment.

1.6.1. Electrical Equipment Standards

In order for the setup of the automated brew system to be safe for the user and to protect the system itself, standards were met for how the electrical equipment is protected from the physical environment. The environment being a number of factors such as the user interacting with it, the possibility of water intrusion, or the possibility of an object hitting it.

To protect the user from putting themselves in a dangerous situation, a detailed instruction manual is provided to show how to go about cleaning the automated brew system explaining that the system should be deenergized by ensuring that the 120V power cord is unplugged from the wall. When designing the system the design made sure that things like the power supply were not just out in the open, since the user may be able to hurt themselves or even die from accidental electrical shock with as little current as 100-200 mA. The power supply and controls are to be enclosed in an enclosure to protect the system from water intrusion which could be harmful to both the system and the user. The design for this project met standards of IP(Ingress Protection) set forth by the IEC 60529. However, if budgeting did not allow it and the water intrusion standard was lowered accordingly. Anti-water intrusion can significantly raise the prices of control boxes due to the gasket and for corrosion resistance, the stainless-steel metal can add more to the overall price. When an electrical device has an IP rating it has two numbers associated with it; the first digit deals with solid intrusion and the second digit deals with liquid intrusion. The following Table 4 and Table 5 are tables provided by the IEC 60529 that describe the various levels of protection that could be designed to. These design standards are very important for keeping people safe in environments such as factories where there are many electrical equipment cabinets that workers may or may not have access to. The water intrusion rating is especially important for pools or water parks where there may be high powered pumps in the same room as electrical panels that provide the power for the pool equipment. In this type of corrosive environment, the cabinets are also usually made of stainless steel.

Table 5, as defined by the IEC, refers to the different levels of physical intrusion protection that are achievable by enclosures for electrical equipment. Physical intruders can be anything from fingers to dust or sand. By preventing fingers from being able to enter, this protects people directly. By preventing foreign materials like dust or a combustible powder from entering the electrical enclosure, then you indirectly protect people from fires or potential arc flash situations due to dust buildup. The levels range from 0 to 6 and start at no protection at level 0 and reach a complete dust tight protection at level 6.

Table 5: Levels of Protection Against Solid Hazards: First Digit

Level	Object size protected against	Effective against
0	Not protected	Not protection against contact and ingress of objects
1	>50mm	Any large surface of the body, such as the back of the hand, but no protection against deliberate contact with a body part.
2	>12.5 mm	Finger or similar objects.
3	>2.5 mm	Tools, thick wires, etc.
4	> 1 mm	Most wires, screw, etc.
5	Dust protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment; complete protection against contact.
6	Dust tight	No ingress of dust; complete protection against contact.

Table 6 is a table defined by the IEC for the levels of liquid protection for electrical enclosures. In this day in age, liquid protection of electronics is very important as can be seen by the increasing amount of water resistant or waterproof products on the market. It is especially important here in Florida where, there is a significant amount of rain and high levels of humidity. It is important for the design to aim for at least a spraying water protection of level 3 since accidents could occur while brewing, such as a boil overs, or even if a severe thunderstorm passes through and the user may have left their garage open, where they may keep the Keur-Keg, open to the elements. Florida and many parts of the country have recently had more problems with flooding, so we would want to try to keep the user as safe as possible to keep them safe and brewing beer.

Table 6: Levels of Protection Against Liquid Hazard

Level	Object size protected against	Effective against
0	Not protected	-
1	Dripping water	Dripping (vertically falling drops) shall have no harmful effect.
2	Dripping water when tilted 15º	Vertically dripping water shall have no effect when the enclosure is tilted at an angle up to 15o from its normal position.
3	Spraying water	Water falling as a spry at any angle up to 60o from the vertical shall have no harmful effect.
4	Splashing water	Water splashing against the enclosure from any direction shall have no harmful effect
5	Water jets	Water projected by a nozzle (6.3mm) against enclosure from any direction shall have no harmful effects.
6	Powerful water jets	Water projected in powerful jets (12.5mm nozzle) against the enclosure from any direction shall have no harmful effects.
7	Immersion up to 1 m	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).
8	Immersion beyond 1m	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects.

Table 6 has levels of protection from liquids ranging from levels 0 to 8. The IEC defines level 0 as having no protection against liquids and the maximum level of protection, level 8, is defined as the ability to be immersed in 1 meter of liquid.

According to the two previous tables' standards, the project goal was to build the product to a minimum IP23 standard so that humans are protected against accessing hazardous electrical parts with their fingers and the electrical equipment is protected from the liquids involved in the automated brew processes that could spray if a hose or pump were to fail. The IP23 standard still allows the Keur-Keg to have an overall reasonable price while maintaining certain standards. Going past IP23 would significantly raise manufacturing costs and therefore make the product even more expensive.

1.6.2. Printed Circuit Board Design Standards

For the printed circuit board standards, the design followed the standards of the IPC. These standards have had input from many individuals in many different industries worldwide in order to ensure reliability and minimum standards. There are quite a number of standards and requirements, but this design focused on the standards for IPC-2221B “Generic Standard on Printed Board Design” under the “Performance Classes” section (Task Group(D-31b) of the Rigid Printed Board Comitte, 2012)IPC-2221B). This section lays out three classes of design standards of printed circuit boards: class one, class two, and class three. Depending on the classification there are different levels of testing and functionality required.

1.6.2.1. Class One

Class one printed circuit board standards are for “general electronic products” as described by the IPC. This is generally for any product that is not intended to have a long lifetime and is not an essential product for maintaining life. For example, this could be for simple cheaper mass-produced personal products such as flashlights or fitness trackers. The products that use this type of printed circuit board are typically cheaper but are not very robust.

1.6.2.2. Class Two

Class two printed circuit board standards are for “dedicated service electronic products” as described by the IPC. This class of printed circuit board is meant for products that require some level of reliability and robustness. The products that use this type of printed circuit board are used for commercial and industrial purposes for products such as TVs and kitchen appliances. For this class of printed circuit board, it does not need to look neat and orderly, the board is only expected to work for the purposes it was designed for. In addition, the PCB should work for the expected lifetime of the product.

1.6.2.3. Class Three

Class three printed circuit board standards are for “high reliability electronic products” as described by the IPC. These products are held to the highest design standard since they are usually for products that usually deal with maintaining or inducing the loss of human life. Some examples of products that use class three printed circuit board designs are missile systems for the military that must always hit the right target or pacemakers that are keeping the user alive. These printed circuit boards are the most expensive type of the three classes.

Because the Keur-Keg is only a prototype with a limited budget, the design met a class one IPC design standard. If there was more time and money, the printed circuit board could have been designed to a class two. In addition, if mass production were already being planned, then a level two printed circuit board would help ensure a quality product that would function as expected in harsher environments for everyday use.

1.6.3. Power Supply Standards

The power supply is an important part of making the Keur-Keg work since it obviously needed electricity for everything to work. The design is intended for the United States standard residential voltage of 120VAC. The Keur-Keg power also followed standards for North America and at this time will not take into consideration the standards for other regions. The design met the safety standards of several national and international agencies that are recognized and respected throughout the world, but specifically met those used in the United States. These standards have been put in place not only to protect people against electrocution, but also from fires and other injuries. The power supply for the Keur-Keg will provide power to a number of components, such as the mixing motor, heating element, relays, contactors, and a battery backup for the timer on the MCU. We will also be following the United States Code for the external power supply section in U.S.C section 6291 subsection 36. The power supply as defined by the U.S.C is an “external power supply circuit that is used to convert household electric current into DC current or lower-voltage AC current to operate a consumer product” (Federal Energy Administration, 2010). That’s exactly what the power supply is doing to satisfy the different power requirements of the Keur-Keg. The first standard that was followed is that of the National Electrical Code(NEC) or NFPA 70. The NEC has many standards in the United States for the “safe installation of electrical wiring and equipment” that are adopted by different regions (Kelechava, 2017). Wiring was appropriately sized according to the NEC 2017 based on Table 7 below. It is usually industry standard to operate at the 75°C temperature in Orlando, Florida, where we did all of our testing.

Table 7: Allowable ampacity based on ambient temperature for insulated copper conductors, Table 310.15(B)(17) in NEC 2017

Size (AWG or kcmil)	**Temperature Rating of Copper Conductor**		
	60°C (140°F) **Types** TW, UF	75°C (167°F) **Types** RHW, XHHW, THHW, ZW, THW, THWN	90°C (194°F) **Types** FRP , SIS , USE-2, FRPB, TBS, XHH, MI, THHN , XHHW, RHW-2, THW-2, ZW-2, SA, THWN-2
18 AWG	-	-	18
16 AWG	-	-	24
14 AWG	25	30	35
12 AWG	30	35	40
10 AWG	40	50	55
8 AWG	60	70	80
6 AWG	80	95	105
4 AWG	105	125	140
3 AWG	120	145	165
2 AWG	140	170	190
1 AWG	165	195	2210

Table 7 was used to determine the wire size necessary for the design of the Keur-Keg. By doing this we ensured that the wires are able to handle the current through them. This is especially important since we are operating with heating elements that draw a large amount of power while it is in operation.

The NEC also has different classifications for power supplies. These classifications refer to the types of circuits for “remote-control, signaling, and power-limited”; class1, class 2, and class 3 (Stallcup, 2019). For our purposes, the circuit the NEC is referring to is the wiring system of the “power-limited supply and all the connected equipment” (Stallcup, 2019). Class one circuits are divided into two kinds; remote-control and signaling circuits and power limiting circuits. The remote-control signal circuits are constrained to less than 600V and the power-limited circuits are constrained to a range of 30V and 1000VA. Another important identifier of class one circuits is the need for an overcurrent protective device that protects the equipment should there be an “overload, short circuit, or ground fault” (Stallcup, 2019). Class two circuits, on the other hand are limited to 24V and no more than 150VA for power sources that are self-limiting. If an overcurrent protective device is required than the limit reduces 30 VAC and 60 VDC. Because these types of circuits are limited to a lower range in voltage, they are the standard for circuits that need to be safer against causing fires or potential electrical shock. This is unlike class one circuit standards. Finally, class three circuits involve an increased amount of current from the load side of wiring to the equipment. These types of circuits are limited to 100 VAC or VDC when there is a self-limiting power source, and unlike class two circuits they increase to 150 VAC or VDC when an overcurrent protective device is used on the power source. For the purposes of this design, we designed to a class two standard in order to maintain safety levels for users and limit the voltages to the needs of our equipment.

The IEC also has their own standards for power supplies. The different types of power supplies refer to protection classes to users: class I, class II and class III. These classes are differentiated from the NECs classes by being represented with roman numerals. Class I power supplies protect the person from electric shock by “combination of insulation and a protective ground” (Bryars, 2018). Class II devices provide protection by two levels of insulation. Class III power supplies provide protection by having the input be “connected to a safety extra low voltage (SLEV) circuit” (Bryars, 2018). For the project design we implemented, the design met a class I design standard. The class I standard should be sufficient enough to maintain safety for the user and allow to be a cost-effective product.

The power supply also followed some of the standards set by the Underwriters Laboratory in the United States. The Underwriters Laboratory is an organization that has been around more than one hundred years testing and certifying the safety of products not only in the United States, but throughout the world. The first standard that will be followed is UL 1310. This standard is geared towards low voltage devices such as “portable or semi-permanent direct plug-in units with 15 A blade connections for use on nominal 120 or 240 Vac mains circuits, cord and plug-connected units with a 15 or 20 A plug for 120/240 Vac mains supply, and units permanently connected to an input supply nominally of 600 Vac or less" (CUI Inc., 2019)). The requirements for this standard include "enclosure strength and rigidity to resist likely abuses, built-in over current and over-temperature protection devices, a maximum potential of 42.4 Vac peak / 60 Vdc for exposed wires / terminals, and protection from "backfeed" voltage" (CUI Inc., 2019). The design will also attempt to meet the standards for UL 60079, which states standards for electrical equipment in which there could be an explosive atmosphere. Beer brewing for the most part is not done in a combustible atmosphere, but the grain dust in theory could combust if enough of it came in contact with sensitive electrical equipment like the power supply. For the design budget it may allow for design with no water intrusion, but if budget allows measures will be added to create a completely dust free environment to the enclosure housing the power supply. By maintaining the standards set forth by UL, we can ensure that our design is something that could be manufactured and sold with the stamp of being "UL Certified" or "UL Recognized" product.

Efficiency of the power supply designed is another important aspect of making a good product. In a world where everyone is becoming very aware of their energy usage with all the technology at hand, an inefficient power supply would be a detriment to the design of the product. Prior to efficiency standards becoming defined it was estimated in the 1990s that the efficiency of many power supplies were as " low as 50% and still draw power when the application was turned off or not even connected to the power supply" (CUI Inc., 2019). This then meant that "external power supplies would account for around 30% of total energy consumption in less than 20 years" (CUI Inc., 2019). Now we see many movements toward energy efficiency such as the EnergyStar program seen with many appliances. The Department of Energy in the United States has also done their part in regulating efficiency by providing efficiency standards for manufacturers to follow. The Department of Energy has set 6 levels of energy efficiency, level I being used if no requirements are met up to level VI with the most stringent regulations.

Table 7 shows the level VI efficiency standards which went into effect February of 2016.

Table 8: Efficiency standards set by the Department of Energy

Single Voltage External AC-DC Power Supply, Basic Voltage > 6V		
Nameplate Output Power (P_{out})	Minimum Average Efficiency in Active Mode (decimal format)	Maximum Power in No-Load Mode (W)
P_{out}≤1 W	≥0.5 x P_{out} +0.16	≤0.100
1 W <P_{out}≤49 W	≥0.071 x ln(P_{out}) -0.0014 x P_{out} + 0.67	≤0.100
49 W <P_{out}≤250 W	≥0.880	≤0.210
P_{out}>250W	≥0.875	≤0.500
Single Voltage External AC-DC Power Supply, Low Voltage < 6V		
Nameplate Output Power (P_{out})	Minimum Average Efficiency in Active Mode (decimal format)	Maximum Power in No-Load Mode (W)
P_{out}≤1 W	≥0.517 x P_{out} +0.087	≤0.100
1 W <P_{out}≤49 W	≥0.0834 x ln(P_{out})-0.0014 x P_{out}+ 0.609	≤0.100
49 W <P_{out}≤250 W	≥0.870	≤0.210
P_{out}>250W	≥0.875	≤0.500
Multiple Voltage External Power Supply		
Nameplate Output Power (P_{out})	Minimum Average Efficiency in Active Mode (decimal format)	Maximum Power in No-Load Mode (W)
P_{out}≤1 W	≥0.497 x P_{out} +0.067	≤0.300
1 W <P_{out}≤49 W	≥0.075 x ln(P_{out})+0.561	≤0.300
P_{out}≥49 W	≥0.860	≤0.310

Table 7 shows the standards of level VI efficiency. The left most column gives the range of the different power outputs. The middle column shows the minimum level of acceptable average efficiency once the power supply is on. This number is show in decimal format show it would just need to be multiplied by a hundred to determine the percentage. The column to the far right the maximum amount of acceptable power in a situation where there is no actual load that is using power. The design made an effort to meet the level VI efficiency standard set as long as it can stay within the budget. If the power supply is not efficient then it can be a deterrent for the user to buy the product since they could see it as wasting too much energy.

1.6.4. Legal Standards

Because the Keur-Keg deals with alcohol in the United States, the product WILL be limited to adults 21 years of age and older in order to comply with most state laws. In addition, many states have limits on the amount that a home brewer can produce. For example, according to the Florida Statute 562.165, homemade beers and wine can either be produced "not in excess of 200 gallons per calendar year if there are two or more such persons in such household" or "not in excess of 100 gallons per calendar year if there is only one such person in such household".

Because these are the laws, the operator’s manual would have to let the user know that they are limited to the amount of beer they can produce. If the product were to go into production, then the company would also have to keep record of the name of each person that buys the product or who it’s being gifted to for legal purposes. If time allows, a notification sent to the brewer could be incorporated into the design that the they have reached their limit of legal allowable home brewing. The Keur-Keg is only meant for home use and is not meant for any kind of commercial brewing.

1.6.5. Economic and Time Constraints

As in the industry, this project is subject to economic and time constraints. Because the budget was funded by the group members, the design attempted to keep close to the originally intended budget restrictions. Typically, students do not have a lot of flexibility with the income at their disposal due to many expenses with very little income. In addition to this, the project must keep to a tight budget, keeping the idea in mind that if this product were sold to actual consumers, keeping production cost low is important in order to make the price of the product enticing enough for the consumer. If the production cost is too high, there will be very little margin to mark up the prices for profitable sales, and therefore would eventually lose too much economically to be a sustainable business.

Another constraint the team faced during the design of this product was time. With an infinite amount of time, an excellent product could be designed with everything situation accounted for. However, summer semester is the shortest semester of the school year, so the best design was put forth as fast as possible. Unfortunately, just because something is designed quickly, does not mean it is the best design. With more time, flaws could be seen and determined in the design process. Certain aspects of the Keur-Keg needed to be redesigned when building begins due to the limited time to brainstorm and design. However, by being efficient and keeping lines of communication open, the group was able to mitigate the effects of the shorter time.

1.6.6. Environmental Constraints

The Keur-Keg is designed to be used indoors, such as in a home or a garage so that it is protected from the elements. Constant exposure to the heat of the sun, rain, or cold was not the intent of the design. Possible water intrusion was accounted for and therefore designed for IP23 standard of ingress protection. However, the entirety of the design was not meant to be in an environment where it could be fully submerged in water. The design will not be able to function and will short circuit in a fully submerged environment. It is also meant to be on a flat level surface. An uneven surface may make the structure that holds everything unstable and therefore unsafe since it could possibly fall on the user. If the Keur-Keg is placed in an environment that is too cold, then the heating element will not be able to counteract such huge differences in temperature in a reasonable amount of time. In addition to this, other elements may not work has they are not rated for temperatures that may be below freezing. Previously, in section 1.6.2, it was stated that the PCB would be designed to a class one standard, which is not meant to support extreme temperatures.

1.6.7. Social Constraints

Because this product was designed and developed in a short amount of time, the main concern for the design is for it to be functional and safe. Certain parts of it may not be aesthetically pleasing for the user. However, the design tries to provide the best user experience by providing them with the options to change recipes, store recipes, and alert the user when the brew is finished or close to finishing.

1.6.8. Political Constraints

The Keur-Keg's main political constraints include the minimum drinking age set as 21 years old in the United States and the amount of beer that the user is legally allowed to produce as home brewers. Both are laws that the Keur-Keg intends to follow. The product cannot be sold to anyone under the age of 21. In addition, the Keur-Keg user manual will have consumers refer to their local laws for the amount of beer that they are allowed to brew at home. If the politics of the United States shifted to allow younger people to have the ability to drink, then there would be no problem allowing the product to be sold to younger people. Another political constraint that the Keur-Keg is must adhere to is that the beer brewed by the Keur-Keg cannot be sold in anyway. This would just be another disclosure to add to the manual informing the user that any beer produced by the Keur-Keg is only for personal consumption.

1.6.9. Ethical Constraints

Due to the ever-increasing production of waste in the world, the design implemented attempted to design our parts with as few unnecessary plastic parts that could end up as waste. In addition, by having quality parts, we can reduce the need of replacements and therefore creating less trash in the end. For example, we used quick disconnects from reliable vendors with a proven track record of quality products. In addition, since we will have a battery backup system for our MCU, we will make sure to choose a rechargeable lithium ion battery that follows the standards set forth by the Mercury Containing and Rechargeable Battery Management Act. This act was established in an attempt to reduce and eventually phase out the use of mercury in batteries, which is harmful to both animals and humans. We attempted to build the best design that will stand the test of time, since nowadays we see many products that are cheaply made and are only good for a few uses, essentially wasting the consumer's money.

1.6.10. Health and Safety Constraints

Health and safety are important aspects of the design for any product that will interface with the general public. There are many aspects of the Keur-Keg that could harm someone if the user is not careful, such as heat, electricity, moving parts in the pump, and something falling on them. For the burn dangers, the design cannot remove the heating aspect of the product, but it can place warning signs to be careful about touching the kettles while heating. As previously stated in the electrical equipment constraint section, the design intent is to protect the consumer from electrical problems by containing our power supply and controls in an enclosure that meets IP23 standards of ingress protection as set forth by the IEC. Although the pumps are small, they can still hurt someone if improperly handled, so in the operating manual it would list out best practices for handling during brewing and clean up. Another aspect of safety to consider is that the amount of liquid the user will be dealing with is very heavy. The design of the structure will be so that not only is the stand housing all containers stable, but also that they are contained within a lip that would prevent anything from potentially falling off the stand onto the consumer. In addition, one of the main reasons that the design will include a constant mixer in the mash container and the brew kettle is in order to prevent boil overs. This operates as a safety feature as well by constantly mixing the liquid mixture to prevent a boil over. Boil overs could be dangerous, since the user expects this process to be automated and may casually walk over to check on the process. If there were a sudden unexpected boil over, the user could get burned.

The Food and Drug Administration (FDA) has set forth certain constraints when related to food or drink in relation to human consumption in the FDA Food Code 2017. Many of the constraints set by the FDA related to the design are for the materials used for different components, such as the mash and boil kettle, hoses, and sensors.

Table 9 describes the characteristics of the materials that can be used for products that come in contact with food and parts that are not always in contact with food. The parts that are not normally in contact with food may be subject to accidental or consistent spills. This is something that can occur during the brew process so it must kept in mind during the design process.

Table 9: Section 4-1 Materials for Construction and Repair

Subpart	Description	Qualities
4-101.11 Characteristics	Materials that are used in the construction of utensils and food-contact surfaces of equipment may not allow the migration of deleterious substances or impart colors, odors, or tastes to food under normal use and conditions shall be:	Safe
		Durable, corrosion resistant, and non
		Finished to have a smooth, easily cleanable surface
		Sufficient in weight and thickness to withstand repeated warewashing
		Resistant to pitting, chipping, crazing, scratching, scoring, distortion, and composition
4-101.19 Nonfood-contact surfaces	Nonfood-contact surfaces of equipment that are exposed to splash, spillage or other food soiling or that require frequent cleaning shall be constructed of a corrosion-resistant, nonabsorbent, and smooth material	N/A

For Table 9 the subpart is under the main section 4-1 of materials for construction and repair. The subparts have descriptions about what standards the materials must meet, and the qualities column gives more details for the descriptions. From these standards, it constrains the design to materials such as stainless steel for the kettles and food grade plastics for storage containers. In addition, the exterior of the entire design must be able to meet the standards of non-food contact surfaces since boil overs are a very real possibility of beer brewing. This section also requires that the design uses food-grade hoses for all the hoses used to connect between the different containers used for the automated brewing. The following Table 10 focuses on the durability and strength of elements in general that come into contact with food. This may include; utensils, equipment, and temperature sensors.

Table 10: Section 4-2 Design and Construction: Durability and Strength

Subpart	Description
4-201.11 Equipment and Utensils	Equipment and utensils shall be designed and constructed to be durable and to retain their characteristics qualities under normal use conditions.
4-201.12 Food Temperature Measuring Devices	Food temperature measuring devices may not have sensors or stems constructed of glass, except that thermometers with glass sensors or stems that are encased in a shatterproof coating such as candy thermometers may be used.

For Table 10 the subpart column, describes what item is being focused on in the durability and strength section. The description provides details about what is an acceptable standard for this. We see that essentially the equipment must be able to withstand wear and tear of being used and that for thermometers, glass cannot come in contact with food. If the temperature sensor has glass in it, then it must be enclosed in some sort of shatterproof material. In the following Table 11, it focuses on the cleanability of multiuse food contact surfaces.

Table 11: Section 4-2 Design and Construction: Cleanability of Multiuse food- contact

<table>
<tr><th>Subpart</th><th>Description</th><th>Qualities</th><th>Sub-quality</th></tr>
<tr><td rowspan="7">4-202.11
Food-Contact Surfaces</td><td rowspan="7">Multiuse food-contact surfaces shall be:</td><td>Smooth</td><td>N/A</td></tr>
<tr><td>Free of breaks, open seams, cracks, chips, inclusions, pits, and similar imperfections</td><td>N/A</td></tr>
<tr><td>Free of sharp internal angles, corners, and crevices</td><td>N/A</td></tr>
<tr><td>Finished to have smooth welds and joints</td><td>N/A</td></tr>
<tr><td rowspan="3">Except as specified in the next description, accessible for cleaning and inspection by one of the following methods:</td><td>Without being disassembled</td></tr>
<tr><td>By disassembling without the use of tools</td></tr>
<tr><td>By the easy disassembling with the use of handheld tools commonly available to maintenance and cleaning personnel such as screwdrivers, pliers, open-end wrenches, and Allen wrenches</td></tr>
<tr><td></td><td>Last quality of previous description does not apply to cooking oil storage tanks, distribution lines for cooking oils, or beverage syrup lines or tubes.</td><td>N/A</td><td>N/A</td></tr>
</table>

Table 11 focused on the use of materials that are easy to clean. So essentially anything that is smooth and without pits where food items can get stuck. The design of the product touching the food must be simple enough to be easily taken apart to be cleaned. It cannot require the use of specialized tools that few people have in order to deconstruct the product for cleaning. In the following Table 12 focuses on the design and construction of clean in place equipment for food equipment.

Table 12: Section 4-2 Design and Construction: Cleanability of CIP Equipment

Subpart	Description	Qualities
4-202.12 CIP (Clean-In-Place) Equipment	CIP Equipment shall meet the characteristics specified under 4-202.11 and shall be designed and constructed so that:	Cleaning and sanitizing solutions circulate throughout a fixed system and contact all interior food-contact surfaces
		The system is self-draining or capable of cleaning and sanitizing solutions
	CIP that is not designed to be disassembled for cleaning shall be designed with inspection access points to ensure that all interior food-contact surfaces throughout the fixed system are being effectively cleaned.	N/A

Table 12 defines the need of allowing sanitary solutions to be able to run through the system surfaces that comes in direct contact with food. If the product cannot be disassembled for cleaning then, some kind of access point needs to be made available to inspect to make sure it is actually clean. This product was designed in a manner so most parts can be disconnected to determine its cleanliness. The system will also have a sanitization setting that the user can run prior to brewing a batch. The user can add the sanitizer of their choice, but it is best to stick to products like Star San since it only needs to be in contact for about 30 seconds for sanitization to occur. In addition, Star san is safe if any residues are left behind and will not affect the beer taste or quality.

For the health of the user, the Keur-Keg was designed to abide by the standards set forth by the Food and Drug administration. The design will ensure to use durable and strong materials for all parts, such as stainless steel, food grade plastics, and proper temperature sensors. The design maintained sanitization standards by making everything easy to clean with a cleaning cycle that the user can engage prior to brewing beer with the use of Star San sanitizer.

1.6.11. Manufacturability Constraints

Keur-Keg was designed in such a way that it can be manufacturable. The parts and equipment were chosen so that they are easily sourced from reputable companies. We also obtained some parts from local hardware stores such as Home Depot, Lowes, etc. In addition, the equipment will be chosen so that it is common, so that it can be easily replaced with an equivalent if the equipment should break or is too expensive at the time of building. In order for the product to be successfully manufacturable, the design attempted to keep the costs of parts, materials, and equipment low. This means that budge was followed closely as possible. When the design, looks like it may exceed the budget, then the budget will need to be adjusted or value engineer the design to scale back on features to bring the costs back down. Once the physical build of the design began, it was determined that a change in design was needed in order to make it more manufacturable.

1.6.12. Sustainability Constraints

The Keur-Keg will not be making use of any sustainable resources. However, if cost were not an issue, stainless steel equipment that was made from recycled stainless steel could be used. The stainless steel from this design could be recycled as well once the product reaches end of life. The Keur-Keg power supply could be adjusted to make use of renewable resources such as wind and solar energies. However, due to budgeting and time constraints it was decided not to incorporate the use of wind and solar energy to power this design. The user has the choice to brew sustainable beers by choosing grains, hops and additional ingredients that have been sustainably grown. However, Keur-Keg will not be limiting the user to only ingredients that have been sustainably grown since this is a choice and not a law.

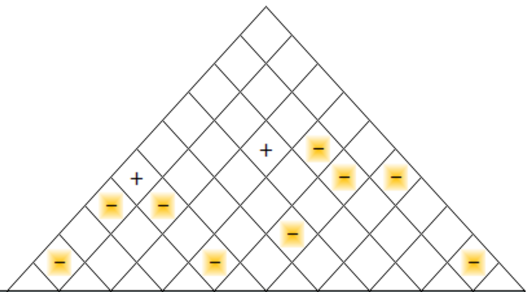
1.6.13. Presentation Constraints

When presenting this project, certain parts of the Keur-Keg will be able to be demonstrated as working, but the whole brewing process cannot be shown since it takes about 2 to 3 hours to brew and fermentation can take anywhere from 2-6 weeks. The project must be completed earlier than most other groups since it is a goal of the design team to be able to present the final product of home brewed beer made by the Keur-Keg.

1.7. House of Quality

The House of Quality, in Table 13 below, shows the correlation between requirements and expectation that are important to general consumers and the engineering specifications required to meet those expectations. Prior to beginning the design of the Keur-Keg, what qualities consumers deemed most important for product success were determined.

Table 13: House of Quality



Column #	1	2	3	4	5	6	7	8	9	10
Direction of Improvement	▲	◇	▲	◇	▼	▼	▼	◇	◇	▼
Functional Requirements / Customer Requirements (Explicit and Implicit)	Battery Life	Display	Memory	Temperature Control	Power Usage	Number of Containers	Liquid Pumps	Ingredient Dispensers	Beer Production Volume	Product Dimensions
Cost	○	●	●	○	○	●	●	●	○	○
Consistency	●	○	●	●	▽	○	▽	●	▽	▽
Durability	○	▽	○	▽	▽	○	○	○	▽	▽
Energy Efficiency	○	○	▽	○	●	▽	●	▽	○	▽
Safety	▽	▽	▽	●	○	▽	▽	▽	▽	▽
User Interaction	▽	●	○	▽	▽	▽	▽	▽	▽	○
Ease of Cleaning	▽	▽	▽	▽	▽	●	○	●	●	○
Target	4 Weeks	3x5 Inches	10 Recipes	Within 1-2 degrees F	<16 Amps, <120 Volts	<4	<4	7	5 Gallons	5x5x5 Feet

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

From Table 13, it was determined that the cost of product, consistency of brew, durability of product, energy efficiency, safety, user interaction, and ease of cleaning the product were some of the most commonly stated topics in reviews. It was established that with the length of battery life, size of display, size of memory, ability to control temperature, power usage, number of containers required for the brewing process, the number of liquid pumps, the number of ingredient dispensers, the volume of beer productions, and product dimensions Keur-Keg can directly impact how well it meets consumer requirements. With this house of quality, only 2 groups had positive correlation, battery life with power usage, memory with ingredient dispensers. Everything else was negatively correlated, meaning if one feature is improved upon, then another feature will be reduce. For example, if power usage were minimized then the size of the display, the number of liquid pumps, and the volume of beer production would have to be reduced.

1.8. The Block Diagram

The following block diagram in Figure 1, provides a visual representation of the system architecture for the Keur-Keg. Figure 1 shows that the MCU will be receiving inputs from the flow meter, two temperature sensors, and one level sensor and will be providing outputs controls for the mixing motor, heating element, dispensers, cooling system, and various pumps. The flow meter and temperature sensor in the boil kettle will provide the data to regulate the heating element, the cooling fan, the filling pump and the mash pump. The dispensers will be controlled by the MCU's timer depending on what the user inputs for the ingredient dispensing times. The level sensor and temperature sensor in the fermenting container will provide the data to regulate the transfer pumps, filling pumps, cooling system, and the rest of the dispensers. The MCU will also regulate the power distribution for the various equipment at the corresponding required voltages. The legend on the right associated a section of the block diagram that each group member was responsible for.

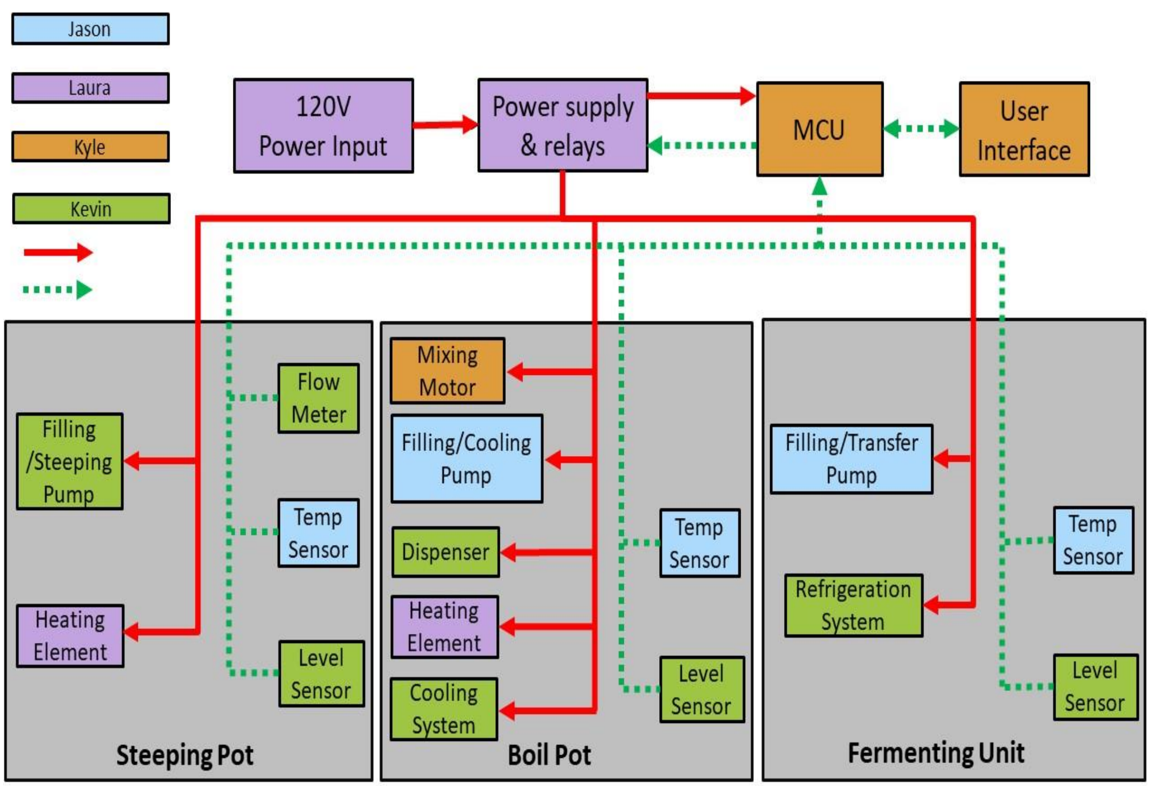


Figure 1: The Block Diagram

1.9. Personnel

In Figure 1 from the previous section 1.8, the distribution of work for the design of the Keur-Keg is shown. Jason Carlisle, Kevin Ruzich, and Laura Hoshino are all electrical engineering students and therefore focused on more of the hardware, power, and controls aspect of the project. Kyle Rits is a computer engineering student, so he was responsible for the MCU, user interface, and most of the programming related to the Keur-Keg. The Keur-Keg also required a lot of mechanical components that had to be designed such as the cooling system and the dispensing system. The group shared the efforts in designing the different mechanical systems. Jason and Kevin's previous work experiences were especially helpful in this aspect of the design since they had more hands-on knowledge about pumps, motors, and the controls for it. However, despite having assigned system designs, the team members helped each other wherever they were needed.

2. Research and Investigations Related to the Keur-Keg

2.1. Similar Projects and Systems

Looking at previous student projects and current designs on the market helped in the understanding of what has previously worked for some and what definitely did not work for others. By reviewing the documentation of other automated home brew systems, the design team can choose features that previously may not have been offered or make improvements on ones that are planned on being offered. By gathering this information, we can attempt to stream line our process and make better decisions based on our research.

2.1.1. "The Brew Boss"

The Brew Boss states that it is an automated all in one kettle system. It uses a central perforated infusion tube spray pattern that pumps water from the bottom of the kettle back through an infusion tube to constantly mix the mash. Based on their website, the process is not completely automated as you have to remove filter by removing the connected elbow and adding a lifting ring and manually pulling the filter out of the kettle. The Brew Boss has an electronic process controller that provides automated control over heat, temperature and mixing. One thing to note about the Brew Boss is its ability to communicate directly with the controller through an app on an android device. This app walks you through the entire process and allows you to change or modify your recipes from your app. There are problems that are associated with an app controlled device however. It was noted that the android app was no longer available due to security issues and updates that would require large amounts of reprogramming to continue to offer the app via the app store. This is good to know as it is a process that we might not would have considered being a problem until it was an issue for us. Their system requires 240 Volt but does not state the amperage. The bottom line cost for their system is $1100 dollars, but when you add most of the accessories you will need, the total cost goes over $1600.00. A feature that we might not would have considered but deserves some consideration is the mixing process the Brew Boss is using the infusion tube, a similar concept may work in our design. (Brew-Boss Automated Electric Homebrew Systems, 2019)

2.1.2. "Pico Brew"

With the Pico Brew you are limited to buying your beer from Pico Brew. You can purchase recipes that are already created or for a little more money you can create your own recipe. The Pico Brew Pod is coded so that the Pico Brew knows the recipe to use when you put the pod into place. This means all of the timing, temperature control, and other features are automatically programed. The user simply installs the "pod". The Pico Brew site offers little about how they accomplish the process but do mention that the base model at $599 is capable of brewing 5L of beer. The pros to this system are it truly appears to be fully automated and in a small table top form. The limiting factors appear to be that 5 L is the most you can produce, and you must purchase your product from Pico Brew directly. By Picobrew controlling the pods they can control the ingredients meaning they can make you brew your beer in a specific manor. This most certainly helped them control their constraints by not allowing users to go to the brew store and purchase any brew kit to use in their system. (Picobrew.com, 2019)

2.1.3. "Automated Brew Extractor"

The Automated Brew Extractor was not designed for mass production or even cost. The design is to easy the process of home brewing and allowing user interface to fine tune the final product. Quality should be gained from the automated process. The overall process of the Automated Brew Extractor seems to follow some of the same principle concepts as our Keur-Keg, control the temperature and time of boil, cool quickly and give user interface. The wort cooler that was chosen by Automated Brew Extractor was a counter flow plate chiller. This was not even a consideration for the Keur-Keg until examining their design, but it will now definitely be researched further. Researching the Automated Brew Extractor design and reading through their research, it appears a top to bottom design was better so as not to lose any product that might remain in the pumps between processes (Robert Bower, 2014).

2.2. Relevant Technologies

Through the research of similar products, we found many similarities between other products that aligned with the direction we wanted to go, as seen below in Table 14. All systems have temperature control. This is an important part of the process, if your temperature is unregulated you stand the chance of burning off the sugars which are used to make the alcohol. If your burn the grains you tend to get a burnt flavor in your mash. By using temperature probes and relays connected to a processor your goal should be to maintain a ±5 degree control of your mash. Another noticeable process of most of the researched products was the wort chilling efforts. Cooling the wort quickly is an important way of stopping off-flavors from being created due to dimethyl sulfide that would otherwise keep producing. Cooling quickly also has an affect that will "Cold Break" proteins permanently. This will help with beer clarity. (Palmer, Chapter 7 Boiling and Cooling, Cooling the Wort, 2019). User input seems to be themed among all beer brewing technologies, of course, who does not want to be able to manipulate their recipes slightly, This is what makes one cook different from the next. User input is a must on all of the researched products. Whether it be an app, touch screen, or simple up down arrows, the user must be able to select different recipes and/or change some variations of the recipe.

Table 14: System Comparison

System Comparison							
Name	Temp Control	Liquid Level Control	Flow Control	Automated Ingredient Addition	User Interface	Program Recipes	Wi-Fi Connect ability
Brew Boss	Yes	No	No	Optional	Yes	No	Yes
Pico Brew	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Auto Brew Extractor	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Keur-Keg	Yes	Yes	Yes	Yes	Yes	Yes	Yes

2.3. Water System

When brewing beer, one of the most important aspects of the brewing process is the water that is chosen to brew with. There are varieties of water that can be used for this process such as tap water, spring water, distilled water, and many others. Beer is brewed using a few ingredients such as malt, hops, grain, yeast, and water. The correct water is important because different types contains different PH levels, magnesium, sodium, sulfates, chlorine, calcium, and carbonates. Water that lacks or has too much of any of these aspects can severely impact the beer. For absolute perfection in the water desired, one can test water and provide additives to get the water perfect or start with reverse osmosis water and build it back up with the correct minerals. Research was performed on the effects that the water used can have on beer.

The minerals and properties of water mentioned above can impact different parts of the brewing process. Calcium effects the hardness of the water which effects the PH during mashing and the clarity of the output. 100 mg/L is an ideal calcium level. Magnesium also effects the hardness of the water and is important for the yeast to ferment properly. The ideal amount of magnesium is 20 mg/L.

Carbonate and bicarbonate are important for the acid levels in the water. These can be modified at an expert brewing level and are adjusted for different brews. The sodium, chloride, and chlorine will affect the taste of the beer and containing too much will diminish the desired flavor. The ideal sodium level should be 40 mg/L and chlorine shouldn't exist in the water. Sulfates lower PH and assist in bringing out the hoppy flavor to the beer. Other metals can be found in water such as zinc, copper, and lead but most drinking water contain very minimal amounts and will not pose a problem when brewing beer.

For this project, a simple and in-expensive water was chosen that contained a good balance of minerals which balance the PH to an ideal level. This eliminated the need for having to perform the chemistry to get the water perfect before each brew and still produce a tasteful and quality product. Distilled water and reverse osmosis water will not be used since they lack the minerals required to produce a quality output. Bottled water can be expensive when looking to get an output of 5 gallons. Tap water produced in Florida contains plenty of minerals and utility companies will try to keep the PH balanced between 6.5 and 8.5 which is acceptable for brewing beer. The water chosen to be used in this project is spring water or filtered tap water which can be found in 5-gallon jugs and purchased at any grocery store at a reasonable price.

2.4. Heating

Controlled heating is an important part of the brewing process in order to facilitate the chemical reactions throughout the beer brewing process. First, heat is needed to get the water to a user defined temperature usually between 145ºF to 155 ºF or 62.78ºC to 68.33 ºC in order to let the grains steep for a set time to create mash. This step is important for users to be able to control the temperature of the liquid due to it being the basis of the beer flavor. After the mashing of the grains is done, then the mixture needs to transfer the mash to the boil kettle. Finally, the liquid, now called wort, is brought to a rolling boil at 212 ºF and maintained at that boil for a set time while other ingredients such as hops are added. During all these steps it is important be able to provide heating that is not only effective, but efficient for the Keur-Keg to meet consumer requirements.

For the Keur-Keg, there were 4 heating methods considered to get the initial water and wort to the correct brewing temperatures. The four heating methods were a propane gas burner, magnetic inductive heating, resistive heating element (stovetop style), and a fully submerged water heating element. All these options were considered because they are the standard heating methods used that are readily available. When considering the different heating elements, we kept the following in mind: convenience, safety, efficiency, precision, and cost. With a more convenient heating method, it allows the Keur-Keg to be portable within reason and placed anywhere in the home with the ability to also be plugged into a standard 20A, 120V receptacle. For safety, the heating method, should minimize the user's risk as much as possible. Efficiency deals with how well the heating method heats up the liquid. The heating method must be able to maintain the liquid temperatures precisely as the user dictated. Finally, the cost must be kept low in order to meet the consumer requirement to keep the overall cost of the product low.

The first heating method that is very commonly used for brewing beer is a propane gas burner. In this process propane combustion provides the heat necessary for brewing the beer. Although this method is most commonly utilized, it is not the best method. The propane container is portable, but it also takes up valuable space. In addition, while a person is cooking, the container may run out of fuel and require the consumer to inconveniently have to go out for a refill. This method of heating can be very unsafe since the heating is usually done on the ground, which can pose a risk of other things catching on fire or pose danger to children or animals in the area. Also, for the sake of the user's direct safety an automated unattended fire is never recommended for anything based on basic fire safety recommendations. This method of heating is also the most inefficient due to the amount of heat that is lost to the surrounds during the heating process. Gas heating can be accurate with providing steady temperatures, but the amount of heat lost to the surroundings makes this method very inefficient.

The next three methods of heating that were considered converted electrical energy to thermal energy by magnetic inductive heating, resistive heating element through a conductive material, and a resistive heating element directly submerged in the water. With some basic thermodynamic equations, we can determine the amount of energy required to bring the initial water to proper steeping temperature depending on the recipe and the wort to a rolling boil at 100^{o}C. For the purposes of this equation, we assume that the wort has the same properties as water. The energy absorbed by the initial water and wort is given by the Heat Capacity Formula shown in equation 1 below:

$$Q = mc\Delta T, (J) \qquad \text{(Equation 1)}$$

For the mash, we assume the starting temperature of the water is about 22.22 ^{o}C and will assume 66^{o}C for the user defined mash temperature. The mass of water for 5 gallons of water is about 22.024 kg. The specific heat of water is a constant we know to be 4.18 J/g* ^{o}C. When we plug these numbers into equation (1) we get that the water absorbs about 3.18 MJ of energy during the initial heating to mash temperature. For the wort we assume the starting temperature is the final mash temperature and that it must get to 100^{o}C. At this stage the wort absorbs 4.00 MJ of energy. By using equation 2 below, we can then determine the amount of time necessary to bring the water or wort depending on the step to the proper temperatures using electrical energy depending on different commonly available power ratings that are typical for 120V heating methods. Table 15 below shows the results of the times for different commonly available power ratings.

$$t = \frac{E}{60*P} = \frac{Q}{60*P}, (min) \qquad \text{(Equation 2)}$$

Table 15: Time for Initial Water and Wort to Reach Proper Temperatures.

Power (W)	Initial Water to ºC (min)	Wort to 100ºC (min)
1500	44.41	35.28
1600	41.63	35.08
1650	40.37	32.08
2000	30.31	26.46

From Table 15, we see the 2000 Watt heating element would heat the liquids the quickest. However, for safety and power requirement limitations, we chose the power requirement for the electric heating element to be a 1650 Watt heating element.

Magnetic inductive heating induces heat within a metal due to eddy currents which occur with a changing magnetic field. This method would then heat up the water via the conductive stainless steel that holds the liquid. The main problem with this method of heating is that the heat is not directly applied to the water, so energy is lost through the kettle to the environment in the form of convection, radiation, and conduction. The other issue was that Keur-Keg needed to be as portable as possible so having to carry around a burner is not conducive for that. In addition, if there were a boil over in the brewing process, this would add to the items that the user must clean up and therefore making it less convenient.

The next option that was looked at was a stovetop resistive heating element. This operates by a current running through a resistive wire for the sole purpose of dissipating energy as thermal energy. This method has similar issues to the magnetic inductive heating method, in that heat is lost to the environment through convection and conduction. Although, there are portable versions of stove top burners, it would be another part to have to carry around with the whole brewing system. This heating method is also subject to getting very messy if a boil over should occur.

The heating method the was chosen for this project was a fully submerged heating element, as seen below in Figure 2. This heating method also makes use of having current run through a wire surrounded by a filler material that allows heat to be transferred to the conductive metal that surrounds it. The conductive metal best suited for beer brewing is stainless steel, since it holds up the best to all the chemical processes involved in beer brewing. In this method of heating, the water is in direct contact with the heat, but the conductive metals heat dissipated is being directly transferred to the water. The heating element is inexpensive and was easily integrated into the mash and brewing kettle. Table 16 is the ranking system used to determine the best heating method for the Keur-Keg. The ranking system is from 1 to 5, one meaning the worst and five being the best at the category. The most important factors kept in mind were, convenience, safety, efficiency, precision, and cost.

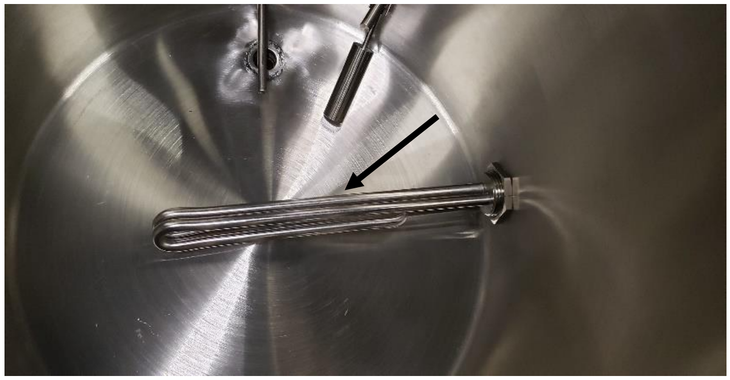


Figure 2: Fully Submerged Heating Element (courtesy of Group 4)

Table 16: Ranking System

	Convenience	Safety	Efficiency	Precision	Cost	Total
Propane Gas Burner	2	1	2	4	5	14
Magnetic Inductive Heating	4	3	4	4	3	18
Resistive Heating Element	4	3	3	4	3	17
Fully submerged Heating element	5	4	5	4	3	21

For convenience, the design took into account how easy and accessible the heating method was. Propane gas scored the lowest since the user had to go to another location for refills. Magnetic inductive heating and the stovetop element scored fours because they could be ordered online and easily installed but were limited by how well the cooking container conducted heat and the fact that they took up more space. For example, the magnetic inductive heating requires the cooking container to have a certain level of iron in order for heating to work, so this is limiting for the user. The submerged heating element was the most versatile and therefore convenient since it could be ordered online and installed easily, earning it 5 points in that category. In the next category of safety, the heating method's level of safety for the consumer was compared. Propane gas scored the lowest again because it makes use of open flame at floor level or a little bit higher, which could cause other things to catch fire. That was followed by a resistive heating element with a score of three because it has an exposed heating element outside of the container that the user could burn themselves on or accidentally set something else on. For safety, magnetic inductive heating and submerged heating element scored fours since with anything the user could get burned, but due to their set ups it was more difficult for the user to burn themselves.

The user would not be able to burn themselves with the magnetic inductive heating if they touched it, the dangers in this case would be more so electrically related. For the efficiency category, propane gas once again did the worst since a great deal of the heat produced by combustion is lost to the environment. The electrical methods were more efficient at transferring most of the heat produced and were differentiated by what they delivered heat to. The fully submerged heat element was the most direct method of heating liquids, which is what the design for the product is aiming to achieve. All the heating methods were the same in the ranking of precision since with any kind of temperature sensing feedback system they all operate at about the same level. The advantage of propane gas is that it can heat up quickly and can control temperature by being turned off completely but, may heat too quickly causing overshoot of required temperatures. The advantage of the electrical heating methods were that they are slower and steadier, but the heat is not immediately "off" when they are off. Finally, the heating method comparisons in the cost category were determined. For this category, propane gas did the best since it is by far the cheapest. The other three electrical heating methods received scores of threes since utility prices vary greatly depending on the provider and region.

By totaling the assigned point values from 1 to 5, it was determined that the fully submerged heating element best suits the needs for this project. It satisfactorily met all the conditions that needed to be addressed by this design including, convenience, safety, efficiency, precision and cost. At this point, the decision has been made to use the fully submerged heating element as the main type of heating method for this project. It was also determined that for the power limitation and safety the design will keep the heating element to 1650 Watts. Then a decision had to be made between using a low watt density or high watt density fully submerged heating element. The watt density is in reference to "amount of wattage per square inch of surface area" (Steffan, 2019). A low watt heating element has more surface area with the intention of spreading the power dissipated over a larger area so the watts per unit of area is less dense. A high watt heating element has less surface area so that it can dissipate power across a smaller surface area, therefore creating much higher power dissipation per unit of area. The advantage of high watt is that it gets extremely hot and quickly heats up the liquid it is submerged in. However, the quick heating also causes it to attract minerals and build up a layer of limescale. For brewing beer, sometimes the water is what gives it the unique flavor. If the user were told they cannot use their own water because it is too hard for the heater, they could just as easily go buy another type of beer brewing system to allow them to use their own water.

Instead, the design will look to using a low watt density fully submerged heating element. Although it is slower to heat, it also becomes coated with limescale at a slower rate. Overall it is more efficient, since the heating element does not have to work against a thick limescale coating to heat up the liquid. For the longevity of the overall product, the low watt density heater works better for the needs of this project since the user would have to replace it less often than a high watt density heating element therefore increasing the user's contentment with the design. The heating element the project will be using is the DERNORD 120V 1650W foldback water heater element screw-in lime life heating element with low watt density with part number DERNORD-13, available on Amazon for $21.99. Using these heating elements in the project worked exactly as explained. Although it took roughly 40 minutes to heat 3 gallons of water, once at a boil, the heater had no troubles keeping the liquid at a rolling boil even with adding the malt and hops.

2.5. Cooling

Cooling the wort is extremely important. This process comes at the end of the boil. If the Wort is above 140 degrees bacteria and yeast are kept at bay but as the wort cools it becomes susceptible to oxidation. If the wort is cooled slowly then the production of dimethyl sulfide will continue. This production can cause off-flavors in your finished product. The "Cold Break" is formed when the wort is rapidly cooled. This shocks proteins into precipitating out of the wort. If the wort is cooled slowly then these proteins go unaffected and later comeback to form as the product warms causing a cloudiness or haze in the product. Although haze does not affect the taste of your product immediately it tends to cause your beer to become staler more quickly than a clear beer. (Palmer, Chapter 7 Boiling and Cooling, Cooling the Wort, 2019). Some brewers prefer to transfer a warm wort to their fermenter. The thought process is that the yeast will get a jump start when placed in a warm wort. The issue with jump starting the yeast in this fashion is you also jump start the bacteria which reproduces much faster than the yeast. Typically, most brewers decide on quickly cooling the wort rather than starting with a warm wort.

There are many process and ways of chilling the wort. A common practice among many home brewers is known as the "Ice Bath". This process is extremely effective but tends to be labor intensive. You must fill a container, such as your sink with cold water and ice. At this point you sit your boil kettle into the ice bath and wait. Replace the water and ice as necessary. It is recommended at this point to leave the lid on to keep from contaminating your wort. If you are careful the you can open the container and stir the wort with a sanitized spoon. This maximizes the exposure to the side of the kettle cooling the wort quicker. It is important at this point to make sure none of the ice bath water gets into the wort as this is a source of contamination.

Similar to the ice bath is the process of adding ice directly to your wort. Even if you start off with a full 5 gallons at the start of your boil you will end up with much less wort after the boil than your beginning volume. This means you will need to add more water to your system at some point. Why not add it now to help cool the wort quickly. This is definitely an acceptable means of accomplishing the wort cooling quickly. There are a few keynotes that must be considered when doing this. Bacteria lives everywhere. Just remember that if you add ice or water to your wort that is not bacteria free you will infect your wort. So, if you are to add ice directly to your wort you need to boil your water that your will turn into ice, store it in a airtight container and freeze the sterilized water that you will add to your wort for cooling. This is labor intensive up front but works well in cooling your wort quickly. Other similar processes are freezing water in containers and adding the containers to your wort. This to is acceptable and the water does not need to be sterilized as the ice never actually enters your wort. With this process you must sterilize the container that you will be placing in the wort and make sure the container is capable of handling the heat from your wort without releasing toxins from the container into your wort.

Wort Chillers are another cooling method. A wort chiller can be either copper or stainless, this will be discussed in more detail later in this section. A wort chiller is used as a heat exchanger, this eliminates the need to carry your boiling wort to a ice or cold water bath. This design is often preferred in terms of safety alone. Although you rarely have 5 full gallons of wort after the boil, if you did this kettle would weigh over 45 lbs. Moving 45 lbs of extremely hot liquid is dangerous. By simply using a wort chiller you eliminate an entire step, moving the wort to a chilled bath, and in turn save yourself the problems of a pulled muscles or more seriously a severe burn. There are two designs in heat exchangers, there is the immersion style and the counter flow exchanger. The immersion style is a bit simpler of an application. The immersion wort cooler is placed inside the wort and then colder liquid is pumped through the coil. The colder the fluid pumped through the coil the quicker the cooling process happens. Seen in Figure 5 below, the heat exchanger would be placed in the wort and cold water run through the heat exchanger. The constant circulation of cold water running through the exchange cools the wort without the cooling water coming into contact with your wort. There are several ways to speed this process up. One way is to stir the wort, making sure not to contaminate it with any unsterilized utensils. Stirring the wort will move the liquid around the coils of the immersion wort cooler allowing more wort to come in contact with the cooler wort coil. Often people will simply connect a water hose to a faucet and run continual tap water through the coil cooling the wart and dumping the heated water back into a drain. A quicker way would be to have ice water being recirculated through the coil returning back to the ice bucket. This works most efficiently but tends to come at a higher price as you need a pump to recirculate your cooling water. If you choose to use the counter flow design of a wort chiller then you actually need to move two liquids through the heat exchanger.

In a counter flow heat exchanger, you would pump cool liquid through the exchanger in one direction and then pump your wort through the same exchanger in the opposite direction. This works great in getting maximum exposure to the wort against a cooler surface but typically cost more money to purchase. If you are attempting to only use one pump with this design, then the heat exchanger and the system has to be designed to use a pump for moving the cooler liquid through the exchanger and then the wort would need to be gravity fed to the fermenter.

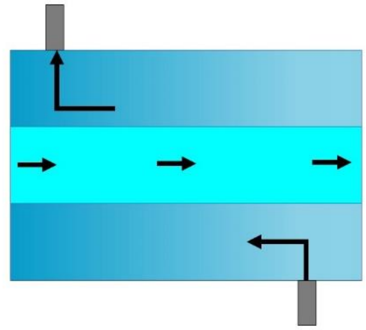


Figure 3: A) Immersion Style Wort Cooler B) Counter Flow Wort Chiller (courtesy of Group 4)

When it comes to copper vs stainless, you can find both styles of wort immersion chillers. Stainless will undoubtably last longer that a copper chiller. There is no reason to worry about stainless reacting with the kettle as the kettle to will be stainless. Undoubtably stainless just looks nicer and stays looking nicer longer than cooper will. The downside to a stainless immersion wort chiller is the thermal transfer coefficient that is only 16 watts/(meter*C). Copper on the other hand has a thermal heat transfer coefficient of 401 watts/(meter*C). This gives the copper a 25 times heat transfer rate of that of stainless steel. Although copper may degrade quicker over time than stainless steel, we don't anticipate the immersion cooler needing replaced often enough to consider this a viable reason to use stainless. As far as cost goes, the copper and stainless-steel immersion wort chillers are similarly priced.

With the research on cooling our wort completed we have chosen a submersible heat exchanger for our design. This design seems to be most prevalent in most home brew setups. Our design will place the cooling coil in the boil kettle. The cooling coil will remain in the kettle throughout the boiling process with no water flowing through it during the boil. Part of the initial setup will include placing several gallons of water in a cooler with 10-16 lbs of ice. At the end of the boil our circulation pump will kick on and start rapidly cooling our boil to a temperature of 70 degrees. At this point we will transfer the wort to the fermenter where we will add our brewing water bringing our total volume to 5 gallons. The addition of this water at this stage will continue the process of cooling our wort. Using this design in the project cooled the wort rapidly from boiling to the required 80 degrees in under 4 minutes.

2.6. The Kettles

There are two kettles need in the process we have chosen, one for the mash kettle and one for the boil kettle. There are several features of different kettles that need to be explored before making a decision on which kettle to purchase. Some considerations that need to be accounted for is the material of the kettle, the size, and cost.

The first consideration is the material of the kettle aluminum or stainless steel? Stainless steel is known to be inconsistent with its heating ability whereas aluminum has a more uniform heating ability. An aluminum kettle would allow the liquid to be heated quicker as it disperses the heat in a more even fashion than stainless. Likewise, it would help in the cooling process as aluminum will cooldown much quicker than stainless. Faster heating and cooling are worth considering since we are limited to the amount of heat we can add to our system and during the cooling process it is important to cool the wort as quickly as possible. Dissembler metals is another concern. At this point we have chosen our heating element and know that it will be stainless steel. If we choose to use an aluminum kettle and a stainless-steel heating element or sensor that is housed in a stainless-steel body then we will need to find a bimetal to go between the aluminum and stainless steel to allow these parts to be joined together. If this is not feasible then creating clearance between the two metals and sealing the hole with a gasket will be necessary. In addition to these concerns there is much hype today about using aluminum cookware. The trace amounts of metals that can be ingested from using this cookware is thought to cause serious health issues. Although we want to avoid any issues arising from using substandard cookware it has been proven several times over that the amount of aluminum you are ingesting from your cooking utensils is less than that you could receive in a aspirin. (Savant, 2014) As far as cost is concerned the aluminum kettle is much cheaper. Our initial estimate for the size of the kettle is approximately 7 gallons or 28 quarts. The cost of aluminum kettles ranges from $30.00 to $50.00 whereas stainless kettles range from $60.00 to $120.00. Although staying on budget is one of our main objectives, it was decided that if we can afford the stainless material over the aluminum material this would be preferred.

The next consideration is the size of the kettle. It was decided early in the planning stages to have the mash kettle and boil kettle equal in size. In our attempts to make the Keur-Keg compatible with as many recipes as possible, we noted early on that the amount of water that could be necessary for the brewing process could vary between 2 gallons and 6.5 gallons. Rather than limiting consumers to only brewing recipes that start with smaller quantities of water we decided on using larger kettles for the project. The minimum kettle diameter is set by the heating element. The minimum length heating element we found in the watt density range that we choose was 12”. This constraint requires are kettle to have a minimum diameter of 12”.

Now having a good idea of the type of kettle we required we hit up google and started looking for something that would meet our specifications and our constraints. Within a couple hours it was clear that Gas One Stainless Steel Stockpot (#ST-32) was a good match for our needs. This kettle is an 8 gallon (32 quart) kettle with a base of 13.25”, which will house our heating element fine. Although slightly larger than our minimum 7-gallon (28 quart) requirement, this is acceptable and will actually aided in keeping boil overs inside our kettle with the additional room. Although the cost is twice as much as an aluminum kettle in the same size this stainless-steel kettle was chosen not only because it met our needs, but it also comes with a steamer rack. This rack will be modified to add more holes to allow more water to flow but will eliminate the need for our false bottom shelving. The false bottom shelving was required in both pots and came at a cost of $30.00 each. Modifying the steamer rack in the Gas One kettle saved us $30.00 on this false bottom bringing the cost of our stainless-steel kettle to the same cost of the aluminum kettle.

2.7. Sensors

In choosing sensors we need to research several aspects. We determined what sensors are needed, e.g. temperature, pH, etc., what type of signal we wanted to receive from our sensor, and the type of temperature sensor. It is worth noting that these analog sensors come with a variety of specifications. You must choose the voltage input of your sensor along with the expected output. Most analog sensors come in either a 0-5-volt signal output, 0-10 volt signal output or a 4-20mA signal.

Why choose one type of output signal over another? A sensor with a 0-5V or 0-10V output signal can be used in most applications where an analog input is required. A 0-10V signal is easy to work with and easy to trouble shoot when there is a problem. The downside to using a 0-10V signal is they are susceptible to noise generated by such things as motors and power supplies. Your signal will degrade over long runs of wire due to the resistivity of the wire. Trouble shooting can sometimes be difficult to tell if you have a faulty temperature probe or if it is truly reading zero. With 0-5V or 0-10V signal, zero is actually a reading but you could receive a zero input if your temperature sensor is faulty.

A 4-20mA signal output typically has less error and an ability to check for errors. With a 4-20mA signal if you get a reading of zero this means you have a faulty device. The lowest reading on your 4-20mA scale should be 4mA. A current signal is less susceptible to noise and distance on the signal carrying wire.

2.7.1. Temperature Sensors

When choosing a temperature sensor four types tend to dominate the market, as seen below in Table 17. These four types are Negative Temperature Coefficient Thermistors (NTC), Resistance Temperature Detector (RTD), Thermocouples, and Semiconductor-based sensors. The first is Negative Temperature Coefficient (NTC) thermistor, seen below in Figure 6, NTC has extremely high resistance at low temperature and as temperature increases the resistance drops quickly. They are fast and have a high accuracy. The second type is a Resistance Temperature Detector (RTD). A RTD measures temperature by correlating resistance with temperature. These can be obtained in platinum for highly accurate readings or in nickel or copper but with a less accurate reading.

Thermocouples, consist of two wires of different metals connected at two points. Voltage varies between these two points and using conversions and a lookup table a temperature reading is achieved. Thermocouples have a large range but tend to be the less accurate. The least accurate of the four sensors is the Semiconductor-based sensors are typically mounted on a integrated circuit board and use voltage vs current characteristics to monitor temperature. This sensor also has the slowest response time of 5-60 seconds. (4 Most Common types of Temperature Senso, 2019). We originally went with the 3-wire PT100 using the MAX31865 board as its own ADC and op-amp board. This board uses SPI to communicate and was very accurate. Later in the project we found that these boards were not compatible with the LCD display used. After running into this issue, we decided to use thermistors and the ADC signal on the MCU. The thermistor we used was 10k ohms and the resistor used in the voltage divider circuit was also 10k ohms. This gave us a lot of precision when using the ADC signal.

Figure 4: NTC Thermistor (courtesy of Group 4)

Table 17: Temperature Sensors

Temperature Sensors			
Type	**Accuracy (C)**	**Range (C)**	**Cost**
NTC	.05-1.5	-50-250	
RTD	.1-1	-200-600	Most Expensive
Thermocouples	.5-5	-200-1750	
Semiconductor Based	1-5	-70-150	

2.7.2. Liquid Level Sensor

There are 7 main types of level sensing switches. These are Optical, Vibrating, Ultrasonic, Float, Capacitance, Radar, and Conductivity of resistance. All though we did research on all seven of these sensors we narrowed the choices to three for the focus of the Keur-Keg. This decision was made on practicality, function and cost. The capacitance level detector, measures capacitance between two plates based on the dielectric constant that the particular capacitance level detector is designed for. An important note is not all capacitive sensors work with every liquid nor every tank material. A downside to using capacitance liquid level sensors is that they will need to be calibrated. The pros to using a capacitance liquid level sensor is that they are accurate and compact. (7 Main Types of Level Sensing Methods-How do they Differ?, 2017)

The Conductivity or Resistance Sensor is a simple design that has a long and short lead. The long lead transmits an electrical signal and when the fluid is high enough to contact the short lead then the electrical signal is sent through the short lead. The pros for using a resistive sensor is there are no moving parts, easy to use, low cost and our acceptable to use in boiling water. The cons however are that they are invasive and require maintenance, cleaning erosion from the leads.

The Float Switch, as seen below in Figure 7 is the most basic and generally the most cost-effective solution for monitoring liquid level. This float switch was used in the project as protection for the heating elements in the boiling and steeping kettles and also as a level indicator in the fermenting pot. The circuit was very simple as it only relied on a digital I/O pin and GND. Once the circuit detects a short, the switch state changes from open to close. As the liquid rises the float switch closes. A magnet in the moving lever activates a magnetic reed switch in the base causing the circuit to open or close depending on what type of contacts you choose when purchasing. The pros include non-powered, inexpensive, and direct indication, while the cons are moving parts, large physical feature, and a large amount of liquid must be present to activate the switch.

Figure 5: Float Switch (courtesy of Group 4)

The DerBlue stainless steel float switch sensor is capable of handling temperatures from -40 – 150 degrees C. This alone makes this float switch a perfect match for our heater safety in the boil pot. If we were to turn the heater on without the mash in the boil kettle, we would quickly destroy the heating element. In the case of a solenoid failure, meaning our mash never made it to the boil kettle, we would want to be certain that the heating element never came on. To accomplish this, we will use a float switch capable of handling the boiling temperatures of our boil kettle. If the float switch does not activate then the heating element will not be allowed to turn on.

2.7.3. PH Sensor

Brewers might consider testing the pH of the brew water, mash, the wort, and the fermentation process. Ensuring the pH stays between specific levels will help maintain a constant quality from every brew cycle. Starting off with your water and mash within specifications ensures consistency and helps keep the remaining processes within specifications.

Table 18: Recommended pH

Recommended pH	
Water	< 6.0
Mash	5.2 – 5.6
Wort	5.2 – 5.6
Fermentation	4.1 – 4.6

Testing the pH of your brewing water will let you know whether you are in range or not of the recommend pH level. You can make adjustments to your pH level using food grade phosphoric or lactic acid. Malt, what you are producing during your steeping or sparge cycle is naturally acidic, however it would take large volumes of malt to lower your brewing water pH. The recommended pH of the malt will vary with the type of beer you are trying to brew. If it is determined that the mash needs to be more acidic then food grade lactic acid pairs well with the beer but does not add any unwanted flavors. Typically, the malt is acidic enough that this step is unnecessary. The wort typically falls within recommendations if the brewing water and mash are properly attained. Checking the pH during the fermenting process can ensure the that the quality of your product is acceptable. Often if you have a pH under the recommended value this is generally a sign of contamination problems. It can be said that checking the pH at the initial stage, the brew water is the most important time as this sets the mode for the rest of the cycle. With many discussions from several home brewers and watching many how to brew at home videos it was noted that not many people test the pH of their water. After completing a broad search for pH sensors, it was found that many sensors are simply to expensive to try and incorporate into the design for a process that not many people even bother with. It was decided that we would like to add the pH sensor but only if we could get something at a much lower price that was fairly easy to work with. Our research brought us to these three sensors to consider for our project.

Understanding how a pH sensor works will help in determining the best sensor to use and how to incorporate it or build a circuit around the principles of its operation.

In the most basic for a pH probe acts as a single cell battery. The probe has electrodes and when the probe is placed in a solution ion will flow producing a voltage. The voltage can be positive or negative depending on which direction the ions flow. This positive or negative reading indicates if the solution is a base or an acid.

“DFRobot Analog pH Sensor” seen in Figure 8 A) is a low cost and designed to work with Arduino controllers. It takes readings with a ±0.1 accuracy at 25 C. It has a range of 0-14 pH and can be measured within temperatures of 0 – 60 C. It comes with a probe, interface cable and a sensor board. The overall specifications of this set up meet our needs but it does have a few issues we would have to address. The probe is not intended to stay in water for long periods of time.

DFRobot’s site says if the solution it is in stays around a 7pH the sensor would last for approximately six months but if it is in a acidic solution it may only last one month. It is recommended to take your reading and then remove the probe from the solution. The probe also should not be stored in a dry condition. The probe should be stored in a solution to prolong the probes life. (Gravity: Analog pH Sensor/Meter Kit for Arduino, 2017)

“DFRobot Analog pH Sensor Pro” seen in Figure 8 B) is a bit more expensive when compare to its base model, almost double the price but still less than half the price of most of the others we researched. This model has a life expectancy of up to 1 year and comes with the ability to monitor online. It is made of a glass membrane with a low impedance. It has a fast response time and its industrial quality allows it to stay submersed for long periods of time. The accuracy, range, and response time are similar to those we have compared it to. (Gravity: Analog pH Sensor/Meter Pro Kit For Arduino, 2017)

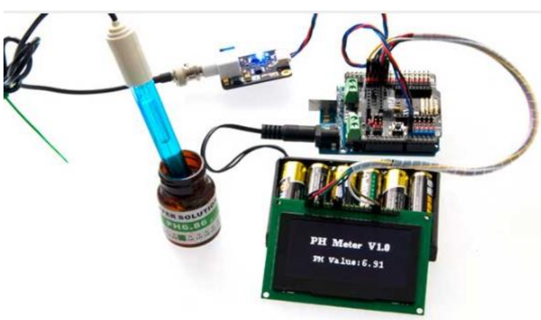


Figure 6: A) DFRobot pH Sensor, B) DFRobot Analog pH Sensor PRO (Courtesy of dfrobot.com)

“GAOHOU PHO-14” pH detector is available on Amazon for quick shipment. The cost is low, but not the lowest we have compared. The specifications for this probe are similar but not as good as others compared, as shown below in Table 19: pH Sensors. Just as the DFRobot pH Sensor, this sensor is not designed to remain in the solution for long periods of time and must be stored in a solution to keep it from drying out. In the project, a PH sensor wasn't used due to not needing one. It was found that spring water or even filtered tap water was best to use when brewing beer. Most all spring water researched was well within acceptable PH ranges.

Table 19: pH Sensors

pH Sensors						
Sensor	**Power (V)**	**Range (pH)**	**Accuracy (± pH)**	**Temperature (C)**	**Response Time (sec)**	**Cost ($)**
Gravity: Analog pH Sensor	5	0-14	0.1	0-60	< 60	30
Gravity: Analog pH Sensor PRO	5	0-14	0.1	0-60	< 60	57
GAOHOU PHO-14	5	0-14	0.25	0-50	< 60	38

2.7.4. Specific Gravity Hydrometer

Although knowing how much alcohol is in your beer is not a necessity, it is definitely nice to know data. Determining the total alcohol in the brew is a fairly simple process of simply measuring the beers density right before fermentation begins. This is when the sugars are at their highest and the yeast has not had a chance to eat converting the sugars to alcohol. This is known as the Original Gravity (OG). Once the fermentation process has completed you take another reading of the beer's density, this is when the sugars are at their lowest. This is known as the Final Gravity (FG). Alcohol is measured in ABV or alcohol by volume and this can be calculated using the OG and FG previously found. The final formula for ABV is $ABV\% = (FG - OG) * 131.25$.

With hours of research completed, it has been determined that there is not a sensor available in the market for small scale projects that can accurately measure the ABV. The common problems that were reported back project after project related to the bubbles from the fermentation cycle drying around the top of the sensor which changes the buoyancy of that sensor yielding inaccurate readings. There are a couple of products that have been launched over the last year or two but have had less than desirable results. The "BeerBug" which was designed and produced to do just what we are looking for had poor results featuring a 1.5 start out of 5 on Amazon.com. The few other companies that have tried producing this have the same overall reviews. It was determined that simply using the ABV equation that the end user can calculate their own results but as an added feature a text or email message could be sent to them letting them know that if they want to determine their ABV the moment is upon them to decide to check.

2.7.5. Flow Control Meter

The use of a flow control meter will be necessary for several reasons. At the beginning of the process a specified amount of water should be added for creating the wort. Although many recipes start with the full 5 gallons of brewing water that you plan on preparing, not all recipes are designed this way. Many recipes will start with 2 to 3 gallons of water which decreases the time for boil when creating the wort. Although water will need to be added at the fermentation stage the flow meter will prove less useful as we won't know the exact amount of water to add at this stage, a float switch will better serve our needs at this stage of the process. Listed below are three different low cost flow meters that we considered.

The "Digiten G1/2" is a well priced flow meter, $8.99 on Amazon, that can measure from 1-30 liter per minute at pressures upto 1.75Mpa. It can work with voltages ranging from 5-18 Volts. It puts out a square wave with a pulse signal. It has a plastic housing with ½" NPT inlet and outlet. The "Digiten 1/4" Quick Connect" seen in Figure 9 likewise is priced well at $9.49 on Amazon. This flow meter can measure in a range of 0.3 – 10 liters per minute. It operates on voltages ranging from 3.5-12 VDC. It can operate with pressures up to 0.8 MPa and has and error rate of only 2%. The output wave form is a square wave with a pulse output signal. It has a plastic body with ¼" quick connects for the input and outputs of the meter and can be connected with a variety of ¼" Hoses.

The "Uxcell G3/4" is a water flow sensor with a brass body. It has a flow range of 2-45 liters per minute and will work with a low pressure start. The sensor needs 4.5 – 18VDC and can handle a max current of 10mA. The inlet and output threads are ¾" NPT. The error rate can be as high as 10% but the with small amounts of water this is not a huge problem. The Uxcell G3/4 is in the general price range of many other low-end models that we researched with a price of $8.53 on Amazon.com. This flow meter was used for the water system to determine how much water was transferred to the steeping kettle. It used a digital I/O pin, 5V, and GND. When coded correctly, it was very accurate and always within 2%.

Figure 7: 1/4" Quick Connect Flow Meter. (courtesy of Group 4)

2.8. Fluid Solenoid Valves

In an effort to keep the total cost of the project within a reasonable budget we will need to purchase several solenoid valves in order to use the same pump for multiple purposes. During the first initial filling stage the pump will be needed to fill the mash kettle with our brewing water. With the proper amount of water added to the mash kettle the pump will then need to circulate the heated water in the mash kettle to extract all of the sugars from the grain. When the mashing process is complete, we will need to pump the wort from the mash kettle to the boil kettle. At the end of the beer brewing process water will need to be added to the fermenter to bring the product back to 5 gallons. We will pump the needed water from the brewing water to the fermenter. We can accomplish all of this with one pump and six solenoids. By switching the input of the pump between the brewing water and the mash kettle we can accomplish using one pump to add water at different cycles or use the pump to circulate the product in the mash kettle. It is important to have the correct solenoid activated to make certain the proper product is going to the inlet of the pump and output of the pump is going to the correct vessel. The process for using one pump is described below in Figure 8.

In order to fill the mash kettle with the brewing water, solenoids 1 and 2 will need to be active while solenoids 3, 4, 5 and 6 are deactivated. This will allow water to flow from the brew water into the mash kettle. In order to recirculate the mash kettle solenoids 2 and 3 will need to be active while solenoids 1, 4, 5 and 6 are deactivated. This will allow the pump to constantly circulate our mash. To transfer the wort from the boil kettle to the fermenter solenoids 3 and 4 will need to be activated while solenoids 1, 2, 5, and 6 are deactivated. Finally, to fill the fermenting container in the final stage we would require solenoids 5 and 6 to be activated while solenoids 1, 2, 3 and 4 are deactivate. When filling the fermenter up to the 5-gallon mark, solenoids 1 and 6 were activated before the pump turns on.

While using this setup it is possible to add water, circulate the mash kettle, and transfer the boil to the fermenter container using only one pump. At this time, we are considered two options for the cooling pump. It would be possible to use the same pump for the cooling system but since that process is done between pumping the mash kettle to the boil kettle and the transfer from the boil kettle to the fermenter, we would have to sterilize the pump and lines between those stages. We plan on using is ice water running through our wort cooler that would not be sanitized. After running this ice water through the pump, we would have to have sanitizer run through the pump again before transferring the wort to the fermenter. This will require two more solenoids, a sanitizer solution in a kettle and a drain pan. This could be a preferred method as we need to sanitize the lines anyhow. The other option would be to purchase a separate pump for the cooling process. This would have less risk of contaminating our product and the cost would not be much more if any as we would not need two solenoids, a sanitizer kettle, and a drain kettle.

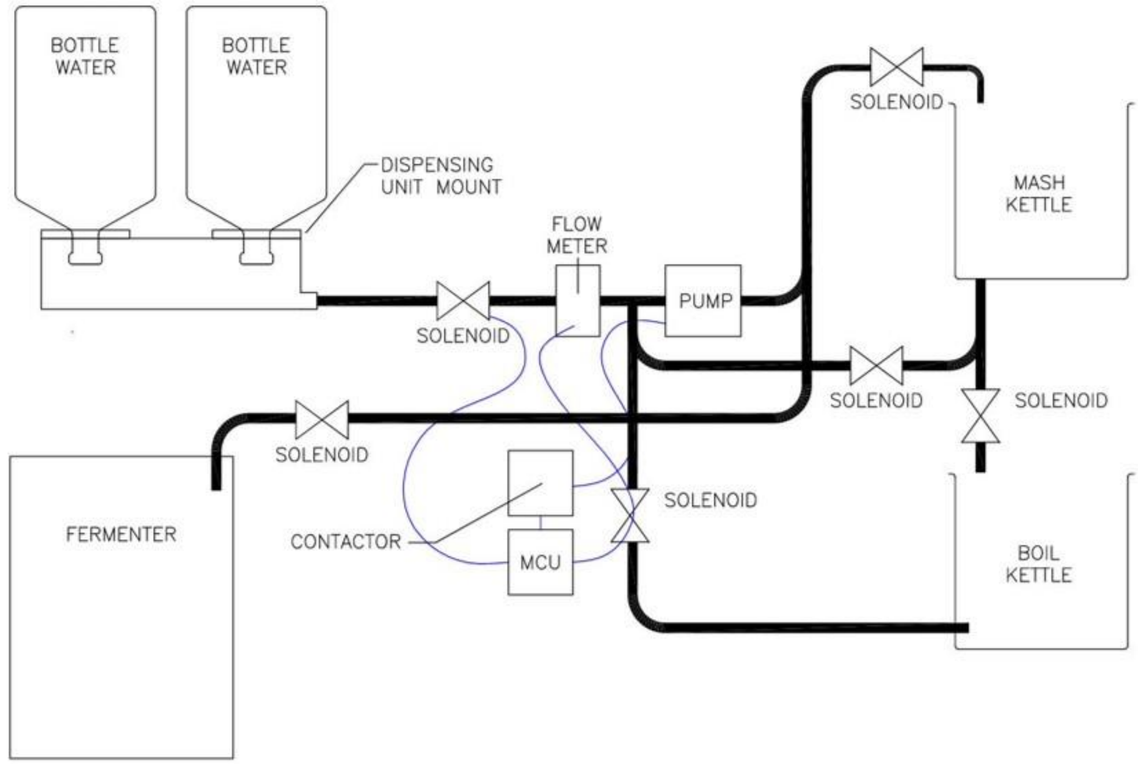


Figure 8: Solenoid Diagram

Finding a reasonably priced electric solenoid is a must as we need so many of them. Most of the solenoids will have very minimal pressure on them, they can be either AC or DC powered, and at minimum one of them should be able to handle boiling water.

The Digiten ½" DC 12V Electric Solenoid with a normally closed water inlet switch is the first solenoid considered. Exact Specifications can be seen in the table xx below. Notable features for this solenoid is the plastic bode, 12V design and the ability to handle temperatures from 0-100C. Most notably is the cost at $7.22 on Amazon.com. The "HFS" Electric solenoid specifications are listed in Table 20. The most notable features of this valve is its brass body, its availability in numerous sizes from ¼" through 1", and its available voltages that range from 12VDC to 110VAC. It has a cost of $8.99 to $10.99 on Amazon.com. The "Precise" ½" NPT solenoids specifications are listed below in Table 20 . Its most notable features are the brass body, the ability to be easily rebuilt, and its higher cost of $20.00 on Amazon.com. The Digiten ½" 12V electric solenoid valves were used in out project. They worked well during the brew cycle and flushed out properly. Better quality solenoids or ball valves would work better due to the grain and hops debris created from the brew.

Table 20: Electric Solenoids

Electric Solenoids (Fluid)					
Valve (See Legend)	**Working Temp (C)**	**Working Pressure (Mpa)**	**Voltage**	**N/O or N/C**	**Threads**
Digiten ½”	0-100	.02-0.8	12VDC	N/C	½” Male
HFS	-5-80	0-0.689	12VDC/110VAC	N/C	¼” – 1” Female
Precise	-5-80	0-0.689	24VDC	N/C	¼” - ½” Female

2.9. Water Pumps

A water pump will be crucial in the automation of the beer brewing process. The initial creation of the wort will require us to pump a specific amount of water into the brewing keg. Different recipes call for different amounts of water during the initial wort making process. With a recipe chosen and the parameters entered a specific amount of water will need to be added to the brewing kettle. Using a flow meter and some relays being controlled by the MCU the water pump will distribute the proper amount of water into the brewing kettle. The wort will be created through a boil and hops will be added and based on the recipe more water will need to be added. Some recipes call for small amounts of water to create the wort and some require the full 5 gallons you plan on brewing. Either way you will have to add water during the fermentation cycle. The water needed during this cycle may come from the recipe only requiring a small amount of water to create the wort or water may be needed to replace the lost water during the boil process. Water will be added during the fermentation cycle to bring the total volume of the product up to five gallons. This step will be controlled with a float switch that will stop the pump when 5 gallons is reached. A decision that was made is whether to purchase two pumps. It was better to have a fluid transfer pump and a designated pump for the cooling system. Another use of the fluid transfer pump was for both the sterilization cycle and the flushing cycle. The fluid transfer system already adequately moved the fluid from one place to another. Simple parameter changes such as heat, time, and volume were changed to add these cycles into the project. Both the sanitization and flushing cycles were very important in this project and worked as expected.

The “SHURflo 2088-594-154,” shown below in Figure 11, is a 115V self-priming water pump. It is capable of pumping water up to 12 vertical feet. It prevents back flow of fluid through the pump and can transfer liquid at a rate of up to 3.3 gal per minute. The pump is designed in such a way that if it runs dry it will not damage the pump. It has an automatic turn on and shut off feature that maintains a 45-psi pressure. The pump has ½” NPT inlet and outlet fittings. The pump is protected so that if pump overheats and overload trips and won’t reset until the pump cools to ambient temperature. This particular pump is approximately $70.00.

Figure 9: Shurflo 115V Pump. (Courtesy of Group 4).

The “Seaflo” 12V self-priming pumps has a transfer rate of 1.3 gallons per minute (5 LPM) with 3/8” inlet and outlet connections. The pump is capable of running dry without damage to the pump. It has a bypass that reduces noise and relieves strain on the pipes and pressure switch. This motor is a 12VDC motor which would require us to incorporate a larger power supply capable of carrying the current of self-priming pump. This pump however comes with a great price of $40.00 on Amazon.com. It can be noted that a pump of similar specs can be obtained on amazon also but at a cost of approximately $100.00. The “Aquatec 5853” is a 1.7 gallons per minute water delivery pump rated for use at 120V. It can handle 60PSI and has 3/8” quick connect fittings located on the pump. It is self-priming and has a quiet operation, when using at low volumes. Like all others in its class it can run dry without damage to the motor. The cost is approximately $99.00. Both pumps used were the SHURflo 2088-594-154. The fluid transfer pump was the pump that supports up to 170 degrees and the cooling system pump had standard specifications. Both pumps worked as expected and had no issues during any of the cycles during testing and operation.

2.10. Plumbing Equipment

There will be numerous non-electrical items needed to complete this project to transfer fluid from one step to another and make thing easy to remove for cleaning and sanitizing. Also, we need specific mounts, fittings, and clamps for ease of removal. The connections need to be made from the water system to the mash kettle, from the mash kettle to the boil kettle, and from the boil kettle to the fermenting unit. We are going to use ½” hoses and fittings to accomplish this which means that every connection made for fluid transfer should be the same to make things uniform and easy to order. In this section we will give a brief description of the specific part needed for the entire system as well as the availability and price to calculate total project cost. To get a better understanding of how the plumbing for the system will work in the system, pictures and descriptions of the plumbing parts used for the fluid transfer system are listed below.

Figure 10 A) is a 5-gallon water jug that can be filled at any nearby grocery store with good filtered or spring water needed for a successful brew. These can also be filled with tap water after the brew cycle is complete for a system flush. This was found at any Wal-Mart and is readily available at any time. The cap size is 53mm and the price is 9.88 per jug. Water jugs can also be purchased at the grocery store or even on Amazon and be about the same price. These will sit on mounts and dump into the reservoir and distribute the fresh water throughout the system. The water jugs used in the project were purchased at Lowes for 14.98 each and contained Zephyrhills water.

Seen in Figure 10 B) below are the means to mount the water jugs on the frame of the system. This will allow the water from the jugs to dump into a reservoir. These mounts have an air escape to let the water flow as needed and an easy to remove air filter to prevent dust from entering the system. They support bottles with a 53mm opening. These mounts were found on Amazon and can be processed the same day for 40.82 each. 2 mounts were used to hold both bottles. In this setup, both mounts with one reservoir that was mounted on the frame for ease of removal and replacements of the jugs. The reservoir had quick disconnect fittings for easy removal of the water lines. Figure 10 C) was going to be used if 2 reservoirs are needed then there must be a fitting on each reservoir and a T-fitting that connects the 2 output hoses to one output. This is a ½" x ½" x ½" fitting that will fit any ½" id pipe and can be found on Amazon for $2.12. There will be more than 1 T-fitting used in this design based off of the fluid diagram designed. We will need 1 for the two water jugs, 1 for the pump, and 1 to route the fluid to the fermenting unit.

Figure 10 D) is a picture of ½" hose that was used in the project to transfer the fluid from one place to another. These hoses were food quality hoses that were able to withstand the heat produced in the system. A food grade hose product was found on Amazon that is ½" diameter hose in lengths of 10 feet. It can withstand temperatures of -40 to 240 degrees C. This hose is very flexible which will make it easier to move around and route through the frame of the project. This hose was capable of having quick disconnects or standard plumbing fittings installed in it for connections to solenoids or the different kettles. Connecting the fittings to the hose is as easy as inserting the fitting and securing it with a hose clamp. The price is $24.92 per roll.

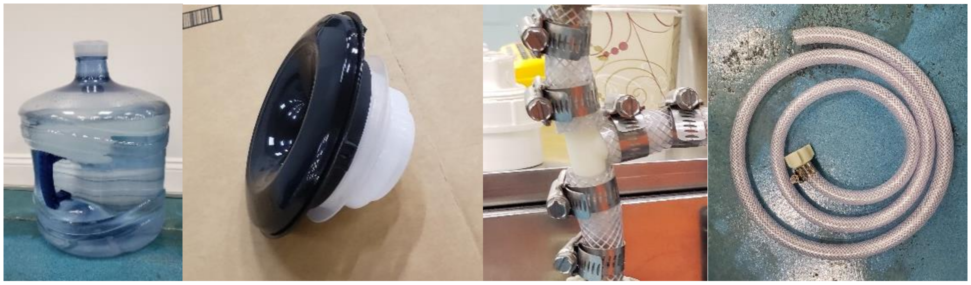


Figure 10: A) 5-gallon water jug B) Water jug holder C) T-fitting for hose junction D) ½" hose (Courtesy of Group 4)

In Figure 11 below is the water reservoir that will be used in this design. This will be mounted to the bottom of a shelf and used for the water supply for the brew. The mounts for the 5-gallon water jugs will be mounted on the shelf and pour into this reservoir. The mounts may need to be sealed to allow no water to escape when filling the reservoir. This reservoir has a 7-gallon capacity and is NSF and FDA approved meaning drinking quality made. this is a non-pressurized tank that will require vents to properly allow water flow. These vents are located in the mounts and should provide adequate ventilation for the proper flow. this reservoir was found on Amazon and manufactured by a company called Class A Customs. Other reservoirs were very expensive and used for RV water storage. This particular reservoir was 29.95 and shipping was 7.25. It comes equipped with one 1 ½" female threading and three ½" female threading for hose to pump connections. Careful thought was put into this reservoir based on the volume and size. The dimensions of this reservoir are 17.5" length x 7" height x 9.5" width. The reservoir has to be large enough to support both mounts and be able to space the 5-gallon jugs out enough. The inside diameter of the mounts are 7" which should leave us 3.5" to spare. The outer diameter of the mounts are 12" which is why we will mount the reservoir to the shelf. Doing this will strengthen our design as well as allowing the mounts to not hang over the sides of the reservoir. This will also prevent sagging in the middle of the reservoir.

Figure 11: 7-gallon water reservoir (courtesy of Group 4)

The project will require many quick disconnect fittings for ease of removal for cleaning and sanitation. There are multiple different kinds of quick disconnects on the market for different applications. Some can be standard and not have heat protection, others are for higher pressure, and some have high heat tolerance and are made for lower flow which is the direction our project is leading us to. These can be rather costly as well so research is needed to determine a few different types and first determine how many we will be needed for general transfer applications or applications that require higher temperature fittings. We will determine which connection will be used for transferring hot liquid or be mounted on the hot surfaces of the mash or boiling kettles. A connection needs to be made between the water reservoir and the solenoid before the water pump. The water pump will then input into 2 different solenoids which supply fresh water to the mash kettle and the fermenting unit. Looking at the solenoid diagram in Figure 8, we can see that we need 4 pairs of stainless-steel fittings for the attachment points on the mash kettle and boiling kettle.

The rest of all the connections can be made with cheaper plastic fittings because there will be very little heat supplying and transferring the water. There could be as many as 15 more plastic quick disconnects for the system in order to be able to remove the hoses for proper cleaning. There may be a way to have less fittings if we can find a better way to flush, clean, and sanitize the system after every use. For both the metal and plastic quick disconnect fittings, one of the ends must be threaded to be able to mount them onto the pump, solenoid, reservoir, and kettles. The pump and the solenoids will come with threads and should screw right in using either tape or an O-ring. The reservoir and kettles will have to be tapped so the fittings can be attached properly. Both the mash kettle and the boiling kettle should have the female metal connector on the kettle so if at any time during the process, it the user must remove a hose, no fluid will come out. These come with a built-in check valve that allows fluid to flow only when connected to the male end. Careful consideration was taken doing research on these components because there will be so many of them present in the system.

Stainless steel metal quick disconnect fittings were found on Amazon as a pair. They are built for home brewing and able to withstand the heat that is applied to either kettle that they will be attached to. The price for the pair is $15.00 and total for what we need are 4 sets for attachment points to the reservoir, the steeping and boiling kettles, and the fermenting pot. The plastic fittings have data sheets attached to them on the website and are manufactured by a company called Link Tech and sold by Coast Pneumatics. These fittings are rated for temperatures between -40 to 180 degrees Fahrenheit. This is sufficient for the water supply, transfer from the mash kettle to the boiling kettle, and transfer from the boiling kettle to the fermenting unit, but the stainless fittings will most likely be used on metal surfaces. In Figure 12 are plastic male and female quick disconnects are plastic male and female quick disconnects that mount to the hoses. They are manufactured by a company called Linktech. The male connecters are 4.91 each and the female connectors are 11.60 each. If we need 15 pairs of these the total cost of the plastic fittings will be 247.65. They are readily available and can get as many as needed in a short notice. The fittings hose clamps to properly mount the disconnects to the hoses.

Figure 12: A) ½" Stainless steel quick disconnects B) ½" Plastic quick disconnects hose mount (Courtesy of Group 4)

Figure 13 A) shows the male and female plastic fittings that are threaded to mount to ½" components such as the pump, the solenoids, or any surface that we chose. These fittings are were manufactured by a company called Sharkbite. The male connecters were not used in the project and the female connectors were only 2.64 each. These fittings needed O-rings and jam nuts to attach them to certain surfaces which are in-expensive and the correct size and thread pitch for the jam nuts can be found at any local hardware store and will probably cost around 10 dollars for everything. The hose clamps in Figure 13 B) was found on Amazon and are able for purchase in bulk. We would need around 20 for the connections for hose to fitting and the price is 7.59 and is readily available at any time. These hose clamps come in all different types and a different one may be used depending on budget.

A one-way check valve is something we considered for us to be able to use the same pump for multiple functions such as the water fill to the mash kettle, the water fill to the fermenting unit, and the fluid transfer from the boiling kettle to the fermenting unit. We need to be able to direct the flow of the fluid with multiple solenoids active without back feeding in the system. This can be accomplished by using a check valve. Both ends of this valve found on Amazon support the ½" diameter of the hose and it can be placed in-line at any part of the system. This will be placed on the first t-fitting for supplying water to the fermenter to top it off with 5-gallons. This will prevent water flowing to the boil kettle from the water supply pump when certain solenoids are active. It can also act as a flush for the system and allow hot water to circulate after the brew cycle is complete.

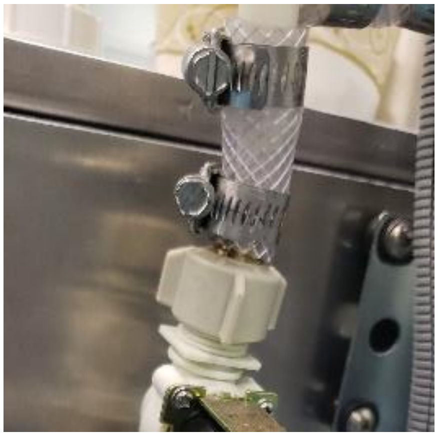



Figure 13: A) ½" Plastic quick disconnects component mount B) Hose clamps (Courtesy of Group 4)

2.11. The Dispensing Unit

When brewing beer by hand, the user will have to add in malt, hops, and dry hops at different time intervals throughout the brewing process. Different recipes call for different times and sometimes the process can differ in certain ways. The user will have to constantly monitor the system and add these ingredients in at the exact time the recipe calls for. The point of this project is to automate everything in the process to have a consistent product every brew and to save hours of time for the user. Automatic dispensing units will be needed to achieve this in our system that will automatically add in the malt and hops to the brew at these certain time intervals. The dispensing units will be needed at the initial mashing stage, the boiling stage, and a manual dispensing unit at the fermenting stage which will be explained in the fermenting section. The dispensing units explained in this section are specifically for the mash and boiling stages.

A dispensing unit for the initial mash stage will be needed for the malt only and a few different ideas are going to be discussed for this dispensing unit. No hops are added in until the boiling stage. Making sure every drop of the malt in the can is used in the mash stage is important for the alcohol content of the product as well as the type of beer being brewed. The malt usually comes in cans and is difficult to get out of the can due to the viscosity of the malt. It's more like a syrup than a liquid which makes a lot of the malt stick inside the can. Heating the can will help lower the viscosity of the malt making it easier to pour from the can to the mash kettle. Another method could be spraying hot water inside the can, flushing all the residual malt from the inside of the can. The can will also have to be punctured for dispensing purposes or the user could open the can at the prep stage and can automatically be dumped at the correct time. Both methods will work to achieve this, and research will be done to make sure the most efficient method will be chosen.

2.11.1. Method 1

The first method is having the user open the can at the prep stage and dumping the can when heated properly. Heating the can could be as easy as having the unit above the steaming mash kettle, which will heat the can. When the time comes a mechanism will turn the can 180 degrees pouring all the malt out of the can into the mash kettle. After a certain amount of time, the can will be returned to the original position. This method will require more of a mechanical arm that can rotate the can 180 degrees for the pour. This can be accomplished with a servo motor attached to a clamp of some sort which will hold the can in place. This method will use low power due to the fact the user will have to manually open the can. The servo motor will most likely be 12 VDC and will only have to rotate 180 degrees and wouldn't have to be variable speed because it is only going to be controlling one motion. Also, when the can is drained, a nozzle that sprays water in the empty can should be incorporated to get any of the residual malt out of the can. This method can be used efficiently if using liquid malt that comes in cans, glass, or even plastic. There is a possibility that there will have to be 2 of these depending on the recipe used. Some call for more than one can and at different times. This method will be power efficient but, will add a task for the user to complete before the process begins. Below is a parts list needed for method 1 and a diagram of how this will look and operate in the system Figure 14 shows how the parts are mounted and how the system will work together to dispense the liquid malt.

Parts needed for method 1

- Servo motor (x 2)
- Clamps for the can (x 2)
- Small pump for flush
- Hoses for pump and nozzles
- Mounting unit

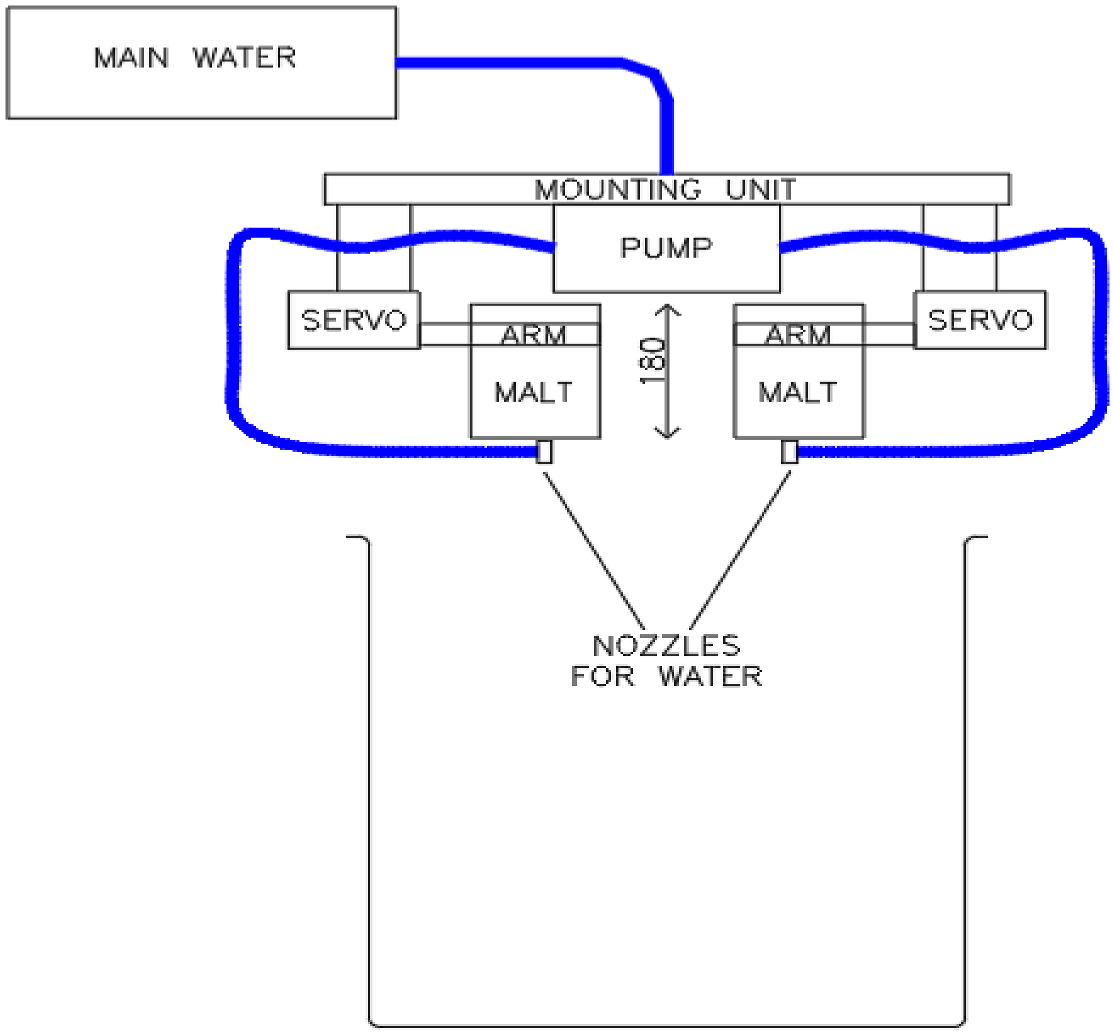


Figure 14: Method 1 For the Malt Dispensing Unit

2.11.2. Method 2

The second method of dispensing the malt during the mashing stage is for the user to just set the can or cans into a holder and have the can automatically puncture each can when it needs to dispense the malt. It will require two different puncture points, one at the top and one at the bottom. The one at the bottom will be a bigger opening for proper flow of the malt and the one at the top can be small for airflow to create proper fluid flow. The cans will slide in between two plates with puncture points and a motor will be used to compress the plates to create the puncture points in the cans. Each lower plate will also include a small puncture point for flushing the cans out with water. When the small puncture points puncture through the can, high pressure water will shoot into the can flushing the remaining malt residue into the boiling pot. This method can only be used efficiently if using liquid malt that comes in cans. The liquid malt in can form only can cause extra constraints on the project and limit the number of recipes that can be used for the brewing process.

The heating of the cans in this method will be the same as method 1 by mounting the dispensing unit above the mash kettle using the steam for the heat. Also, similar to method 1, a pump will be needed to flush the can out making sure all of the malt is extracted from the cans. This method will require more parts in order to puncture the can effectively and will be less cost efficient than method 1 but, will also require less prep work for the user to complete. It may be equal to method 1 or even consume less power because this method uses only 1 motor instead of 2 separate servo motors. This method will also require more cleaning. Everything that comes in contact with the malt will have to be cleaned and sterilized. Below is a parts list needed for method 2 and a diagram of how this will look and operate in the system. Figure 15 below will show how the system works when all of the components are put together. It shows how the system mounts and both compression plates come together to puncture the cans with a motor and a ball screw. It also shows how the cans will be flushed using a pump, hoses, and a puncture point.

Parts needed for method 2

- Mounting unit
- Different size puncture units (x 6)
- Upper and lower compression plates
- Support rods for compression plates (x 2)
- Motor
- Ball screw for compression plates
- Small pump for flush
- Hoses for pump and nozzles

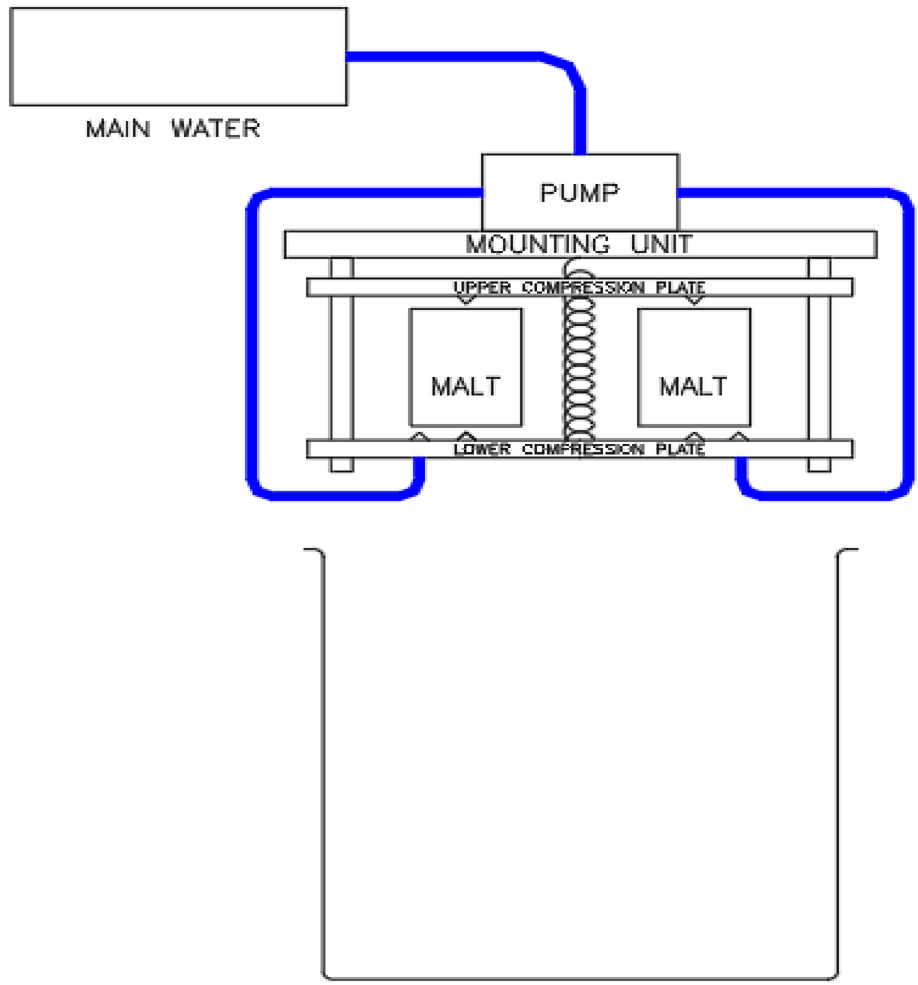


Figure 15: Method 2 For the Malt Dispensing Unit

2.11.3. Method 3

The third method of dispensing the malt when the mash reaches a boil is by building a container in which the user will pour the contents of the malt in and it will automatically dispense when a boil is reached. This method is needed because malt is very thick liquid that comes in different containers such as cans, glass, and plastic. After reviewing various recipes, the other two methods will not work due to the variety of containers the malt comes in. Some recipes call for dumping 9 pounds of malt into the boil. This would require a large container to be built so a variety of recipes can be supported. Instead of automating opening the malt, the user will have to open the container and pour the malt into the container made to dispense the malt. Making sure all of the malt is out of the can and into the boil is important for the flavor and alcohol content of the product being made. If enough malt doesn't make it to the boil, there will not be enough sugars present to react with the yeast during the fermentation process.

There will be a solenoid valve at the bottom of the container to dispense the malt into the boiling kettle. This method also requires a linear actuator for extracting all of the malt out of the container. This actuator would push a piece of rubber with the exact inner diameter of the container mounted between two thin pieces of aluminum to the bottom of the container. The actuator would have to have a stroke capable of making it all the way to the bottom of the container. Both the heat from the boiling pot and the scraper will ensure all of the malt is removed from the container and into the boiling pot. Figure 16 shows how method 3 will be designed and how the system will operate to dispense the liquid malt into the boiling kettle.

Parts needed for method 3

- Container for malt
- Solenoid valve
- Linear actuator
- Rubber for scraping
- Metal sheet (x2)
- Bolt and nut for mounting

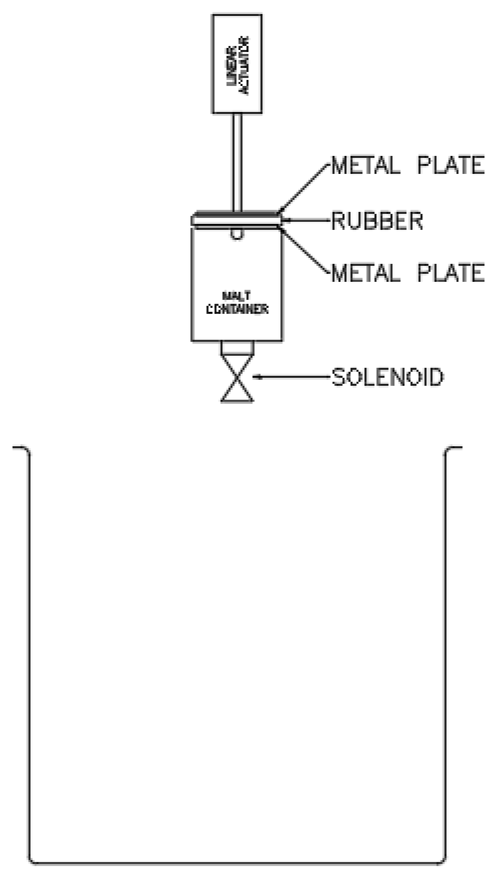


Figure 16: Method 3 For the Malt Dispensing Unit

After we began building the brewer, and testing parts, we realized that making an automated dispenser for malt would in the end be more inconvenient for the user since the malt is so sticky it would be much more of a mess to clean up if it is placed in its own dispenser. Our recommendation will be for the user to warm up and add malt to the recipe if it requires it at the time they would like for it to go in.

2.11.4. Dispensing Unit For Hops

This dispensing unit will be needed to add hops at specific times during the boiling stage. This is also recipe specific and some call for minimal hops at certain times and others are more complex having multiple different kinds of hops being added at different time intervals. Most of the recipes researched for this project have a max of 5 different time intervals of adding the hops. Most of them have hops added at the start of the boil, 30 minutes into the boil, and 50 minutes into the boil. The entire boiling process will be uncovered to let the evaporation escape and help minimize an overboil when hops get added to the mash. The user will have to open each package of hops and place into the correct dispensing container which corresponds to the time input to the user input. The user input will ask the user what time intervals to add the malt during the boiling process. The dispensing unit will dispense the hops based on the time elapsed during the boil.

This dispensing unit will consist of an array of 5 tubes that can be filled with hops or special flavors that will have 2-way valve under each tube. The 2-way valve can either be open or closed. This makes the design very simple, energy efficient, and maintenance free. These will be directly connected to the MCU as outputs and will open and close based off the internal timer. The tubes will need to be attached to a mounting unit and the individual valves can be mounted to the tubes. Different ways of opening valves will also be researched such as pneumatic valves, mechanical valves, and manual valves that can be modified to open electrically. If an electric or pneumatic open or close valve is too expensive, push/pull servos and linear actuators can be used to open and close any mechanical or manual valve. There possible needs to be a heat shield so the vales and other components can stay cooler and minimize the amount of evaporation that gets on the components. This will also allow a fan and a misting system to mount over the boiling kettle to minimize or stop an overboil when the hops are added. Below is a parts list needed for method 2 and a diagram of how this will look and operate in the system. Figure 17 below shows the flap valve option for dispensing the hops and dry malt into the boiling kettle. This shows how the tubes and flapper valves will be mounted to a unit above the boiling kettle. The malt dispensing system and mixing motor will also be mounted above the boiling kettle which were described in other sections. They must be taken into consideration when combining them to the mounting system to ensure there will be enough room for the three separate systems.

Parts needed for hops dispensing unit

- Mounting unit with heat shield

- Rods for the mounting unit (x 4)
- Tubes for hops (x 5)
- 2-way valves (x 5)
- Flapper for valves (x 5)

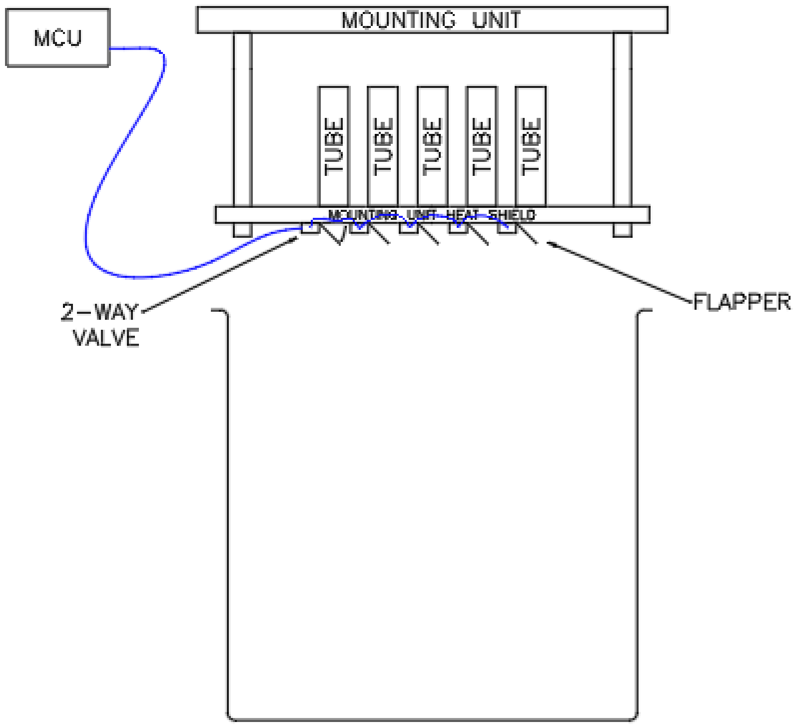


Figure 17: Dispensing Unit For Hops.

2.11.5. Hops Dispensing Unit Parts

Parts were researched for the design mentioned in the previous section and the flapper valves discussed were difficult to find and either were very expensive or operated pneumatically which would cause a separate system to be incorporated such as an air compression system and means to control it. Since dispensing the hops and dry malt at proper times can be done multiple different ways, other parts were researched to achieve this and a method that was briefly discussed needed to be implemented to lower the cost of the system. This method will consist of 4 PVC tubes, 4 slip gate valves, and 4 actuators to operate the gate. The slide gate valves are manual, so a connection will need to be made between the actuator and the valve handle to operate electrically. The tubes will be labeled 1 through 4 so the user knows which dispenser will operate first and which one will operate last. The user will place the hops in the tubes during the prep stage and entering in the times of dispensing in the users input. Different recipes call for different times of adding in the hops and this method ensures the hops get added at the required specific times. The linear actuator will retract which will pull the valve open dispensing the hops into the boiling kettle.

Figure 18 A) is a picture of a gate valve that can be used to dispense the hops and dry malt into the boiling kettle. This gate valve is manufactured by a company called Valterra and is sold by Granger Industrial Supply. The opening of the valve is 1½” and will support any PVC tube from a hardware store. The cost for the gate valve is 12.36 and is available at any time. The handle on the valve can be modified to connect the linear actuator arm. Figure 18 B) shows the 1 ½” PVC pipe that attaches to the gate valve and was found on Amazon. This PVC pipe is sold in 4 ft sections for 14.88 and is available at anytime for order and prompt shipping.

There are many different types of actuators on the market powered by different sources such as hydraulic, pneumatic, and electric. To transfer rotational energy into linear mechanical motion either a pressure system or a ball screw system is needed. For this project we are interested in the most cost-effective way to achieve pulling the valve handle to automatically dispense the hops into the boiling pot. Many different linear actuators were researched, and some smaller low force actuators were more expensive. The maximum stroke limit would be 2” to support fully opening the valve to make sure all the hops gets dispensed. The force limit and speed would not matter as long as it can fully open and close the valve. A good linear actuator manufactured by New Jia Qun and sold by Amazon is readily available and costs 28.00 each and includes the mounting brackets, pins, and cotter keys. Figure 18 C) shows this part and the attachment components that come with it. The stroke limit on this actuator is 2” and the max force is 225 lbs which is more than needed to operate the valve. The operating voltage is 12 VDC and the max current draw is 3 Amps at full load. The speed of the actuator is 0.39in/sec. The price for 4 units will run close to 170.00 using this method.

Figure 18: A) Gate valve B) ½” PVC pipe C) 2" stroke linear actuator (Courtesy of Group 4)

2.11.1. Malt Dispensing Unit Parts

Since the liquid malt was scaled down in this project, the dry malt was still able to be automatically dispensed. One of the 4 hops dispensing units was used specifically for the dry malt. A PVC contraption was created to support over 7 lbs of dry malt by using 1.5”, 2”, and 4” PVC pipes. This add on would screw into the hops dispensing unit and would only be used if there is dry malt to add.

Figure 19 A) and B) below shows the 4” PVC pipe and the hops dispensing 1.5” PVC connection point needed to support the dry malt. 4” PVC pipe comes in 2 ft sections and sold at The Home Depot. This is schedule 40 PVC which is very durable and capable of holding the heavy dry malt. The price for this section is 8.97 and is always available to cut at any time. This piece would be good to scale down if needed to support less than 8.5 lbs of malt. Calculations were made for a 4” by 16” tube and it was found to hold up to 9.193 lbs of malt.

Figure 19: A) 6" PVC pipe B) 6" PVC pipe endcap (Courtesy of Group 4)

Figure 20 A) shows a 1.5” fitting with a threaded 1.5” female end is needed to mount to the endcap so there can be a solenoid valve mounted for dispensing. This can be mounted with epoxy or any other industrial PVC connecting compound for a permanent hold to the endcap. This was found on Amazon for 3.84 and can be ordered anytime. Figure 20 B) is a 1” solenoid valve can be mounted directly into the 1” female adapter located on the end cap. This solenoid valve is normally closed and will dispense the malt when opened. The solenoid operates on 12 VDC and was found on Amazon for 11.99. the 1” opening is feasible for dispensing the malt to allow the mixer to stir the malt to prevent clumps of malt from burning on the heater. This solenoid was not used in the project due to the scaling down of liquid malt. This was supposed to be mounted over the boiling kettle using method 3 of the designs.

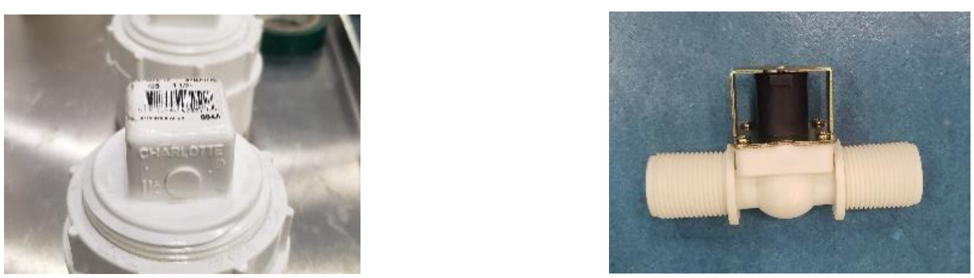


Figure 20: A) 1" threaded plug B) 1" solenoid valve

2.12. Mixing Motor

(AC) During the period of the brewing process when the malt or hops are being added, the water must continually be stirred to make sure the ingredients are completely dissolved and that the liquid does not boil over. To make sure the liquid is completely mixed, a motor with a paddle attached to it is used for stirring.

Although mixing keeps all the liquid at a consistent temperature, it also causes the water to release more heat, this caused an unexpected issue of the water not being able to reach a boil while the mixer was on. To solve this, when the system is in the boil phase, the system will turn off the mixing motor until the water reaches a boil, then the system will start the timer and the mixing motor. A lid was also designed and added to the system to help contain heat. Once the liquid reached a boil, the mixing motor did not cause any more problems. This means that during the hops phase, when the mixture must remain at a constant boil, the stirring motor can remain active to prevent the mixture from boiling over while simultaneously keeping the temperature at the appropriate level.

During the cooling process, to cool the mixture consistently and get accurate temperature readings, the mixture needs to be stirred often. The cooling process has a coil running through the mixture, which has cold water from another container pumped through it, cooling the mixture without contaminating the mixture.

While The benefit of using a variable speed motor is that it allows for a more flexible design, the downside is that it would cause an increase in cost to the project, as an extra device will have to be purchased that can alter the input to the motor to control the speed. These do not seem to be very expensive, and can be found on Amazon from $8-$20, they still would add to an already very expensive project. The other downside is that the more variables and moving parts that are added to the device, the more issues that are likely to be run into, so while the project gains flexibility, there is also an increase in the likelihood for problems. It also seems that most AC motors have the capability to turn into a variable speed motor if attached to the above-mentioned device. Meaning should a single rate motor be chosen and then later a decision is made to switch, the change should not be too difficult to accommodate.

However, as more research was done, it was found that a fast-moving motor is not needed. A motor that spins at around 50 rotations per minute will perform the required job of keeping the liquid mixed, the heating consistent across the brew, and the ingredients from burning on the bottom of the pot. The stirring mechanism attached at the end will require a high torque motor. A higher torque motor, as seen below in Figure 21 is more expensive, costing about $20, but required for the larger stirring mechanism.

Figure 21: Low Speed High Torque Motor

Since the point of the motor is to power the stirring of the brew, research was done into the stirring mechanism attached at the end. There were a variety of possibilities for stirring the mixture, but the project was restricted by its specifications. The first is the height of the pot, a typical 7-10-gallon pot is between 15 and 28 inches tall, so the stirring mechanism must be less than this height, several were looked at that met both the 15 and 28 inches specification. The next was the size of the wort chiller tubing used for cooling the mixture before adding the yeast. Since the stirring mechanism is inside of the coils, its dimensions needed to be less than the diameter between the coils. The coil diameter used was custom made to be as large as possible, so this was no longer an issue.

Stepper motors were another possibility for the mixing motor. Stepper motors are used where accuracy is needed since you can control the motor in steps that can monitor how much they have moved. Although accuracy is not important for the project as a mixing motor the fact that one can control the speed of the motor and the fact that it has high torque at lower speeds makes this a viable mixing motor for the project. These motors generally run at low speeds, typically 800 rpms or less. If run faster than this the motor tends to lose its torque. Although the project does not need much torque, it will need enough to rotate a mixing paddle through both low and high viscosity fluid. As the mash enters the boil kettle it will have a relatively low viscosity, but when adding the liquid malt during the boil cycle the viscosity will become higher for a short time. The downside to using a stepper motor is that it needs a motor driver or a constant current source. Connecting this type of motor directly to a 12-volt source will damage the motor.

Another option for both motor and mixing head was to use a handheld kitchen mixer, Figure 22 below, that had both a low speed setting and a mixing head designed for liquid. These could be found relatively inexpensive, for a low as $15. They have multiple speeds, which eliminates the need for an extra device, and their mixing heads are interchangeable, providing an extra level of flexibility should experimentation with different length mixers or different styles be needed.

Figure 22: Kitchen Mixer (Courtesy of Group 4)

There are currently on the market some mixing paddles designed for brewing that meet the specification, however, due to their specific target audience, they tend to run a higher price, most being around $30.

After doing some more research, a number of paint blenders were found that will also do the job at a much lower price. The first is for a pot that is around 15 inches in height, Figure 23 B) below, its mixing head is a little over 3 inches wide, easily fitting inside of the cooling coils, and the design of the head helps mix the water well. But after purchasing, it was found that they do not withstand heat and stay at food grade level, so another options was found.

The second option was modifying the end of a stainless steel stir paddle to fit on the motor of our choice. The paddle with the handle cutoff is seen below in Figure 23 A) below. It was a reasonable price at $22. This worked very well and made it easy to clean while also mixing and preventing boil overs.

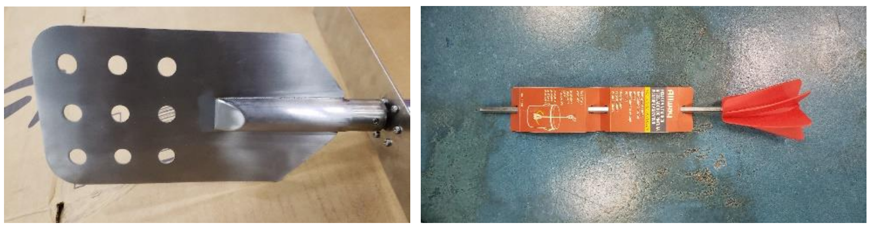


Figure 23: A) Cutoff Mixing Paddle B) Plastic Paint Blender (Courtesy of Group 4)

For the motor, the decision was made to go with the low speed high torque motor, above in Figure 21 B), due to its small size, cost, and power consumption. For the head, the plastic paint blender, above in Figure 23 B), was originally chosen to mount to the motor because of its price, style of mixing head, and the smaller amount of force required to rotate it, but then for the actual build was replaced by the cutoff mixing paddle. It was modified and attached to a mount that would hold it and the motor above the boil pot.

2.13. Power Requirements

One of the main objectives was to keep the unit below 20 amps at 120 volts. With this in mind, this provided a total available power of 2400 watts. The National Electrical Code, NEC, states that branch circuits for heaters must be sized 125 percent of their rated value. Since only a 1650 watt heater is being used, the minimum size branch circuit that was needed was (1650 * 1.25) + all other loads that will be on while this heater is on. This allowed for 338 watts available for all other items that will be run at the same time as the heater. This proved to be one of the greatest challenges.

When choosing components for the main power coming in, it was kept in mind that the unit is running at a full 20 amps and therefore cords were purchased that were capable of handling the full power. In this case, it was made certain that a minimum of 12 awg wire was used, which according to the NEC is good for up to 30 amps, if one uses 90-degree wire, but is not allowed to be used above 20 amps. This extra 10 amps allows for derating the wire based on ambient temperature. So a minimum of 12 awg wire was needed, but it was also required that a Nema 5-20p plug was used. This plug has the neutral blade turned 90 degrees. This ensures that one will only plug the plug into a 20-amp outlet. If one attempts to plug this equipment into a 15-amp receptacle it will not fit. This is important so that the Keur-Keg is only plugged into a 20-amp circuit with a plug that is also rated for 20 amps.

Safety is always of concern. Whenever one is using high voltage near water extra care must be taken. While it would be easy enough to put a warning label on the control panel telling the user to only plug into a ground fault circuit interrupter receptacle, GFCI, it is common sense that this will not always happen. Because of this, it was decided to add GFCI protection to the equipment right from the beginning. Two options were considered for this. First, power could be brought directly to the control cabinet and a GFCI panel mount protection could be added, or second, an inline GFCI cord attachment could be purchased. When considering panel mounted GFCI protection it can be noted that the average cost for a blank GFCI panel mount is approximately $45.00. This is intriguing as a standard 20-amp GFCI receptacle is only $25.00. Adding an outlet was not ideal as per the NEC, this outlet would have to be calculated as 180 volt-amps. Since the system design was already running short on power, this was not an ideal solution. Another solution was the inline GFCI which is added to the power cord that connects one's equipment to the wall outlet. This GFCI ,as shown in Figure 26, has buttons built in to the device to allow the user to test and reset the inline GFCI. At a cost of $25.00 this was the most cost effective and viable solution, and also the solution chosen.

Figure 24: Inline GFCI (Courtesy of Group 4)

2.14. Grounding

Grounding was of the most importance with this project. Not only was it important for everything to be grounded, but it was just as important for every ground to be at the same potential. Accomplishing this was straight forward, simply take a ground to every metal component. Most grounding could be accomplished through the bolts and nuts that connect all of the equipment together. To ensure the grounding in the design, when the equipment was not bonded together through the mounting process using threaded connections then a bonding wire or bonding jumper was added, joining these sections together. The kettles were just as important, if not more important, to be bonded as any other portion of our project.

The bonding of the kettles was accomplished through the cable supplying the high voltage to the kettle heater. Inside the custom junction box a ground stud was solidly attached by a stud welded to the side of the kettle. This made certain that at any point that power is connected to the kettle, a proper ground is also connected.

2.15. Consultants

As part of the research, several individuals who have extensive experience in brewing beer as well as experience with designing complex products were consulted. The first was Michael Rits, a civil engineer for 34 years, who has been brewing beer for over 10 years. The second was Daniel Faraday, an electrician for over 20 years, who has also been brewing beer for over 10 years. He also provided a hands-on experience of beer brewing to give a clear idea of what the process entails and what components are required.

3. Automatic Brewing Hardware Design

3.1. The Water System

The water dispensing unit for the system consists of two 5-gallon jugs of filtered or spring water which are gravity fed to a hose, which connects to a pump that has flow control, and has several output hoses. One hose supplies to the initial mash kettle while another one supplies to the fermenter. Different recipes will have a different initial water input amount so less water will be needed in the beginning process, but more will need to be added in the fermenting process, or vice versa. Before starting the system, the user will be requested to input how much water is needed for the mash cycle and or boil cycle. When the start button is initiated, the system will fill the mash kettle to the desired level by the MCU communicating with a flow-sensor in which the program will turn on and off the pump as necessary. When the brew cycle is almost complete and reaches the stage where the wort is transferred to the fermenter it is cooled and then transferred into the fermentation kettle. The pump will turn on again and supply fresh water to bring the product back to the desired 5 gallons. This time, instead of controlling the amount of water being added by flow, the 5-gallon mark will be obtained by filling the fermenter until a fluid level sensor signals that fermenter contains 5 gallons. Depending on the recipe, boil times can differ causing different losses within each cycle. This eliminates attempting to calculate the loss amount of water and just brings the product back to the desired 5 gallons.

Parts required for the Water System

- 2 5-gallon water jugs
- 2 water dispensing units (mountable)
- Food quality water hose (1/2 – 1” diameter, 10 ft)
- Food quality quick disconnects (5 sets)

- T quick disconnect
- Self-priming pump (1/4 to 1/2 hp, 120 V)
- Contactor or relay for pump
- Shutoff switch if needed
- Flow meter
- 2-way selector valve
- Nozzle end for no splash output (if needed)
- Fluid level sensor

There should be two side by side 5-gallon water dispensing units mounted near the middle left of the system to be able to replace the jugs with ease. This gravity feeds through a food quality hose with quick disconnects for ease of removing and cleaning. These lines are connected through a series of solenoids and plumbing fittings attaching them to the input of the pump. A flow meter is placed inline with the hose going to the mash kettle. This flow meter communicates with the MCU which allows a signal to turn the pump off when it reaches the desired output flow. The contactor is attached to the controller so the signals from the flow meter, fluid level sensor, and shut off switch can turn the pump on or off as needed. The shut off switch is only for if the system runs out of water, the pump will not run dry. The pump will turn on when the controller sends the signal to turn on during the 2 stages of the brew where the water is needed and operate through a series of solenoid valve that selects the location in which the water is needed. It will select either the mash kettle or the fermentation fill. Figure 25 is a sketch of the system which is shown below.

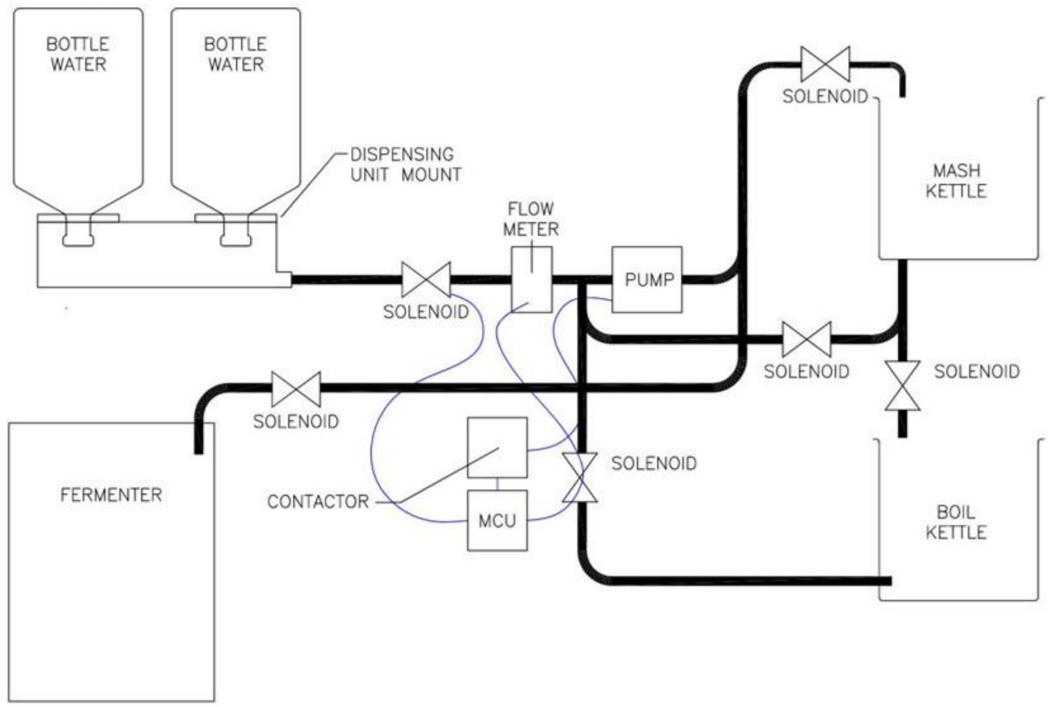


Figure 25: The Water System

3.2. The Mash Kettle

The mash kettle is used for steeping the grains, as seen below in Figure 28. Steeping certain types of grain is a way of adding flavor to your beer. The grain one uses can come in one of two forms. If purchasing a beer kit the grain will likely come milled and one will simply add it to a muslin or nylon mesh bag. If whole grain is obtained then it will need to be milled and then added to a muslin or nylon mesh bag. The bag will help keep the husks from the grain contained and out of the beer. The grains contain tannins which cause off flavors in the beer if not brewed properly. When brewed properly the tannins bitter taste is not noticeable to the consumer. Tannins really add a bitter taste if the grains are boiled so it is important to keep the mash kettle at or below 168F (76C). One will not want the grains sitting to close to the heater as this may will be a hotter point and the tannins will add a bitter taste or if to close to the heater the grain will burn and add a burnt taste to the beer. Another way of getting excess tannins in the wort is by using to much water. You want you the water and grain mixture to be below 6 pH. Most waters are around 7 or even higher but the grain is typically acidic and will lower your pH to an acceptable range. If there is too much water, then the grain will not have enough acidity to lower the pH and it will leach more tannins into the mixture. (Smith, 2017)

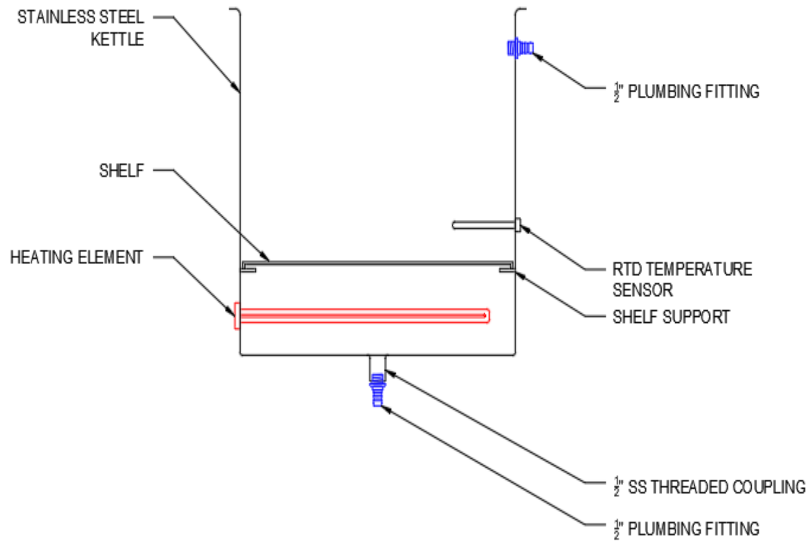


Figure 26: The Mash Kettle Diagram

The mash kettle is stainless steel and holds up to 8 gallons (32 quarts) of liquid. It has a heater located in the bottom of the kettle to heat the mixture to the appropriate mash temperature, not exceeding 168 degrees. The kettle has two plumbing connections, one located on the bottom of the kettle and one near the top. These connections allow the pump to be connected to the mash kettle. Using the same pump that adds the initial water to the mash kettle through a series of solenoids the pump will draw the mash from the bottom of the kettle and return it to the top of the kettle for the entire steeping process. This constant circulation act as the stirring mechanism for the steeping process. The mash is heated to a specific temperature based on the recipe during this process. The temperature is monitored through a temperature sensor located on the side of the kettle. Since the heating should not exceed 168 degrees, boil over is not a concern during this process. The mash kettle has a stainless-steel colander style shelf located one quarter of the way up the side wall from the bottom of the kettle. There are 3 feet fastened at this location to hold the shelf in place. The purpose of this shelf is to keep the mesh bag of grains from getting to close to the heater. This will help prevent the grain from touching the heater but still allow a current to flow through the kettle properly steeping our grains. Before transferring to the boil kettle, a small amount of water is added to the pump and pumped back into the mash kettle to clear out all of the mash that remained in the pump and lines. The transfer to the boil kettle occurs by opening another solenoid that is connected to the same plumbing fitting located on the bottom of the kettle and then activating the pump. Keeping safety in mind, it is important to make certain the heating element does not turn on if there is not a minimum amount of water in the mash kettle. In order to accomplish this, a float switch is used to determine if the minimum amount of water that has entered the mash kettle is met. It is then ensured in the programming that the heater does not come on unless a minimum amount of water has entered the mash kettle.

With plenty of research completed, the Gas One ST-32 kettle was chosen for the mash kettle. This stainless-steel kettle is large enough to handle all 5-gallon recipes, of which some 5 gallon recipes call for 6.5 gallons of initial water. There was plenty of room to mount the stainless-steel heater at the bottom of the kettle and being a stainless kettle there were no problems mounting the plumbing fittings and sensors to the top, bottom, and sides of the kettle.

During the mash cycle, when steeping grains, the malts from the grains are extracted to add to your brew. There are several types of steeping bags including mesh, nylon or muslin. Muslin is the better of these three due to its durability and permeability. Using a muslin bag will help in keeping the grains all together during the mash cycle. This will also help in keeping the grains from leaking out and reaching the boiling pot after transferring from the mash kettle. This bag also helps in the cleanup process as the grains do not remain caught up in the kettle and strainer. Sticking with the ecofriendly design, the muslin bag is strong enough to be washed and reused.

3.3. The Boil Kettle

3.3.1. The Kettle

The actual kettle that is used for the boil is the same as the mash kettle. It is a Gas One Stainless Steel Stockpot (#ST-32). It meets all the specifications and constraints set for the project. It has a large enough diameter to support our stainless-steel heating element, it is large enough to handle up to 8 gallons (32 quarts) of liquid, it is made of stainless-steel allowing heaters and sensors to be added without fear of corrosion from dissembler metals.

The boil kettle, as seen below in Figure 29, has a lot going on once it receives the mash from the mash kettle. The heated mash is pumped into the boil kettle. Once the mash is received into the boil kettle and the float switch has been triggered, the heating element in the lower portion of the kettle can turn on. As the temperature sensor, mounted in the side of the kettle, reads a temperature close to boiling then the mixing motor attached to the mixing paddle can begin to operate to prevent boil over. If liquid malt is required, the system will send an email to the user informing them that it is time to add the malt. For more information on the dispensing unit please see the research behind the mixing unit in Chapter 2 or the dispensing method chosen later in this chapter. Most recipes require hops to be added to the boil at specific times dictated by the recipe. The hops dispensing unit releases these hops at the specified time. For more information on the hops dispensing units please see the research in Chapter 2 on the hops dispensing unit, or the section later in this chapter on the chosen method for this project. Once the recipe has completed its boil it is time to cool the wort. The wort cooler is intentionally left in the boil kettle to limit the number of kettles necessary and to limit the human interaction. It is also worth noting that even though the wort cooler is sitting in the boiling water, little of this heat is transferred back to the ice water mixture as the plastic tubes that connect the cooling pump don't transmit heat as well as the heat exchanger. During the cooling process water is run through the heat exchanger while the mixing paddle is constantly stirring the wort to cool it as quickly as possible. More on the cooling procedure can be found in the section on cooling. Once the wort is cooled to the proper temperature it will then be transferred to the fermenting container via the same pump that provided the initial water and performed the circulation cycle in the mash kettle. This is done through a series of solenoids and check valves.

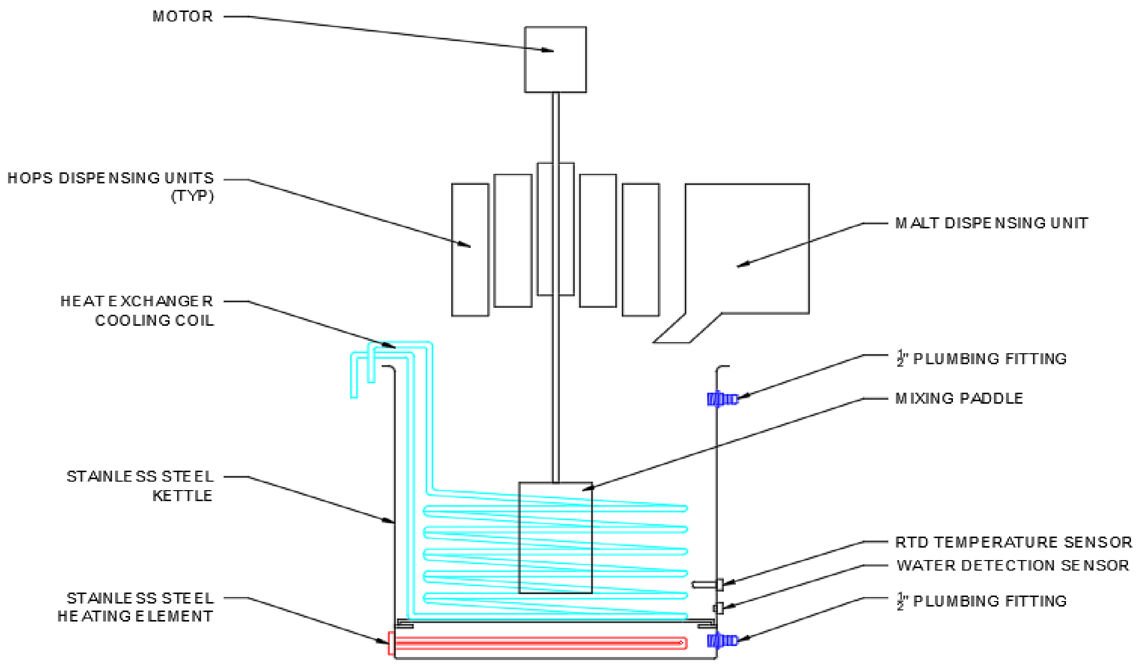


Figure 27: Boil Kettle Diagram

3.4. Fermenter

The fermentation of the beer brewing process is probably the most important part. This process is also the step which takes the longest amount of time. It can take anywhere between 8 days to 2 months to complete depending on the recipe used. This step includes having a sealed container, so no toxins or bacteria enter the container, using the proper yeast that is required in the formula, adding dry hops at the specific time required if needed, and most importantly, maintaining a certain temperature required by the recipe. Before the fermenting process, yeast is added to the final wort before being sealed and stored at a certain temperature. For example, the temperature required to ferment for an Ale is 68 degrees and for a lager it's 48 degrees. After this, the fermentation process can begin so the yeast can convert the sugars produced from the malt and grains into ethyl alcohol and carbon dioxide gas to give the beer its alcohol content and some carbonation. During this process, a one-way air valve must be present on the container to let excess air escape without introducing new oxygen into the container.

After the boiling process, the wort needs to be cooled down as rapidly as possible to minimize the amount of time left in the open boiling kettle to prevent contaminants from entering the system. the cooling process will be discussed in the chiller section. From there, the wort will be pumped into the fermenting kettle. The transfer unit from the boiling kettle to the fermenter consists of hoses and quick disconnect fittings that are easy to remove for cleaning between batches. It is imperative that the wort is cooled to 68 degrees before the yeast is pitched. This will prevent yeast cells within the yeast from dying so that the batch is not wasted. If yeast is pitched at above 75 degrees, this could result in spoiled beer or beer with very little alcohol content. After the wort is cooled to the correct temperature and transferred to the fermenter, water is added to the fermenter to get to the proper level and the yeast can be pitched and the fermenting process can begin.

The fermenting unit is able to maintain different temperature ranges as discussed previously. This is partly needed to be done because living in certain climates it is possible for the temperatures to be very hot and the AC in the house might be set to 75 degrees Fahrenheit which is not enough. It is also required because some recipes, as mentioned above, require the temperature to be as low as 40-degreese Fahrenheit. In order to keep these temperatures in the fermenting container between 40- and 75-degrees Fahrenheit, two ways were considered. The first was to have a wine cooling unit that can be set to these specific temperatures by the user input and controlled by the MCU. Wine coolers can range at these temperatures from the factory and would be easy to control and keep idle at a certain temperature for a long amount of time. The second way to keep the fermenting container at an ideal temperature for an extended period of time would be using a refrigerator that has a temperature sensor inside which monitors the temperature constantly. The refrigerator will be controlled by the MCU which sends a voltage to a contactor constantly tuning the unit on and off depending on the temperature range input to the user input. This would have to be done because the temperature of a standard refrigerator only ranges from 35 to 45 degrees making it impossible to reach recipe conditions that require 65 to 75 degrees. The chosen method was the refrigerator, due to the cost effectiveness, as it was provided by a team member.

The refrigerator was then modified for the input hose to allow for the input from the water system, which is needed to top the wort off to the desired 5 gallons needed to ferment properly. The temperature probe cable was also added into the refrigerator and mounted to maintain the proper temperature of the environment. The input from the transfer unit was incorporated in the cooling unit as well. This was added so the user can remove any components once the fermentation process begins and clean the equipment, so it is ready for the next use. During modification of the refrigerator, sealing was added around the hoses and wires, so the cool air inside does not escape from the unit.

The fermenting container has a sealed lid that can be removed for cleaning when the batch is bottled or kegged. It also has a spout connected to it that is an inch up for the bottling or kegging process. The reason the spout is an inch up is after the fermentation is complete, sediment will be present in the bottom of the container which should not be added to the final product. There is also a container attached on the outside lid that has a manual valve for the yeast, dry hops, and any extra ingredients that need to be added during the fermentation process. The extra ingredients have to be added manually due to their unknown nature and/or requirements for storage. The yeast is the last step before fermentation begins and if dry hopping is required, this usually happens days into the process and the hops must be opened and used at the same time. A notification will be sent to the user via email when the dry hops should be added. The user then simply opens up the small container on the lid, put the hops in, and closes the container. This can be done multiple times and prevent a lot of air being introduced into the system. The lid will also have a one-way valve on top to allow carbon dioxide to escape and not allow any air to be introduced. Below is a parts list and a diagram of how this will look and operate in the system. Figure 28 below shows how the fermenting pot will sit inside the mini refrigerator and how all the components will attach to the refrigerator and pot.

Parts needed for the fermenting unit

- Mini refrigerator
- Contactor for refrigerator
- One-way valve
- 7-gallon kettle with sealable lid
- Container for yeast and hops
- Manual valve for container
- Input disconnect from transfer unit
- Spout for bottling or kegging
- Temperature probe
- Rubber seals
- Food quality hoses
- Quick disconnects for hoses

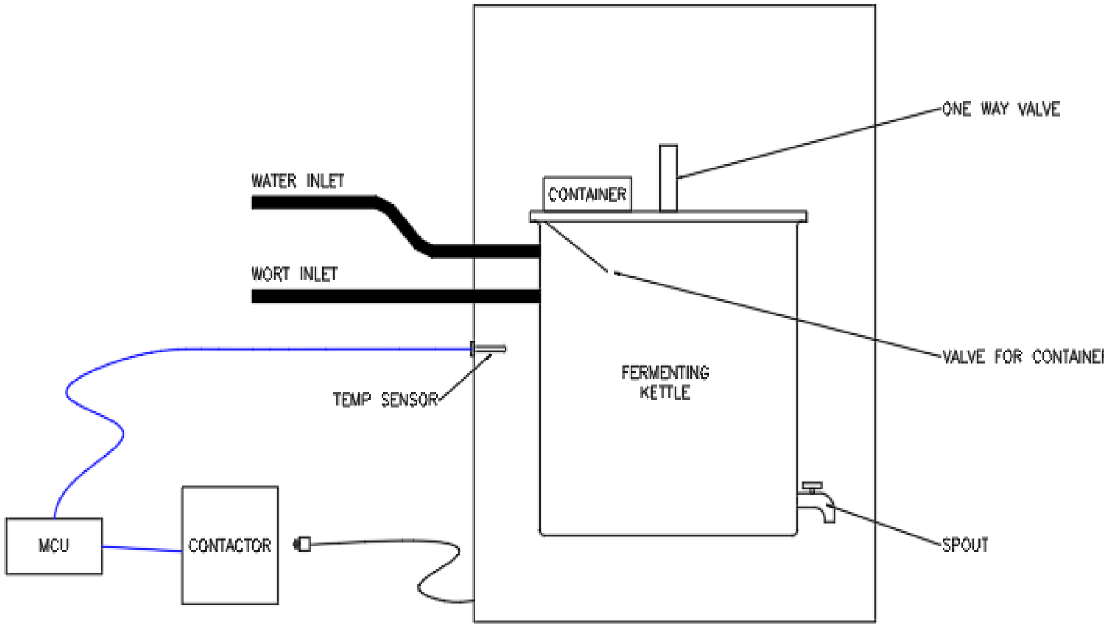


Figure 28: Fermenting Unit.

3.4.1. Fermenting Parts

Figure 29 A) shows the mini refrigerator that is large enough to hold a 7-gallon fermenting pot. This refrigerator will be used for the fermentation process as discussed in the fermentation unit section. This component will not cost anything and is already available for use. The refrigerator chosen for use is in the figure mentioned above. The inside dimensions are 17” wide by 17” long by 20” high and can support a fermenting pot that fall under those specifications. There is also an 8” high space that can be modified in the future if desired by the user. The outer dimensions are 21” wide by 21” long by 33” high. The voltage is 115 rated at 1.45 amps and runs at a 60 hertz frequency which is good for the fermenting process. The cooling range of this refrigerator is 20 – 40 degrees Fahrenheit and by controlling this with a contactor and a temperature sensor, the range can easily achieve 40 – 70 degrees F which is where all different recipes need to be. This will support different recipes such as a lager which needs to be fermented at 40 degrees or an ale which ranges from 65 – 70 degrees Fahrenheit. This refrigerator has also be modified to support the transfer hose and the temperature sensor.

Figure 29 B) above shows the fermenting pot that is inside the refrigerator. The fermenting pot used for this project is sealable, easily modifiable, and fits in the refrigerator so the internal temperature can be controlled. This pot has a hole on top for the airlock and a sealed container to pour in the yeast, dry hops, and any special flavor. There is also a quick disconnect for the transfer from the boiling pot and to fill the fermenter up to 5 gallons with fresh water and a spout mounted 1” up from the bottom for bottling or kegging. Since the system only supports 5-gallon brews, the pot is only 7 gallons to support any sediment rise during the process. A good fermenting pot was found on Amazon that met all the criteria needed for this process. the 7-gallon pot diameter is 12” and the height is 16”. It comes with a predrilled hole that's 1.75" on top for the airlock and will fit a #10 stopper to mount the airlock. The price is $123.12. This pot was easily modifiable and came with a stopper and an airlock. The lid is sealed and easy to remove with quick release clips.

Figure 29 C) is a picture of the stopper and Figure 29 D) is a picture of the airlock needed to fit inside the refrigerator. The airlock provided made the total height 20" which is the same size as the refrigerator inside height so other stoppers and airlocks were required to be ordered in order to fit. The stopper and airlocks were also found on Amazon and were relatively inexpensive. The stopper is #10 and the price is $6.71 each. The height of the stopper is 1" in which half will be in the fermenting pot. Small airlocks were found that were only 1" high and support the fermentation process. These airlocks come in packs of 3 and are $7.03 for the pack. This put the total height at a maximum of 18" which leaves 2" leftover in the height and fit perfectly in the refrigerator. The airlocks and stoppers can be reused and replaced when needed. Both are easy to clean and sanitize after each use.

Figure 29: A) Mini refrigerator B) 7-gallon sealable pot C) Stopper for lid D) Airlock (Courtesy of Group 4)

The quick disconnects were discussed in the part for the water system section and can be mounted on the fermenting pot exactly like the steeping and boiling kettles. To dispense the yeast and dry hops into the fermenter, an easy to access port was created on the lid to allow something to be added without taking the lid off and minimizing the amount of air introduced to the fermenting process. This was accomplished with a polypropylene can and a groove male fitting with a cap. These parts are both 2" to allow plenty of space to dispense the yeast, hops, or other special ingredients. Figure 30 A) show the 2" tube for dispensing the dry hops and Figure 30 B) shows the cap that seals this tube during the fermenting process. The male fitting and cap were found on Amazon and are both 2" in diameter. The cap is $16.39 and the male fitting is $9.49. Both parts together can withstand a pressure of up to 125 PSI which is adequate for the fermenting pot. The air valve will let air escape but not let air in and these fittings are sealed which will not let any air in also. To mount to the lid, an O-ring and jam nut were needed.

Figure 30 C) is the spigot needed to dispense the final product. The fermenting pot needs this spigot mounted an inch up from the bottom so that the sediment that builds up during the fermentation process will not get dispensed into bottles or a keg. One was found on Amazon for $13.55 which comes with all of the washers and jam nut and supports an opening of 5/8”. The flow from a 5/8” opening is large enough to quickly dispense the product. The spigot is stainless steel, easy to remove for cleaning, and was easy to attach to the fermenting pot. It was mounted on the front bottom of the fermenting pot and did not impact the pot fitting in the refrigerator.

Figure 30: A) 2" tube for dry hops B) 2" cap for tube C) Spigot to dispense final product (Courtesy of Group 4)

3.5. Process Control

In order for the system to be automated, there has to be logic to determine what steps occur next and what decisions to make. To design this logic, a batch of beer was brewed by the team and the steps of the process were noted, as well as the variables and sensors that were checked. Below, in Figure 31: Overview Flow Diagram, the brewing process was split into 7 phases, the User Phase, the Recipe Phase, the Grain Phase, the Malt Phase, the Hops Phase, the Cooling Phase, and the Fermenting Phase.

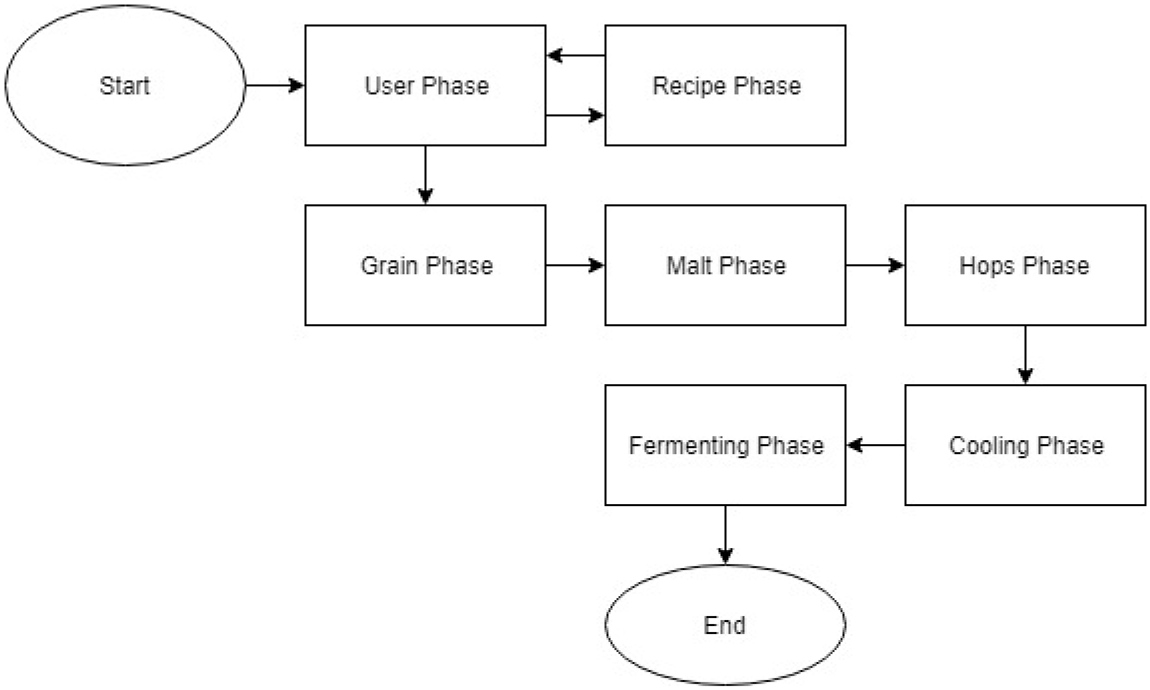


Figure 31: Overview Flow Diagram

In the below Figure 32: User Phase Flow Diagram, the microcontroller checks inputs from the user. First, it will ask the user if they would like to manage recipes, if the user selects yes, they go to the Recipe Phase, as seen in Figure 33, otherwise, it brings up a menu to select a recipe. Once the user selects a recipe, it displays the required ingredients, and asks if the ingredients are loaded, and waits until the user has loaded all required ingredients before moving onto the mashing phase. This is the last phase, as seen in the below Figure 38: Fermentation Phase Flow Diagram, that the user will be required to interact with the machine.

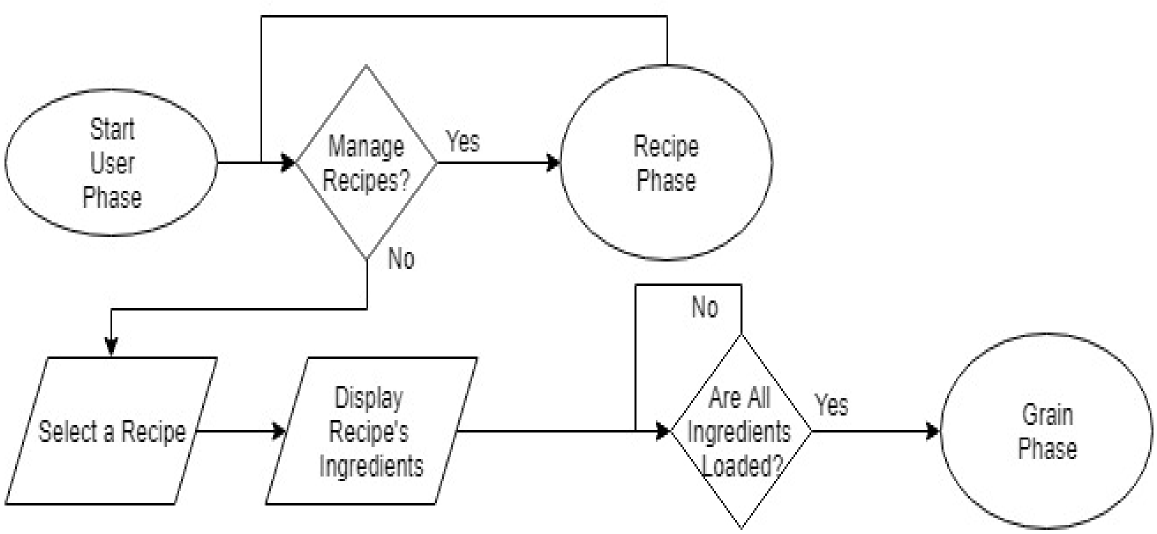


Figure 32: User Phase Flow Diagram

In the Recipe Phase, below in Figure 33 the user can choose to either view recipes, modify recipes, add recipes, delete recipes, or move back to the User Phase, above in Figure 32. This is where the microcontroller will access its main memory to store or modify existing data regarding the recipes and their ingredients.

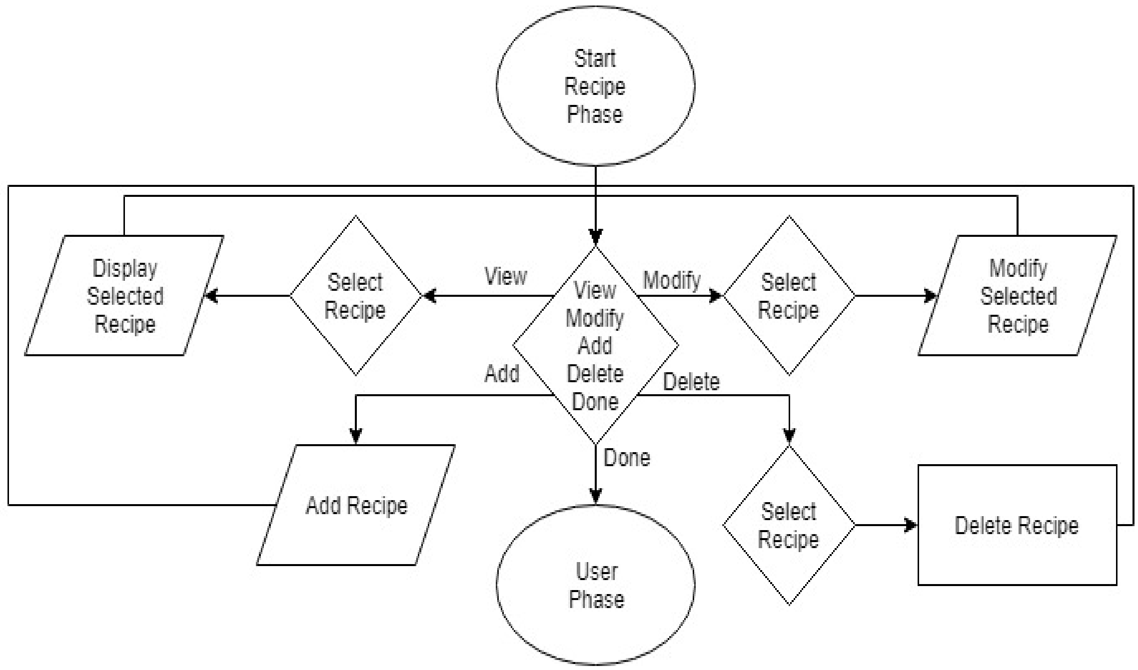


Figure 33: Recipe Phase Flow Diagram

In the Grain Phase, as seen below in Figure 34, the system will start adding the water to the first container. At this point, the user will have already added the ingredients to the first container as part of the initial setup. After adding the water and ensuring the container is full, it turns off the pump and adjusts the appropriate valves. Next, it turns on the water heater and changes the required valves before reactivating the water pump and starting the timer. During the timer duration, the system will be continually checking the water temperature to ensure that it stays within the bounds as set by the user, turning the heater off once the water reaches a high enough temperature, and reactivating the heater once the water cools down too much. After the required time has finished and the timer has been triggered, the system will turn off the heater, turn off the pump, and activate the gravity feed to move the liquid from the first container into the next container, which then transitions the system into the Malt Phase, as seen below in Figure 35.

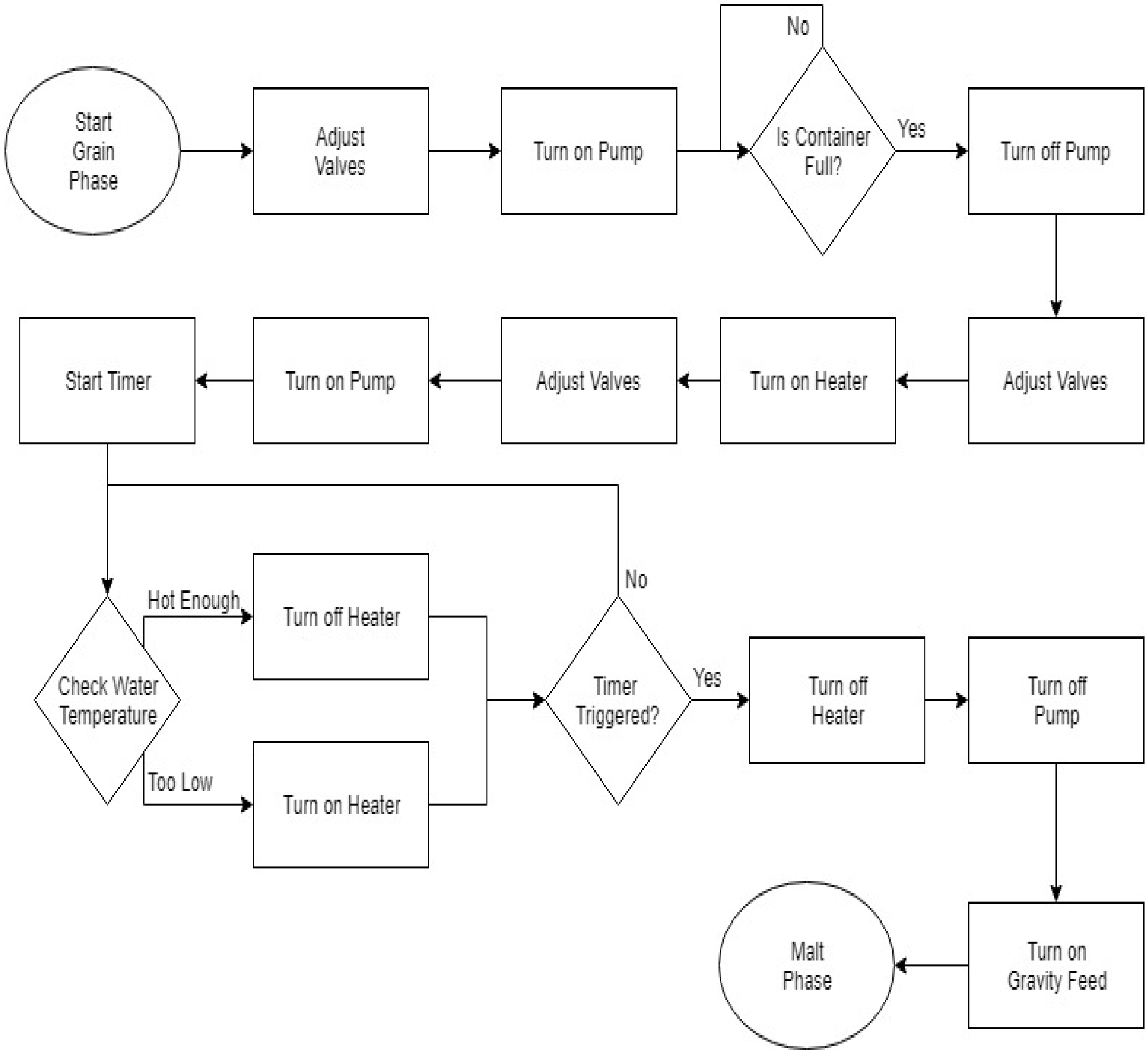


Figure 34: Grain Phase Flow Diagram

The Malt Phase, in Figure 35 below, starts by ensuring the water level is correct by checking the inputs of the water sensor. Next, it heats communicates with the heater and mixer to turn them both on. It then starts a loop of checking the temperature sensor until the water is at the correct heat, before turning off the heater and starting the timer. It then enters a continuous loop to check the water temperature, adjusting to make sure it stays within the required bounds, and the timer, ensuring all ingredients are added at the correct time. Once the timer expires, it moves into the Hops Phase, as seen in Figure 36 below.

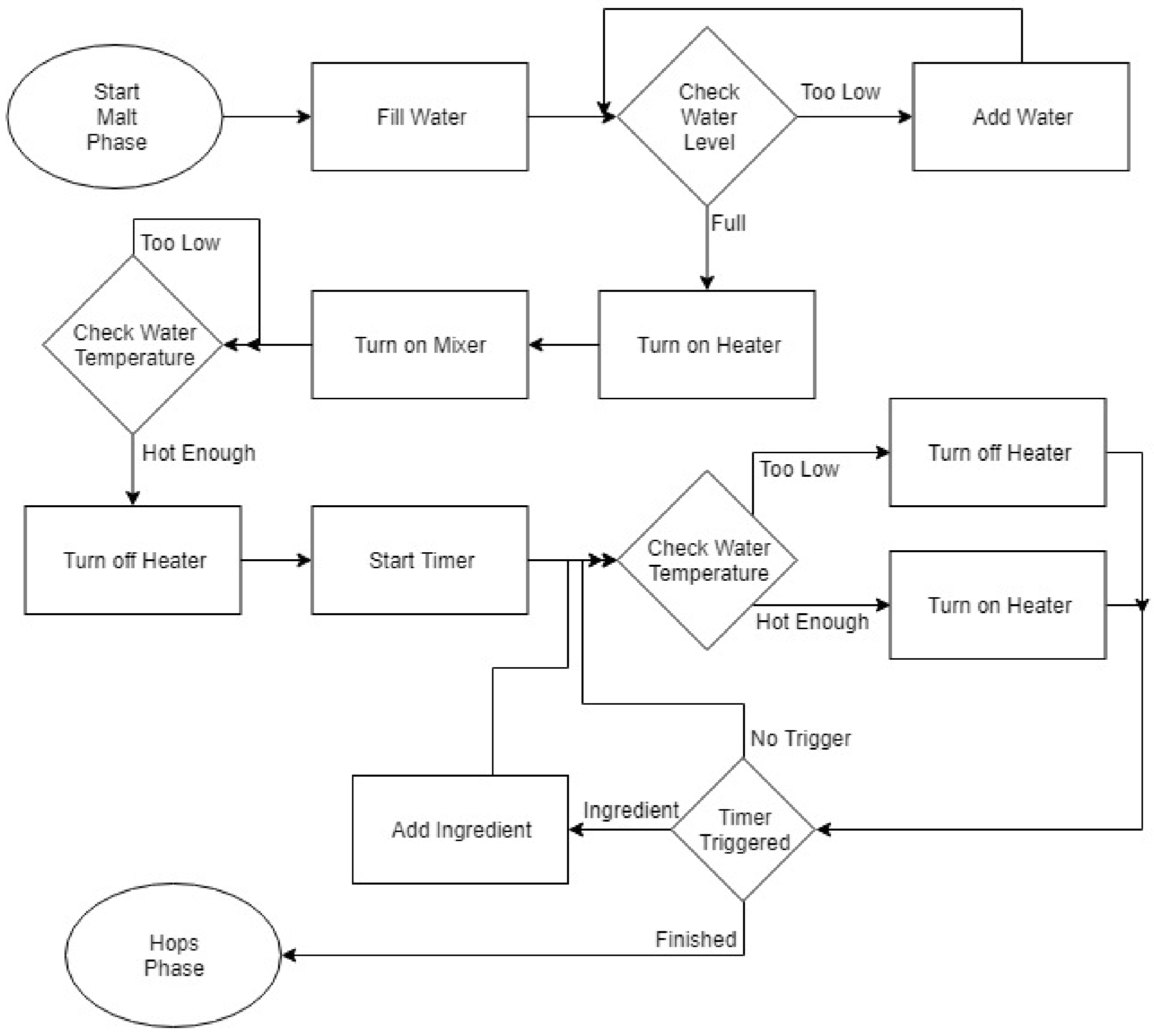


Figure 35: Malt Phase Flow Diagram

In the Hops Phase, Figure 36 below, the brewing system turns on the heater and then waits until the water is boiling before starting a timing. It then checks the timer until it is either time to add an ingredient or the timer expires. During this time, the heater and mixer stay continuously on. Once the timer expires, it turns off the heater and enters the Cooling Phase, as seen in Figure 37.

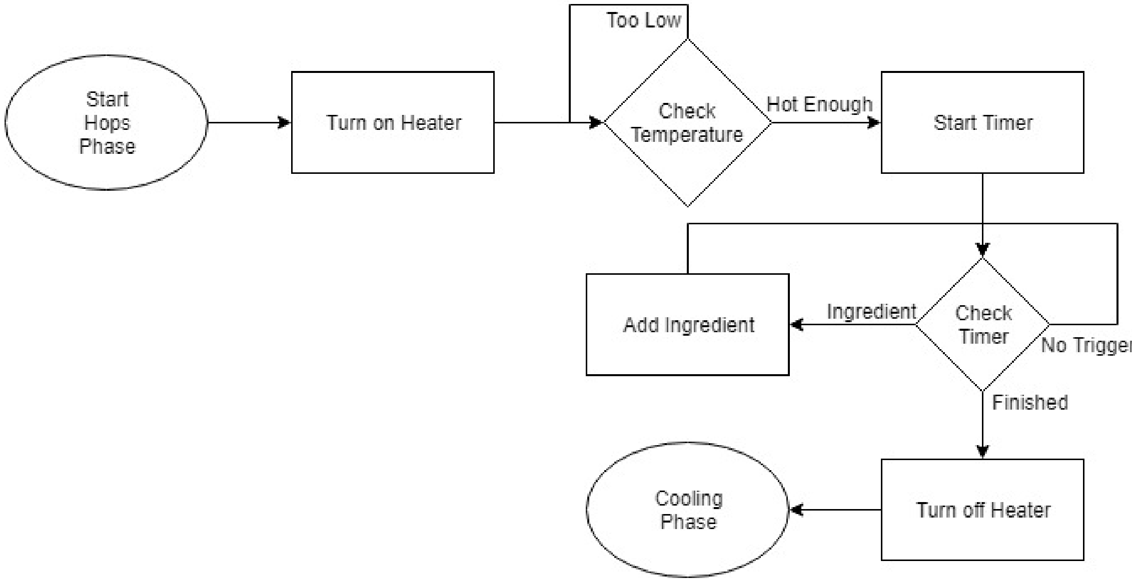


Figure 36: Hops Phase Flow Diagram

The Cooling Phase, Figure 37 below, leaves the mixer on and turns on the cooling pump, which flows cool water through a metal pipe to lower the temperature of the water. The microcontroller communicates with the temperature sensor until the water is at a cool enough temperature for the yeast. Once this point is reached, the system turns off the mixer and cooling pump, turns on the transition pump, and moves to the Fermentation Phase, as seen below in Figure 38.

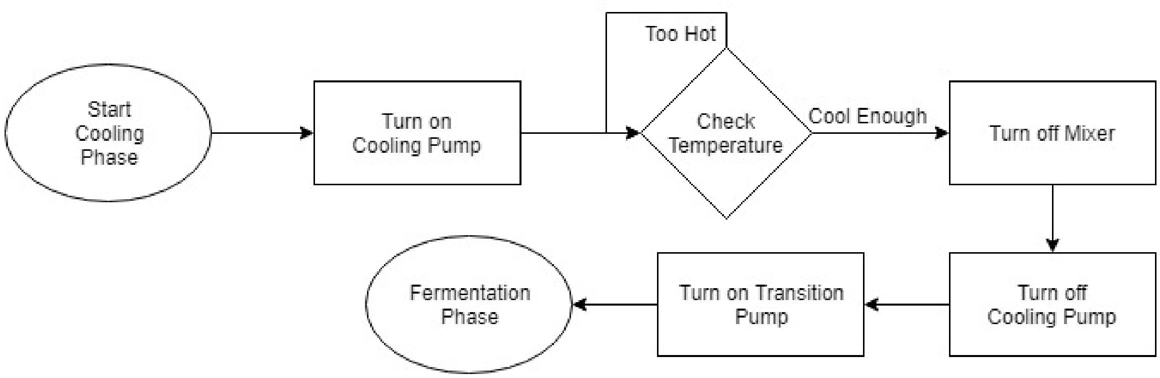


Figure 37: Cooling Phase Flow Diagram

The Fermentation Phase, Figure 38 below, is the longest of all the phases, and the last phase to communicate with the user. It starts off by reading the input from the water level sensors, if they are too low, it turns on a water pump and begins filling the container until the water level sensor reads an appropriate input. It then turns off the water pump and activates the water aerator for a brief period of time before starting a timer. This timer will check for either when an ingredient needs to be added, or when the brew is finished fermenting. In both cases, it will initiate the communication protocol with the user to inform them that a special extra ingredient needs to be added, which is manually done by the user, or that the brewing process is completed, in which case the user manually stores the brew in their desired container.

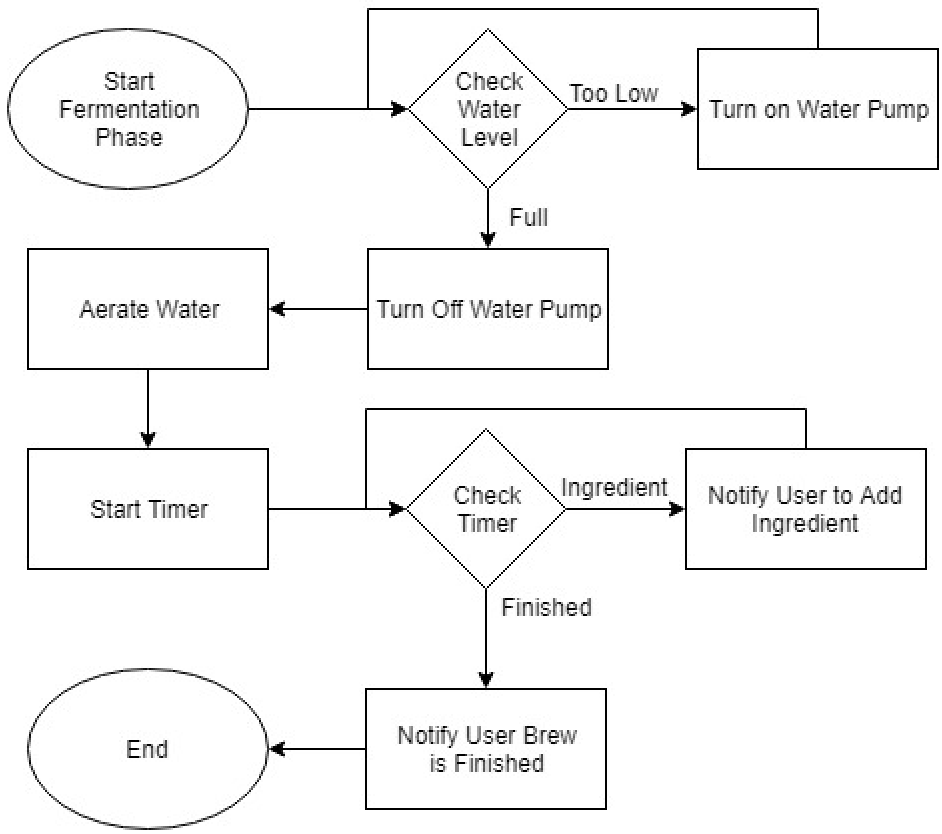


Figure 38: Fermentation Phase Flow Diagram

3.6. Temperature Control

3.6.1. Heating

Heating is important for two stages in the brewing process: the mash and wort production. The automated controls of the Keur-Keg begin the heating process after the mash container fills with the initial water. Once the flow meter signals to the MCU that the initial amount of water has been filled to the proper level, the MCU sends a signal to the relay controlling the submerged heating element to begin heating and the relay controlling the mixing motor to begin stirring the water. The mixing of the water helps evenly distribute the heated water throughout allowing for faster overall heating. During this time, the temperature sensor continuously measures the temperature of the water in the mash kettle. Once the temperature sensors send the data that the water has reached the user defined mash temperature, then the MCU sends a signal to the dispenser to dispense the grains to begin the mash production. The temperature sensor keeps measuring the mash temperature to ensure proper mash temperature. The MCU then sends the on or off signal to the relay controlling the heating element as needed to maintain the user defined mash temperature. After the mash has steeped for a user defined amount of time, the MCU sends the signal to transfer the mash to the wort kettle. Once the wort kettle is filled, then the MCU sends a signal to the relay controlling the second heating element to turn on to heat the wort up to a rolling boil at 212ºF or 100ºC. As in the previous mash stage, the MCU receives temperature date from the temperature sensors and regulates the wort's temperature accordingly. A timer runs during this process for the MCU to send signals to dispense malt extract, hops, and other ingredients at the user defined times and to allow the boil to occur for the user defined amount of time. After the wort has boiled for the required time, the MCU sends the off signal to the relay for the heating element and the cooling controls begin. The heating element is the DERNORD 120V 1650W foldback water heater element screw-in lime life heating element with low watt density with part number DERNORD-13, found on Amazon for $21.99.

There are a few ways that were considered for connecting the heater in a way that will allow the heater to remain with the kettle for cleaning but allow the heater and element to be removed from the stand disconnecting it from the wiring harness. Regardless of the method chosen, the heater would have to have a box built around the element to conceal and protect the high voltage terminals. This box was custom made and welded to the kettle with the heater element in the center of it. It has an access cover for servicing and is gasketed to keep any boil over from entering the box.

One method would be to use a sealed 20amp power inlet and then use an IEC plug connected to the wiring harness that would plug into the kettle. Using this method, the plug would actually stay with the wiring harness and would simply plug directly into the kettle. When removing the kettle for servicing or cleaning there would not be any wire tripping you up while cleaning the equipment. While this was the preferred method, finding a power inlet with a temperature rating high enough to handle the heat coming from the boiling kettle posed the problem.

The second idea, which was the idea that was implemented, was to simply have a 20-amp molded power cord leave the kettle box via a squeeze tight connector. The end of the power cord has a Nema 5-20P plug that connects directly to a 20-amp outlet located in the side of the control panel. This outlet is controlled with relays that are controlled by the controller. When removing the kettle from the stand the user simply unplugs the heater and the cord remains with the kettle.

While this proves to be somewhat inconvenient when cleaning, option two proved to be the better solution, and can be seen below in Figure 39.

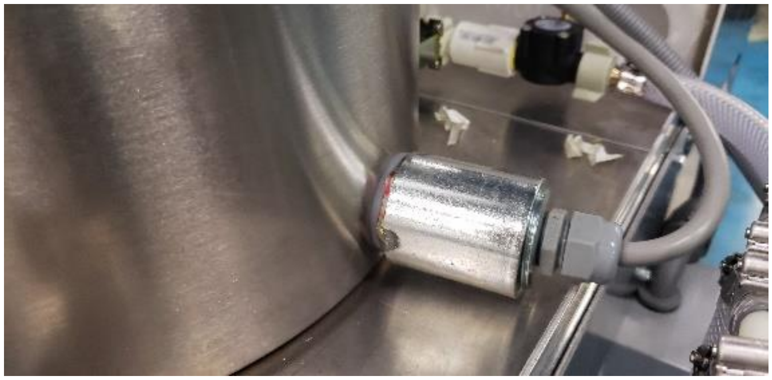


Figure 39: Power Inlet for the Electric Heater (Courtesy of Group 4)

3.6.2. Cooling

Once the wort has boiled for its intended duration it is time to start the cooling process. The automated system continues by starting the cooling process. The cooling process begins by removing the signal commanding the relay on for the heating element. With the heating element off, the circulation pump turns on and start circulating icy water through the immersed heat exchanger coil. Throughout this process the mixer continually circulates the water maximizing the exposure of the wort to the cold cooling coils. A temperature probe continually monitors the wort so that when it reaches the ideal temperature of 70^{o}F, or about 21.1 ^{o}C, the circulation pump and mixer are commanded off.

After all research was completed it was decided to go with an immersion style wort chiller. These are typically bought as a package that come pre-bent with a diameter of 9”. Most of the immersive style wort chillers come with connections on the end to hook directly to your garden hose. As described in the research, many home brewers connect one end to a garden hose and the other end is left to drain wherever you choose. This method causes more waist than necessary. The designed wort chiller is connected to a pump and recirculates ice water through the wort chiller. This will not only help reduce the amount of water needed but will also cool the wort much faster than simply using tap water. Upon testing, it was found that this style of cooling can cool the wort from boiling to 75^{o}F in 5 minutes. Once the decision to use the immersion style wort chiller was made, a search was made for a style that would fit tighter around are boil kettle so that as much room as possible could be kept to give the mixer and dispensing units as much room as possible. Unfortunately, there were not many companies that created the wort chiller in a diameter larger than 9”. Although there were a few companies that did create larger diameter immersion wort chillers, they were far and few between and came with a price at double the normal 9” diameter chiller. This in conjunction with the fact that most wort chillers come with garden hose fittings the decision was made to design and build a custom wort chiller in house. After some research it was determined that soft drawn 3/8” copper would make a good start to building a immersion style wort chiller. Using 25’ of soft drawn copper, coils were tightly wrapped around a bucket with a diameter required for the boiling kettle. Special care was taken when bringing the return end of the chiller back to the top of the kettle and bending the copper so that it can return up the coils and turn outside of the kettle. The same care was also taken when turning the inlet side of the wort chiller outside the kettle. By building a custom wort chiller, it was easy to dictate the diameter and the plumbing fittings connecting the wort chiller to the plumbing for the pump. At this point the decision was made to get more technical and add the ½” NPT fittings so that it is easy to remove and clean.

3.7. Sensor Connectors

In order to make the sensors easily serviceable or replaceable, Molex connectors were installed on each sensing device. This the sensor to be easily removed when in need of repair or replacement. This also allows the kettle or fermenter to be removed from its wiring so that it can be removed from the stand for cleaning and servicing. The Molex connectors are two and three pin connectors that simply plug together connecting the senor to the wiring harness.

3.8. Control Cabinet

The control cabinet in this project contains all of the electrical control systems such as contactors, relays, transformers, power supplies, the MCU, terminal strips, DC converters, and every other components needed to make every individual system operate keeping all the electrical components out of the elements. This is a standard electrical box with rails for mounting the components and cable trays to make the routing of the wires clean inside. The power supply box consists of any input and output openings for the cables going to the specific component. These openings have rubber around them to prevent any chafing with the box and are not too big so excess dust and moisture cannot enter the box. The input to the power supply is a standard 120-volt, 20 AMP outlet from any house or building. Proper cable gauge has been used for each component in order for proper insulation of the cable. The power supply box also has a cooling fan mounted to remove the heat from the electrical components when operating and openings to allow air inside the box. These openings have dust vents to protect all the electrical components from dust and moisture.

The 120-volt input is used to power the main components that require the most amperage to keep the power output lowest. This voltage supplies the heating elements, the water supply pump, the transfer pump, the chiller pump, and the mixer motor. This supply also is connected to a transformer which steps the voltage down and converts the 120-VAC to 24 VDC. This voltage is needed to power the smaller components such as the relays that control the valves for the drain, dispensing unit, MCU, and fans. Due to the parts chosen, other DC to DC converters are used to achieve 12 VDC for items such as the linear actuator. Most everything in this project is controlled by either a 12 or 24 VDC relay or contactor.

These components are either on or off. Other components like the motor for the mixer, temperature sensors, the flow meter, and fluid level sensors are used as inputs and use either current or voltage to detect the signal. The following table, Table 21: Electrical components showing voltages and operating current, was created below to help distinguish the voltages required by the different parts used throughout the product.

Table 21: Electrical components showing voltages and operating current

Component	Type	Supply Voltage	Coil Voltage	Supply Current	Coil Current
Fluid Transfer System					
Water pump	Relay	120 VAC	5 VDC	900 mA	50 mA
Solenoids (x 6)	Relay	12 VDC	5 VDC	50 mA (ea)	50 mA
Float switch	Input				
Flow meter	Input				
Heating, Cooling, and Mixing					
Temp sensor (x 2)	Input				
Heating element (x 2)	Relay	120 VAC	5 VDC	15 A (ea)	100 mA
Cooling pump	Relay	120 VAC	5 VDC	900 mA	50 mA
Mixing motor	Relay				
Fermenting Unit					
Refrigerator	Relay	120 VAC	5 VDC	1.5 A	50 mA
Temp sensor	Input		24 VDC		
Dispensing Units (Malt and Hops)					
Actuator 2” (x 4)	Relay	12 VDC	5 VDC	3 A (ea)	50 mA
Actuator 10”	Relay	12 VDC	5 VDC	3 A	50 mA
Solenoid	Relay	12 VDC	5 VDC	50 mA	50 mA
Temp sensor 3	Input	12-24 VDC		4-20 mA	
Fan for PS	Relay	12 VDC	5 VDC	300 mA	50 mA

The control cabinet chosen for this project is a 18”x18”x6” NEMA 1 junction box with a hinged lid, as seen below in Figure 40. Although a NEMA 4 sealed boxed would be preferred as it does not come with concentric knockouts located around the panel and has a gasket cover that would help in keeping out any accidental liquid the NEMA one box chosen is suitable for the project’s needs. The cost of a NEMA 1 control panel is about one third the cost of a NEMA 4 control cabinet. The hinged cover makes it easy to open and access the internal components. This proved to be extremely helpful in the trouble shooting stage when the screen and touch pad were located on the front cover. This particular control box does not come with a back plate, but one was made with a piece of piece of aluminum flat plate and some threaded rod couplings by simply sticking short bolts through the back of the panel and using the threaded rod couplings as the fastening nuts. Studs were used that have lock tight applied to them to keep the backplate assembly from coming loose. The back plate then attached by installing the back plate and using washers and nuts to secure the backplate. The back plate is necessary due to the quantity of components that will be mounted inside using self-drilling screws, riv-nuts, and tapping the metal back plate to install the different components. Using the back plate keeps all of these fasteners from sticking out the back of the control panel providing a cleaner look and safer install.

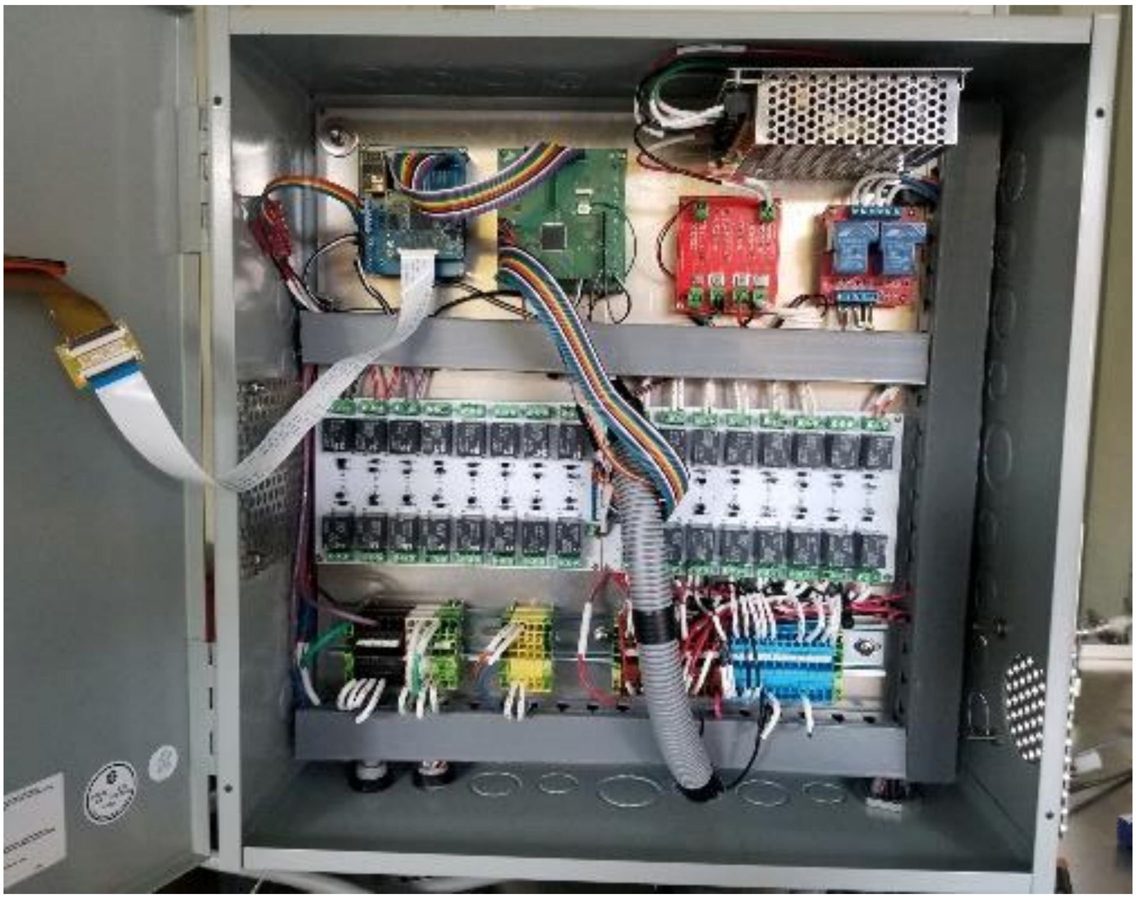


Figure 40: Control Cabinet

3.8.1. Control Cabinet Organization

In order to keep the control cabinet neat and organized a slotted track is used. Slotted tracks are available from a number of manufactures in a variety of sizes ranging in body size from 1" x 1" to 12" x 12". For this project, a 1 ½" slotted track was used. This slotted track was fastened with 3m double sided tape. Where wires were needed to be extended or made serviceable from the controller, a terminal block was used. The Wago brand terminal blocks, as shown below in Figure 41 A), allowed a connection to all of the incoming and outgoing wires into the control cabinet without using irreversible splices or unsightly wire nuts. The terminal blocks are din mounted for a clean look that makes adding or removing blocks a relatively simple task. All terminal blocks are labeled with letters, numbers, or names that correspond with all wiring schematics. All wires that terminate at a device via a screw terminal are labeled with heat shrink labels on the wire that also list a letter, number or name that is identified on the wiring schematic. Wires that enter or leave the control cabinet are solidly connected using a nylon squeeze connector, as seen below in Figure 41 B).

When wiring a control cabinet one will have high, 120V AC, and low voltage systems coming together. Every attempt is made to separate the high voltage from all of the low voltage power and signal wires. Where AC and DC have to come together every attempt was made to keep a barrier and as much space as possible between the two different systems.

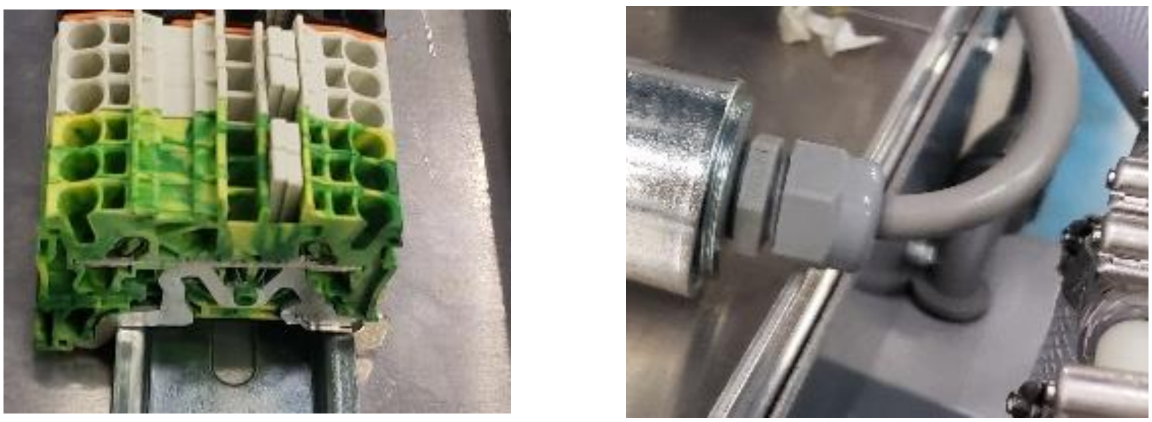


Figure 41: A) Wago Terminal Block B) Nylon Squeeze Connector (Courtesy of Group 4)

3.8.2. Bringing Power To The Control Cabinet

The control cabinet has a section dedicated to allowing the 120 volts to enter the control cabinet and have joints made via wire splices or terminal blocks. This section is separated from the remaining control cabinet via metal barriers and an access plate. Although 120 volts may have to enter other low voltage areas of the control cabinet for control, this is minimized and protected as well as possible. Power comes to the control cabinet through a molded 20-amp power cord with a inline GFCI attached. The power then enters the control cabinet on lower left side and branches out as needed from there. Circuit protection is a critical aspect in the design. By adding circuit protection of different calibers, it decreases the size of wire necessary in making the connections. One 20-amp circuit was added to the incoming power cord. Because there is no way of knowing what type of breaker the user will be plugged into, there is no guarantee coordination between the over current device and the user's branch circuit over current device. What this means is, if the system's equipment happens to become faulty and starts drawing more than the allowable 20 amps, there is no guarantee that the system's circuit breaker will trip before the end user's. This is not a huge deal due to the fact that nothing else should be plugged into the circuit that is running the Keur-Keg.

The desire is for the system's local circuit breaker to trip before the branch circuit trips. There is one 20-amp circuit breaker that feeds the entire system. It is from this point that the heaters directly get their power. The NEC says that a heater branch circuit should be sized at 125% of the rated load. So even though the 1650-watt heater draws less than 14 amps when multiplied by 1.25, the system's next available overcurrent size is 20 amps. All of the controls branch off of this 20-amp circuit and downsize to a 5-amp circuit. This allows the system to run smaller wires to the pump motor, the mixing motor and power supply that will be running the remaining equipment. In order to provide the overcurrent protection, a decision had to be made of whether to use fuses or circuit breakers. Fuses are easy to install; they could go directly into a wago fuse holder that would fit on the din rail next to the other wago terminal blocks. The downside to using fuses us if one blows, the user needs to have more on hand. For circuit breakers, there are a list to choose from that would allow a variety of different mounting styles, trip curves, and sizes. A circuit breaker that was readily available to the group was the TE circuit breaker, seen below in Figure 42. This particular circuit breaker is appealing to the group because of its size and its panel ability. More appealing than its size and its mounting style is the cost at only $7.00 each. However, due to constraints, the circuit breakers were unused.

Figure 42: Circuit Breakers (Courtesy of Group 4)

3.8.3. Electrical Components

For all electrical components such as the solenoids, linear actuators, pumps, motors, fans, and heaters to operate at specific times or conditions, switches that turn these devices on and off were required. These signals are controlled by the MCU which reads the input signals from the system, such as the float sensors, temperature sensors, and data from the user input panel. The MCU also has various timers to control any timed events in the system. The idea to accomplish this was to use relays to handle a supply current of 10 amps maximum for every circuit except the heaters which needed 20 amps maximum rating. Relays can handle different ratings for many different control applications. The focus in this case was on a coil voltage of 5 VDC that has a load rating for up to 30 VDC and

250 VAC at 10 amps. The relay or relay board is controllable by any MCU, which allows an easy connection and allowed it to not be constrained by which MCU was chosen. The MCU was designed to handle the worst-case scenario, which would be every relay on in the system. This is roughly 20 different circuits. Using a 5 VDC coil voltage, each relay draws roughly 50 mA and if all on at once the circuit total is 1 A. There are spare relays in the system in case any additions need to be made, or if any relays burn out. The maximum current the MCU needs to drive is 1.5 A.

To keep the power supply simple, parts researched for the 7 solenoids needed, as well as for the fluid and malt dispensing systems were all kept to 12 VDC with a 3-amp maximum current output. The 5 linear actuators for the dispensing units are also 12 VDC with a 3-amp maximum current output. Figure 43 was a relay board found on Amazon for $28.39 and manufactured by a company called Wal Front. This 16-channel relay module supports a high/low level trigger of 5 VDC and has a rating of up to 250 VAC at 10 amps and 30 VDC at 10 amps. It is also user interface friendly and can be used with any MCU. Having 16 channels will also allow the system to incorporate any add-ons or options due to the 4 extra relays on this board. These add-ons allow for the system to be upgradable by the user. This relay board also has a built-in finite current resistor which allows either the positive and negative pole control of the power supply to be used or the I/O port of the MCU control. It comes equipped with power indicator LEDs and relay status indicator LEDs for detection of power and relay position status. The board dimensions are 5.9 x 3.9 x 0.8 inches and it weighs 8.8 ounces.

An 8 channel relay board was also found on Amazon and manufactured by a company called Huayao. The price for a 2-pack is $13.99. This product is similar to the 16-channel relay board in the previous figure except this one has 8-channels. These relay boards still support a high/low level trigger of 5 VDC and has a rating of up to 250 VAC at 10 amps and 30 VDC at 10 amps. The board is also very user interface friendly and can be used with most any MCU. Having the 2-pack would provide the same amount as the last board while also costing less. These relays are specifically used for smart home control, PLC control, and MCU control. These relays can either support normally open or normally closed positions and have power and status indication LEDs. Putting both of the boards together yield the same dimensions as the previous board and when compared, ultimately will produce the same outcome.

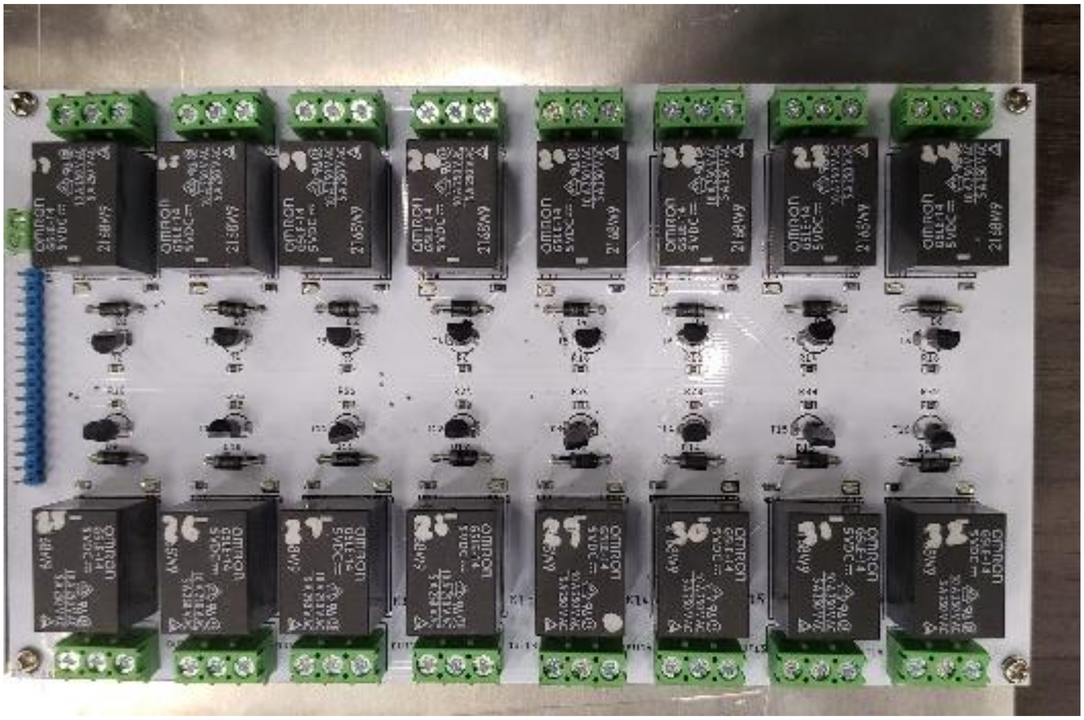


Figure 43: 16-channel, 5 VDC coil, 10 A relay board(Courtesy of Group 4)

Figure 44 A) and Figure 44 B) were 2 possible options for the heating elements. To control the two heating elements for the steeping kettle and the boiling kettle, a larger relay will be needed that supports 110 VAC at 20 amps. In this project the heating elements will draw the most current in the system and will not be able to run at the same time due to design constraints. One heating element is for the steeping pot and the other is for the boiling kettle. Figure 44 A) is a rail mounted passive 2-channel power relay board. It was found on Amazon for $28.99 and manufactured by a company called Electronics-Salon. This board consists of 2 channels for both heating elements, a 5 VDC coil voltage, and has a max rating of 250 VAC at 30 amps. A 20 amp relay would be sufficient for this except the cost was higher so the decision was made to go with 30 amp rating. The board can support a 15, 32, or 35mm rail system and its dimensions are 2 x 3.5 x 2.5 inches and weighs 6.4 ounces. This relay can also be controlled by any MCU that can switch 5 VDC on and off. Figure 44 B) is the second type of relay researched for the heating element and is a 30 amp high current contactor relay switch. Similar to the previous version, this relay is a board mounted relay, but only consists of one relay or single channel. It supports a 5 VDC coil voltage and has a max rating of 250 VAC at 30 amps. This relay is specifically made for cooling and heating control. It was found on Amazon for $8.16 and manufactured by a company called Yeeco. Ultimately, the 2-channel 30A relay board was chosen for this project.

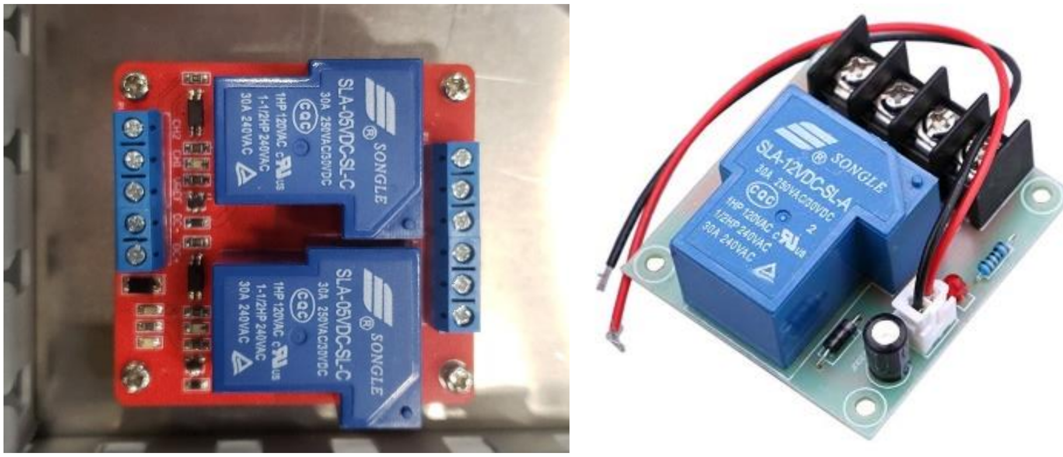


Figure 44: A) 2-channel 30A relay board (Courtesy of Group 4) B) 1-channel 30A relay board (Courtesy of Yeeco, an Amazon Seller)

Ice cube relays were also considered to control the pump for the fluid system, the pump for the cooling system, the mixing motor, and refrigerator for the fermenting unit. All systems ran on 110 VAC like the heaters but did not draw as much current. Each of these components maximum output current was below 5 amps or close so relays rated at 10 amps max that support the 110 VAC output with a 5 VDC coil voltage were used. This kept all components controlled with a 5 VDC coil voltage and satisfied the power supply requirements. A 5-pack of relays was found on Amazon for $12.69 and manufactured by a company called Houtby that was also considered. Getting the 5-pack would have provided an extra relay for either a spare or any modifications that needed to be made to the project. The relays were all rail mounted and would support a 32mm rail. The voltage specifications match as the coil voltages were 12 VDC and the contact capacity is 250 VAC at 10 amps. The action and reset times were less than 20ms, the dimensions of all 5 relays were 7.2 x 5.3 x 1.6 inches, and the weight is 10.6 ounces. A single ice cube relay found on Amazon for $8.89 each and manufactured by a company called Uxcell was also considered. The properties were the same as the 5-pack with the exception of manufacturer and cost.

For the implementation of the project, the 16-channel, 5 VDC coil, 10 A relay board was used to control everything, but the heaters. The board was designed and ordered by the group. There were several spares that were useful since some of the relays were burnt out during testing due to condensation on the board. For the heaters, the 30A 2-channel relay boards were used. For this relay board, the group decided to use them as is from the manufacturer since it is cost prohibitive to design and order it for this project.

Safety features can be optional and should be in place to shut the system down in case of an emergency and protect the high current circuits from an overcurrent. To shut all power off an emergency stop that is normally closed could have been implemented before the main breaker to ensure power is cut at the event of an emergency. If the user got a warning message or senses something out of the ordinary, they could have gone to the system and pushed the emergency stop cutting all power to the machine. An emergency stop button was found on Amazon for $10.99 and manufactured by a company called Tiass. Fuses could have also be implemented on the heating element circuits for further protection. There are many different types of fuses on the market. Open fuses or modular fuses could have been chosen, if it was decided that further protection of the system was needed. They were expensive so only 2 would have been needed. A good modular fuse holder was found on Automationdirect.com for $37.50 and manufactured by a company called Edison. It held three 30 amp fuses and was mounted with a 35mm DIN rail mount. This would have been sufficient for protecting the heating elements.

Due to cost, the emergency stop feature was removed since it was deemed that the same could be accomplished simply by unplugging the whole system from the power source. This solution was simpler and more cost effective for the user.

3.9. Power Supply

The power supply was meant to distribute power to the different components of the Keur-Keg at different voltages. The project design required the use of both AC and DC power. When designing the power supply, footprint of the parts, the cost for the bill of materials, and efficiency were kept in mind. The first step was to determine all the voltages that were necessary. Below in Table 22 is a list of the different voltages necessary and what part of Keur-Keg used that voltage.

Table 22: Power Supply Outputs

Voltage	Output Use
120 VAC	Filling/transfer pump, cooling pump, heating elements, refrigerator
12VDC	Temperature sensors, solenoids, float switch, flow meter, actuators, fans, mixing motor
5VDC	Relays, microcontroller
3.3VDC	WiFi Module

Table 22 showed the different voltages that Keur-Keg's current design required, and if it is AC or DC power. The components that required the most energy were on the 120VAC power while the rest was on a much lower voltage. The challenge for this project was that the available power was limited due to the heating elements. Due to the NEC the 1650W heating element must be rated at a 125% safety factor so it took up 2062.5W leaving 337.5 W for everything else. This meant that only one heating element can be on at a time and concurrent power usage everywhere else had to be minimized. This also meant controls had to be strategic to turn off the heating element if more power was needed than what was available with a heating element on. The power supply was kept separate from the MCU so that troubleshoot during the build process was easier.

After the voltages required were determined, then the amount of power that could be used at once was determined. In the following Table 23, the maximum power that could possibly be on at once in the worst-case scenario is shown.

Table 23: Possible Concurrent Load Combination

120VAC		
Component	**Current (A)**	**Power (W)**
Heating Element (1)	17.19	2062.5
Mixing Motor	0.15	18
Refrigerator	1.5	180
Total	18.84	2260.5
12VDC		
Component	**Current (A)**	**Power (W)**
Temperature sensors (4)	0.08	0.96
Solenoids (2)	0.1	1.2
Float Switch (1)	0.5	6
Flow Meter (1)	0.02	0.24
Actuator (1)	3	36
Fans (2)	0.6	7.2
Total	4.3	51.6
5VDC		
Component	**Current (A)**	**Power (W)**
Relays (8)	0.4	2
Microcontroller	0.02	0.1
Total	0.6	2.1

Table 23 shows all the loads that could be on concurrently at the different voltages along with the load current and power required. The table is divided into the voltages that the components require and then further divided into the components, current, and power draw that each contributes to the load. Under the components section, we state the count of how many may be on at a time and have accounted for that in the current load and power draw calculations. This table is very important for the design of the power supply to see what the maximum output current must be made available at each stage of voltage conversion and how much total power can be drawn at one point. Using WEBENCH® Power Designer, specifically the Power Architect tool, the requirements for voltages and currents at the different stages were input and the program came up with two power supply layouts. For this design the input power sources were 120VAC and with 2 loads, one at 12VDC with a current load of 5A and the other at 5VDC and a current load at 2A. The designs that WEBENCH® came up with using these inputs included a design of an AC to DC converter in which both required custom designs for a transformer. To ensure all parts be easily acquired, it was decided to modify the design by keeping the 24V to 12V DC to DC converter and 24V to 5V DC to DC converter, but instead choosing an off the shelf transformer and then adding a rectifier, filter, and finally a regulator to the WEBENCH® designs. If a part needed to be quickly replaced, waiting on a custom transformer is not feasible since it would have a much longer lead time. From the previous designs done in WEBENCH® we observed that we needed 3A at 24VDC to be able to supply enough power to the switching controller to go from 24 VDC to 12VDC and the switching voltage regulator to go from 24VDC to 5VDC. By using a prefabricated transformer in combination with a rectifier, filter and regulator we would have been be able to achieve the 24VDC power that was required. Table 24 shows the efficiency, footprint, count of parts, and the cost for the bill of materials for each regulator section that was designed in WEBENCH®. With these designs, trying to keep to less parts in addition to keeping costs at a minimum were kept in mind. By having less parts, it would have helped to avoid dealing with as many malfunctions of parts that would have been needed to be debugged. Also, this would have helped for the physical build by having less components to have to put onto the power supply PCB. From the efficiency column the average efficiency was kept above 90%. For the footprint, minimizing the area taken up on the PCB was important so that there is plenty of room to spread out on the PCB to make it easier to work with. For the BOM count, any design suggested by WEBENCH® that was more than 20 elements, waqs automatically dismissed because time was limited. If another PCB had to be ordered and required over 200 components to be soldered, there would be a high risk of running out of time.

Table 24: Efficiency of Regulator Designs

Regulators	Efficiency(%)	Footprint (mm^2)	BOM Count	BOM Cost
24VDC to 24VDC	98	546	16	$12.40
24VDC to 12VDC	96	887	18	$8.18
24VDC to 5VDC	84.8	297	16	$2.08

Figure 45 below shows the 24V DC to DC regulator, that would have regulated the unregulated DC power provided by the 120VAC to 24VAC transformer, rectifier, and filter circuit. This was to provide a constant DC power source with minimum ripple voltage for the other two switching voltage regulators.

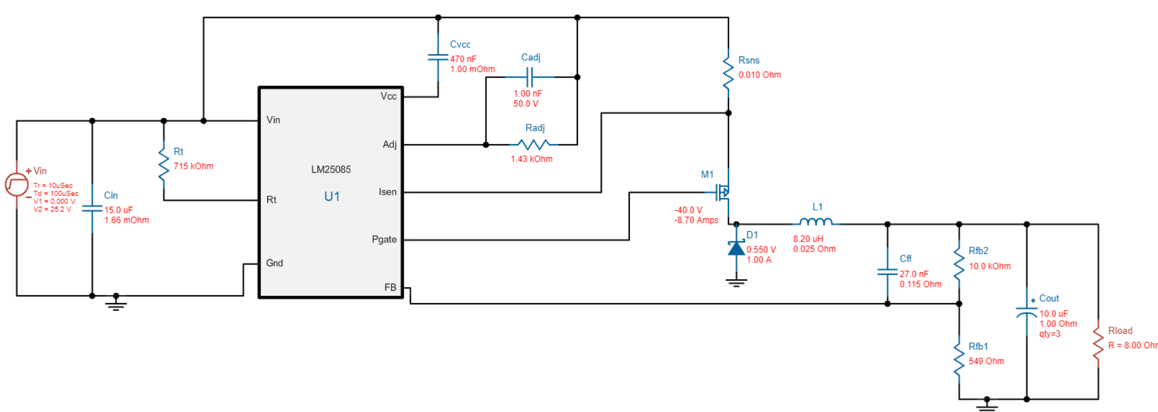


Figure 45: 24V DC to DC Regulator Schematic Design

Figure 46 below was the 24VDC to 12VDC switching regulator. Implementation would have used TI's LM 3150 IC. This section would have provided power for the temperature sensors, solenoids, switches, and fan.

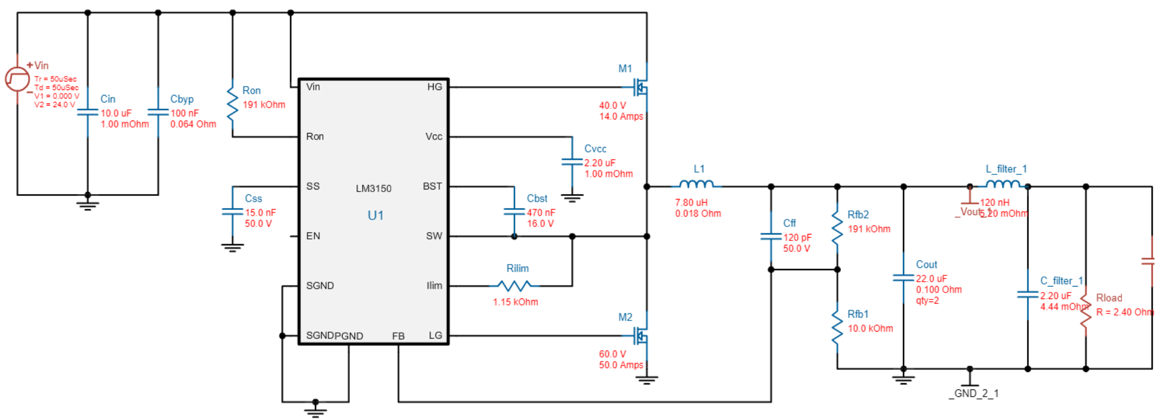


Figure 46: 24VDC to 12VDC Switching Regulator Schematic Design

Figure 47 below was the 24VDC to 5VDC switching regulator. This section would have powered the microcontroller and relays. For this design we would have used TPS54334DRC IC.

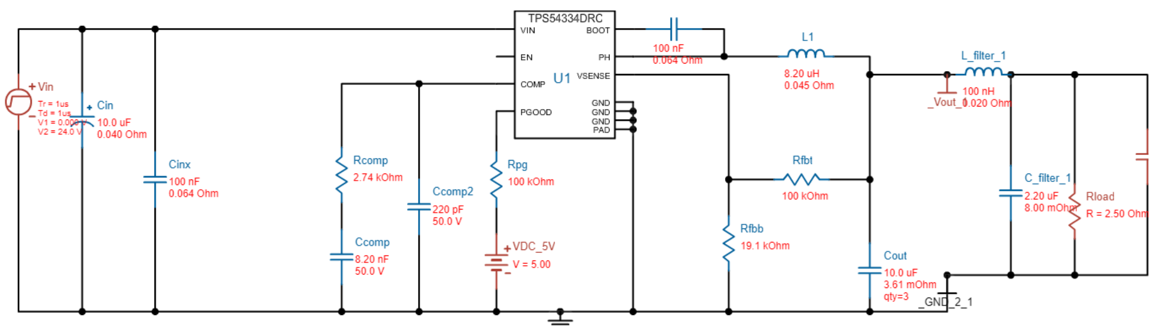


Figure 47: 24VDC to 5VDC Switching Regulator Schematic Design

For the transformer we would have used the F1-93U to go from 120VAC to 24VAC. This transformer would have allowed at least a 4A load which is more than enough for the purposes of this project. The bridge rectifier that would have been used was the Rectron BR62 since it was able to handle a maximum forward current of 6A which was more than the 3A load of the rest of the circuit.

In order to make the power supply easier to trouble shoot and more cost effective, the power supply design was redesigned at the beginning of Senior Design 2. The power distribution was changed to the following shown in the following Figure 48. For this design, the LEDMO switching converter was used to convert from 120VAC to 12VDC. This power supply was capable of producing at least 10A, which was more than enough for the purposes of this project. Then, WEBENCH® was used to design the rest of the power supply to convert from 12VDC to 5VDC and 3.3VDC.

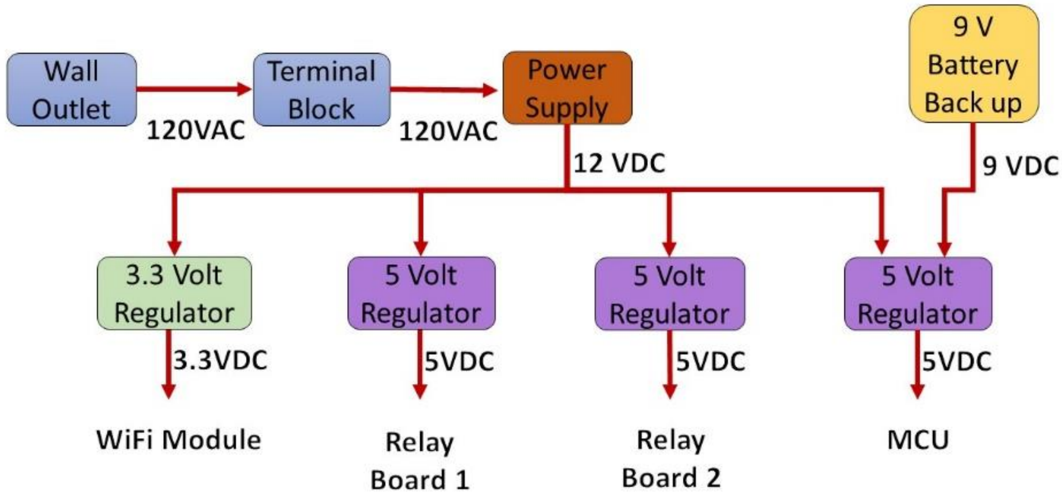


Figure 48: Power Distribution System Diagram

The full schematic of the power supply designed in WEBENCH® and modified in Eagle is shown in the following Figure 49. The top rail is the 12VDC circuit. The three circuits on the right are the 5VDC circuits and the leftmost circuit is the 3.3VDC circuit for the WIFI module spare. The second from the left circuit is the circuit that powers the MCU with a 9V battery back up system. For the 5VDC power, Texas Instrument's TPS563231DRLR synchronous step-down voltage regulator was used. For the 3.3VDC power, Texas Instrument's TPS564201DDCR synchronous step down voltage regulator was used. Through the different iterations of the design of the power supply, it was decided to separate the 5VDC power into 3 separate circuits to reduce the current going though each 5VDC circuit. By doing this, it simplified the circuit so it made the circuit easier to troubleshoot and allowed spares to be available. In addition, by separating the 5VDC loads to separate circuits, the MCU could be isolated to its own power supply circuit. By separating the MCU to its own circuit, a back up battery system was easily integrated by using 2 Schottky diodes to allow the flow of current in the intended direction of only towards the MCU. In the event of a power loss, the 9V battery automatically supplies power to the MCU

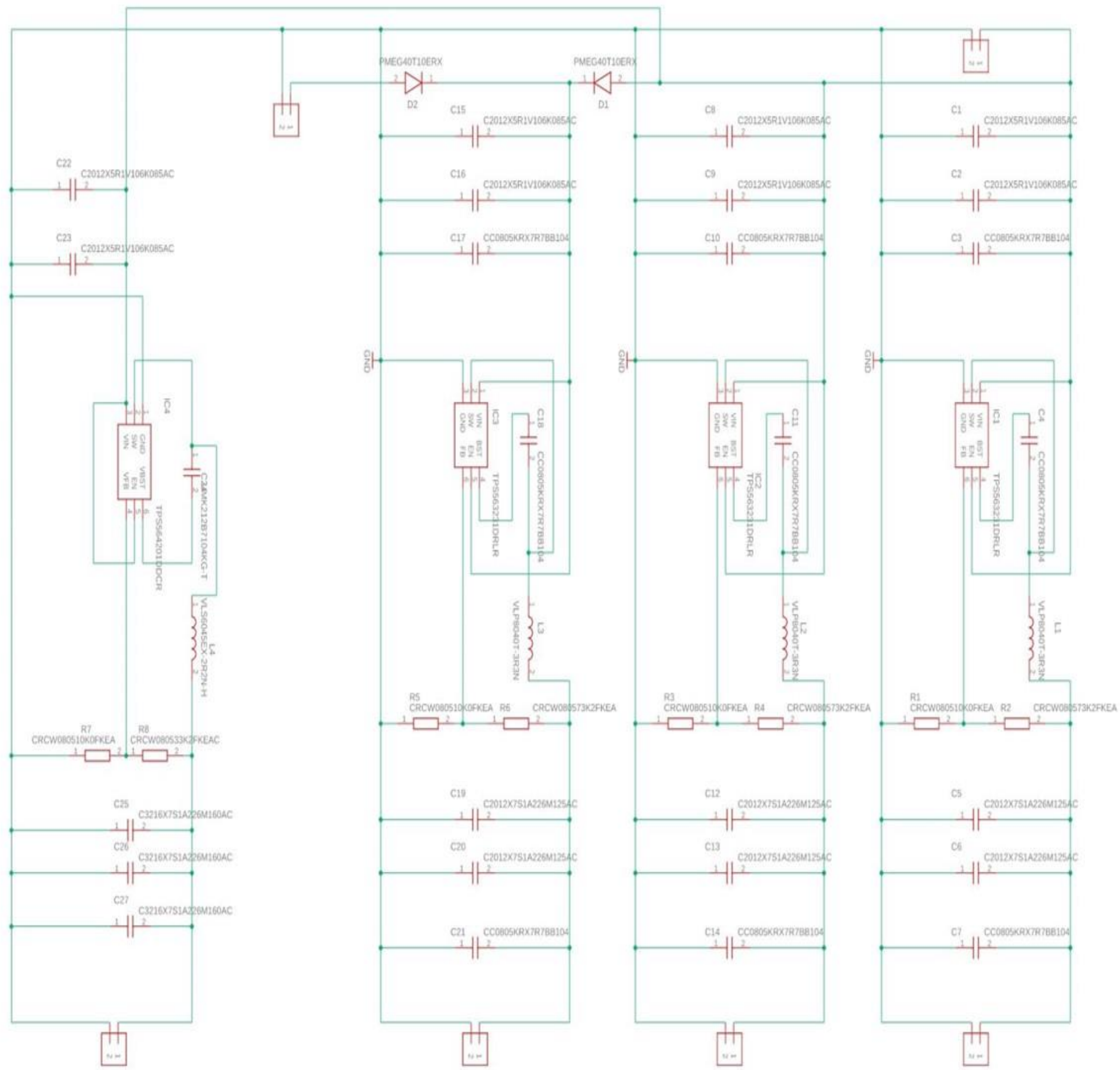


Figure 49: Power Supply Schematic Design

The Schottky diodes allow current to flow through the voltage regulator without back feeding the other power supply and possibly causing issue. The Schottky diodes chosen were the PMEG40T10ER by Nexperia. This diode was specifically chosen for its low forward voltage at a maximum of 460mV and very low leakage current. Choosing a diode with a minimum leakage current was important because the 9V battery back up is not meant to be charged and therefore needed this protection. The 9V battery is meant to maintain power to the MCU in cases of temporary power loss.

The power supply PCB was kept separate from the MCU PCB in order to make it easier to troubleshoot. In addition, we could then easily layout everything in the control cabinet. Figure 50 shows the layout of the power supply PCB.

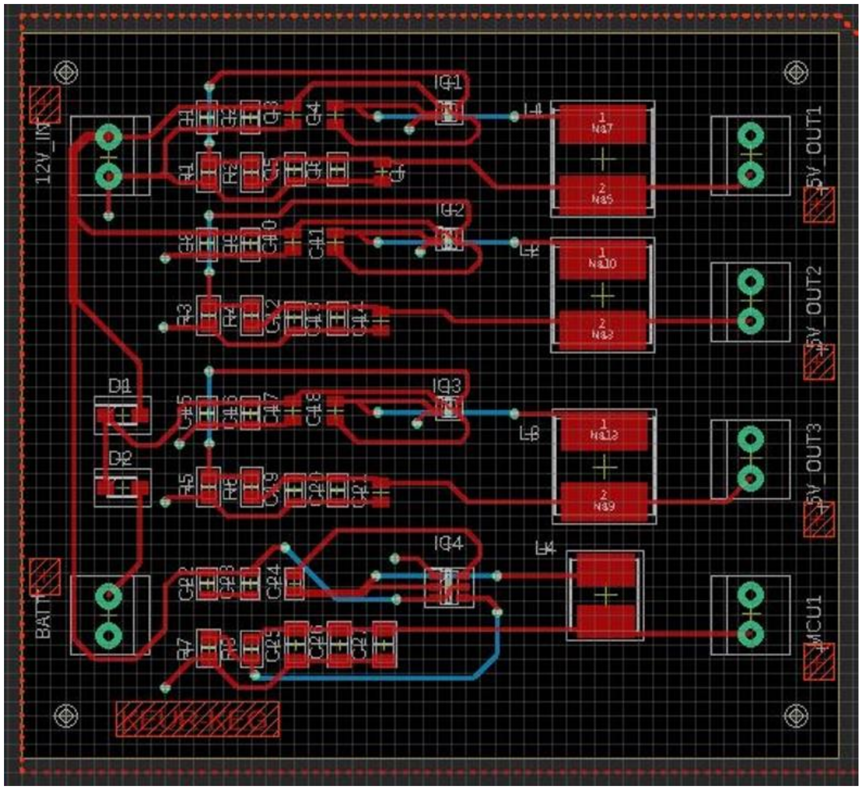


Figure 50: Power Supply PCB Board Layout

This board layout was the final design of the PCB for the power supply. It was the only power supply design that a PCB was ordered for.

4. Automatic Brewing Software Design

4.1. Communications

Since the main idea of this project was to automate the brewing process, it was essential to have a method of communication with the user. This communication was for when there were any issues during the brewing process, such as an overflow; reminding the user when it was time to add special ingredients, such as adding a flavoring during the fermentation stage; or letting the user know that the fermentation process had finished and the beer was ready for storage.

One possible route was to have an option on the display that the user could check periodically to see any messages regarding the brewing process and status, as well as some type of sound system and light system to alert the user of any urgent notifications, such as an error in the process. The benefit to this system was that it simplified the construction and design, as it did not require any extra hardware or software for the network interface, and only needed the sounds and light added, as the user interface would likely already be required for inputting recipes. The user also did not have to input, or change any existing form of contact information, such as email addresses or phone numbers. It also did not require the user to have an internet connection, or to be in an area that has coverage, such as cell phone reception. The only requirement was that the user remains nearby, which they will likely be, as the majority of the notifications would occur during the few hours of initial brewing, and the user is required to be there are the start of the process to initialize the brewing system with the recipe and ingredients. However, the issues with this solution was that in order for the user to receive a notification, they had to be close enough to hear the alert noise or see the lights. As mentioned before, while the majority of the notifications would have likely occurred during the first several hours of the brewing process, as that is when the majority of the moving parts happen, this did not mean that other complications would not occur later on, such as runoff during the fermentation phase, or when it was time to add a special ingredient. This also assumed that the user would store the brewing system in a location that they could readily check. If the user had to leave during the initial several hours of brewing, or is gone during the 4 weeks of fermentation, and a notification occurs, especially an error alert, they would have no way of knowing until they were within the physical vicinity of the brewing system. While this was a potential solution, there were too many unfavorable factors for the user interaction so this option was not chosen.

Another option was utilizing a SIM card. The user would have received a text from the brewing system anytime there was a message they needed to see regarding the brewing process and status. The major benefit of this was that the user does not have to be near the system at any time or store the system in a location they checked periodically, in order to have updates on the process. In fact, with this method, there could have been more updates, informing the user each time of the brewing system moving on to the next stage in the brewing process, so the user would know that everything is proceeding smoothly on schedule. However, the complications on the user's interaction are that they would have needed both to store their system in a location that has cellular coverage to send messages, and that they were in an area that had cellular coverage to receive messages. Another complication was that in order to use a SIM card, the user would have had to pay a recurring fee, a maintenance issue they would have had to kept up with, and a constant cost of automating the process. If they did not use the brewing system for a period of time, either they pay for the SIM card they were not using, and waste money, or they cancel the SIM card until they were ready to use the brewing system again, meaning time and effort they have to spend to call and disable and set the SIM card back up again. From a design perspective, it also required the hardware to house the SIM card, as well as the software to send and possibly receive messages, which could potentially be highly complicated.

Another potential solution was to send messages over the internet, using the user's WiFi. This added the benefit that the SIM card had of being able to send notifications, not just of when the user needs to perform an action, but also during transitions of each phase of the brewing process. It also meant the user did not have to remain on site during any phase of the brewing process, besides initial setup. A benefit over the SIM card was that the user was not required to pay extra fees in order to use the brewing system, instead, it utilized the resource most users would already have, WiFi. However, this still had the same issue the SIM card had, that the brewing system would need to be stored somewhere that it had coverage, though this time internet instead of cellular, and that the user had a device that has access to the internet when a notification is sent. It also required an initial setup on the user's part in order to be used, such as connecting the brewing system to the WiFi and setting the contact information for themselves. Other complications arose on the design side. The first was the hardware needed to send and receive the WiFi signal as seen below in Figure 51. The second was the software required to interact with the hardware. Along those lines, the platform for sending and receiving messages would have to be chosen in order to move forward with this solution. For example, if the brewing system sends notifications through email, then the code would need to be written to support email, an email address would need to be created for the brewing system, and the user would have to input their own email address into the brewing system that they could then receive notifications on. If a messaging application were to be used, then once again, the brewing system's MCU would have needed to have a way of containing and accessing the application, performing updates on the application when they occurred, and setting up an account if needed. If a unique system of messaging was used, it would have required a complete design and creation of a messaging system, both for the brewing system, and for the user to receive messages.

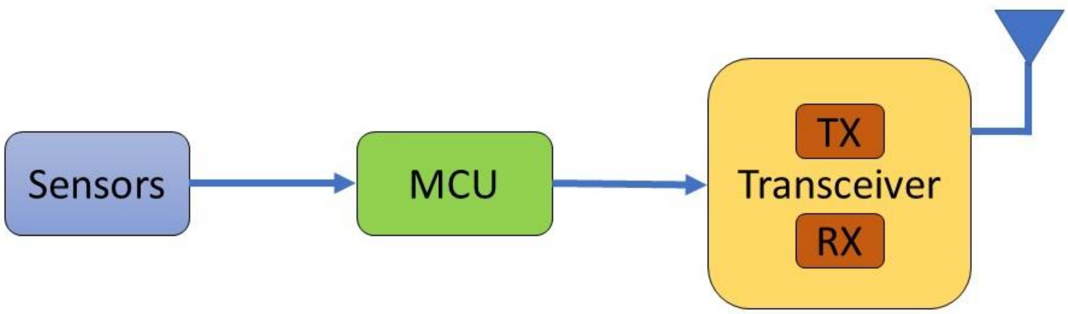


Figure 51: WiFi module architecture (Courtesy of Group 4)

For both the SIM card and WiFi designs, a more complex MCU were needed. This would increase the cost of the design, and the complexity of the software and hardware, but, depending on how advanced the MCU is, it may not have presented a problem.

In the end, the decision was made to move forward with the final option, sending messages over the internet. To do this, the ESP8266 was used. This board was chosen due to its low cost and large community support, as well as its compatibility with the microcontroller that was chosen.

4.2. Components

There are several components required for the system to be fully automated. The first is a microcontroller, which is the core of the entire system, storing recipes, reading the inputs from both the user and the sensors, performing calculations, and sending signals to the user, as well as to other components, such as the pumps and heaters, to activate them. The next component was the user input interface, which is what allowed this system to brew several types of beer, letting the user to add and modify recipes to their choosing. Finally, was the user display device, which was how the system communicated with the user, and was crucial for understanding what needed to be done in order to operate the system.

4.2.1. Microcontrollers

One of the biggest components of the automated brewing system was the microcontroller, as it is what handled the entire automation of the brewing. Microcontrollers are used in almost every form of electronic component that has some aspect of control in it, and as such, there are also a massive range of microcontrollers to choose from.

One of the first aspects considered when choosing the microcontroller was the type of peripherals that would be used on each of the inputs and outputs, as well as how many of each type. As seen in Figure 1, the microcontroller had at least six different devices it communicated with, both receiving an input, as well as sending information. Some of those devices, such as the user interface, could possibly have been two or more different devices, like a display and a keypad of some kind.

Each of these devices will have a method of communication, and in order to choose a microcontroller that can appropriately communicate with each of these devices, either a microcontroller must be chosen that has far more peripherals than needed, or prior knowledge is required as to what kind of communication interfaces the devices will use. As mentioned in the user input section, if a keyboard were used, then the system would have required either some kind of translation device to go from USB to the microcontroller, or a microcontroller that had a USB connection built into it.

On top of knowing the method and number of communication interfaces, knowledge of the digital inputs and outputs, such as if there is analog to digital, pulse width modulation, and so on, is required.

The next step was to determine how intensive the computations of the system would be. Could everything be done with just integers, or would we need to do some floating-point mathematics? How fast would each of the tasks need to perform? Was the system dealing with a hard-real time system, where if a task failed to perform exactly at a certain deadline, it all failed, or was there some leeway in the system?

While not all of these questions could be answered immediately, there were a few known answers during initial design. The system was not a hard-real time system, so if it took a few extra seconds to turn off the water, or the heater, the brew would still turn out correctly. However, there were one or two scenarios that action would need to be taken fairly quickly, such as an overflow situation, but the system was be designed to try and avoid those whenever possible.

Then, the next decision is the type of architecture needed. How many bits are required, and what style of architecture is familiar. While it is important to determine the number of bits needed, and the fewer used the lower the cost, it is also important to take into account the unknown factors that could appear, and plan for those with either a second microcontroller or more bits.

Next, determining the amount of flash and random access memory space is critical, as it will determine the way it can be programed, how much information can be stored and processed on the current brewing cycle, how the information for each brewing recipe can be stored, and how many recipes are available for the user to input. As with the number of bits, it is often better to overestimate how much is needed, and end up with unused space, than it is to run out of space and have to either redesign the board, or cut features from the brewing system.

Another aspect to consider when choosing a microcontroller is what family they come from, as this will impact the available coding environments, as well as community support, development tools, and libraries available to choose from, as this can greatly help with the learning curve, coding speed and efficiency, as well as debugging of the process. A table detailing these can be seen below in Table 25.

Table 25: MCU Manufacturer Specifications (Agarwal, n.d.)

	8051	**PIC**	**AVR**	**ARM**
Bus width	8-bit	8/16/32-bit	8/32-bit	32/ 64-bit
Communication Protocols	UART, USART,SPI,I2C	PIC, UART, USART, LIN, CAN, Ethernet, SPI, I2S	UART, USART, SPI, I2C, (special purpose AVR support CAN, USB, Ethernet)	UART, USART, LIN, I2C, SPI, CAN, USB, Ethernet, I2S, DSP, SAI, IrDA
Speed	12 Clock/instruction cycle	4 Clock/instruction cycle	1 clock/ instruction cycle	1 clock/ instruction cycle
Power Consumption	Average	Low	Low	Low
Families	8051 variants	PIC16,PIC17, PIC18, PIC24, PIC32	Tiny, Atmega, Xmega, special purpose AVR	ARMv4,5,6,7 and series
Community	Vast	Very Good	Very Good	Vast
Cost	Very Low	Average	Average	Low
Popular Microcontrollers	AT89C51, P89v51, etc.	PIC18fXX8, PIC16f88X, PIC32MXX	Atmega8, 16, 32, Arduino Community	LPC2148, ARM Cortex-M0 to ARM Cortex-M7, etc.

In the end, the decision was made to look into the AVR manufacturer, this was due to three main reasons. The first being that members of the team have had previous experience in using Arduino devices, which will help speed along the process of designing and testing the project. The second is the vast community support that exists for Arduino boards, the ease of access to different modules for programming, and because of how compatible they tend to be, there will be little issue finding the parts required for the project. The final reason is the advice received from other Senior Design II groups. As research took place on different microcontrollers, other groups were also asked for their advice and opinion firsthand. Most said that they found TI boards to be difficult to manage, a few also mentioned that ARM boards were presenting a variety of challenges due to the nature of the project, but almost every group mentioned that would have chosen Arduino if they could redo their project.

After choosing this manufacturer, the next step was to look into the different microcontrollers available. After looking at a variety of devices, the choice was narrowed down to two different microcontrollers. The first was the AT91SAM3X8E, and the other was the ATmega2560. Once again, the Senior Design II community was reached out to, to seek firsthand experience and advice. The general consensus was that going with a microcontroller that had an ICSP header would be ideal, as it makes sending the code to the microcontroller much easier. The ATmega2560 met this requirement, therefore it was chosen. The ATmega2560 also provided the team with plenty of extra components, should something go wrong, such as 54 digital I/O pins and 16 analog input pins for reading the variety of sensors in the project, as seen below in Figure 52.

The main PCB, which housed the MCU, was designed in Eagle starting with a blank ATmega 2560 chip. An excel document was created to verify and map all 100 of the pins on this MCU. The pinout of the MCU consists of 27 digital I/O pins, 8 PWM digital I/O pins, 16 ADC pins, 3 TX/RX communication sets, a 3.3V voltage regulator, a reset button, a protection circuit for VCC and GND, and an output to the sub PCB containing SPI communication (MOSI, MISO, SCK, and CC), 1 set of TX/RX, a 3.3V connection, 2 digital I/O pins, and 3 PWM digital I/O pins. The power consumption was then tested for all components needed to run the entire project. These components consisted of all the inputs which are the temperature sensors, flow meter, float switches, WIFI module, and LCD display. The outputs were also tested for switching relays on and off, turning LEDs on, and having loads on the 5V and 3.3V circuits. This was done to test and verify the ATmega 2560 could handle all the components needed to operate the project under a worst-case scenario. The schematic was then created and checked for any errors and warnings before the board layout was created.

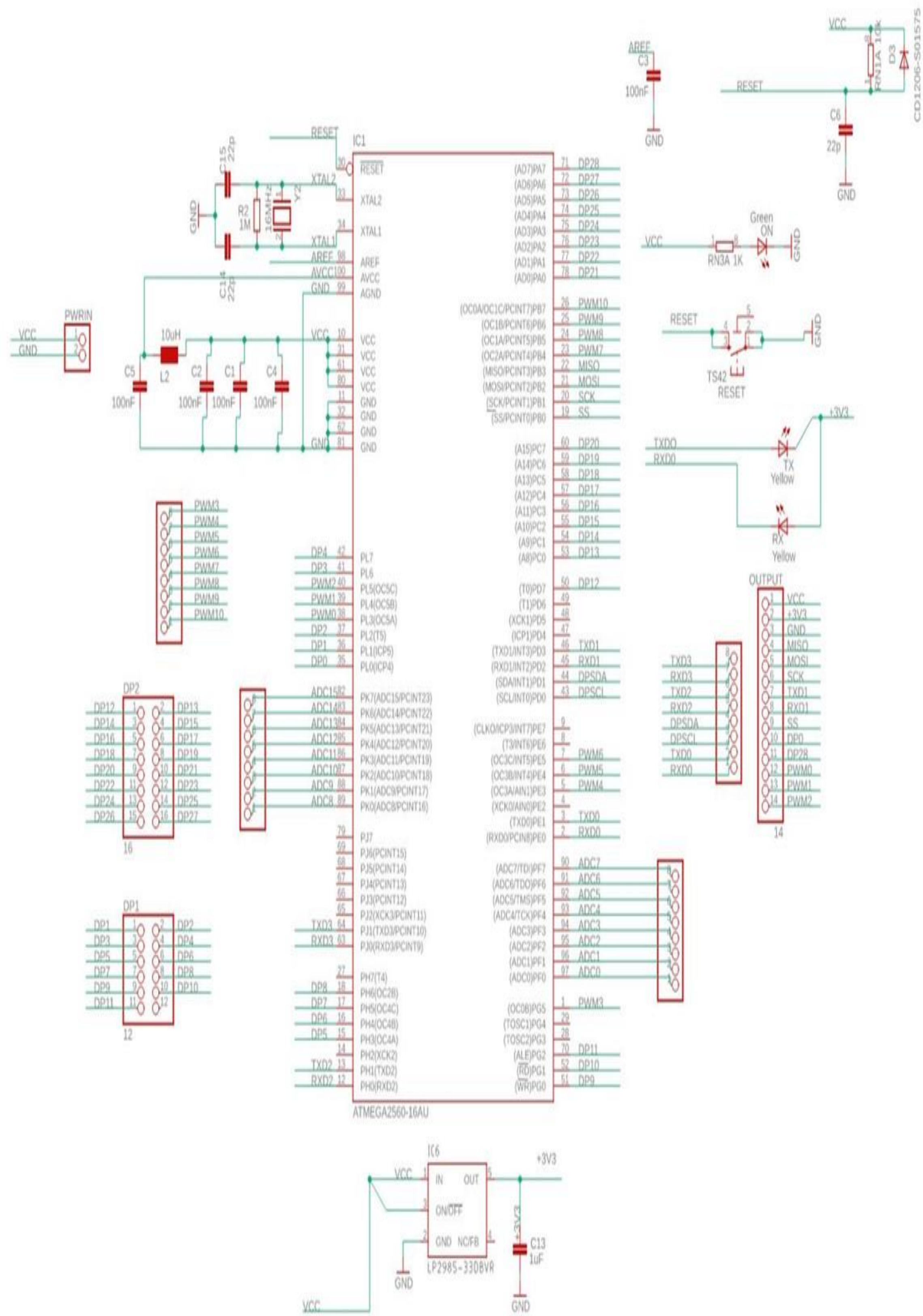


Figure 52: MCU PCB Schematic

After creating the board layout, the traces were carefully routed, and the correct sizes were taken into careful consideration before finalizing. Bigger traces were needed for circuits that operated under heavier loads. The final board layout is shown in Figure 53.

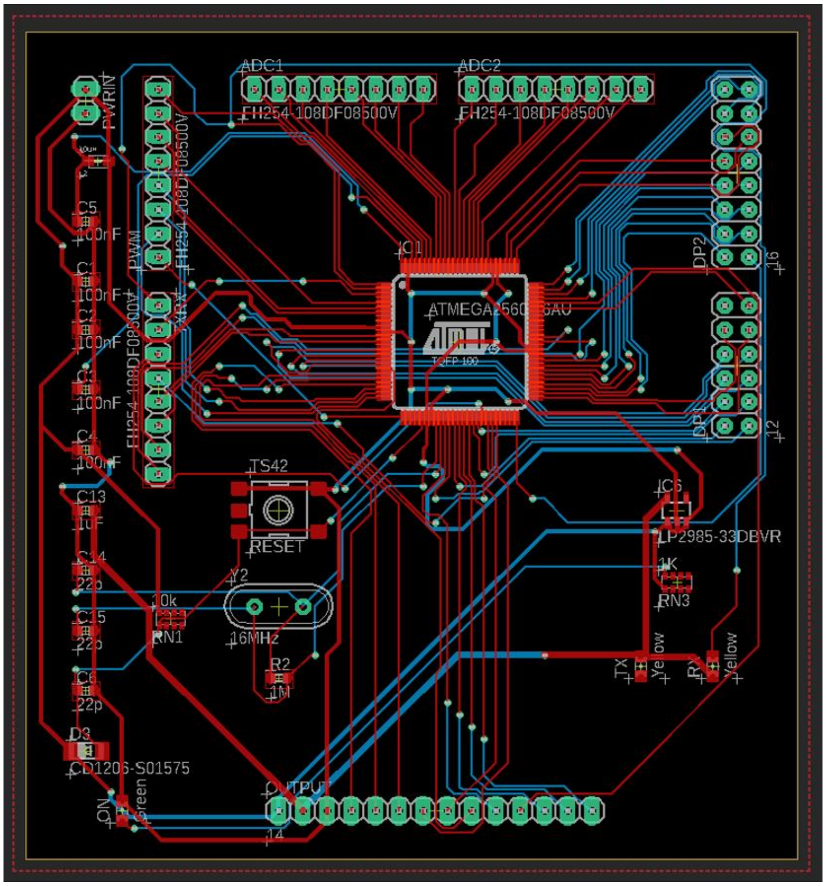


Figure 53: Main PCB Board Layout

4.2.2. User Input Interface

User Input Interface

- Initial water level
- Initial mash temp/time
- Boil temp/time
- Stages of hops/times 1,2,3,4,5 etc…
- Timing of extra ingredients
- Fermentation temp

Inputs #1 (For mash and boil)

- Initial flow control for water
- Temperature sensor 1
- Timer 1 and 2

Inputs #2 (For fermenting)

- Fluid level sensor
- Temperature sensor
- Timer 3

Outputs #1 (For mash and boil)

- Filler pump
- Mixer motor
- Heating element
- Dispensing unit
- Valve and pump for transfer
- Transfer pump

Outputs #2 (For fermenting)

- Cooling unit
- Same pump for water
- Contactor for temp control
- Dispensing unit 3

4.2.3. User input device

A necessary feature required to both brew and store different beer recipes was the capability to input the recipes into the brewing system. As seen in the recipe portion, the user needed to be able to specify several variables, such as whether they are using grain and malt, or just malt; how many different types of grain and/or malt they are using; how many types of hops they are using, and when each of the flavor of hops needs to be added, whether they want to add an extra ingredient later; and so on. There were several ways to implement allowing the user to input their desired recipe, and below three of them are explored.

The first option would be to purchase a touch screen display, as seen below in Figure 57 A). This would provide two different features. The first being the output display to show the recipes, options, and status of the current brew. The second being the user input. Having one device for both user input and output can be very helpful, since it means only having to learn and design one protocol, rather than setting up several different libraries, protocols, and interfaces for both the input and output. The downside is designing the graphical user interface for the menu. The implementation of designing the layout and interactions with the buttons would present a challenge, especially if done on a simple microcontroller unit. However, if a more complex microcontroller is used, one with an operating system, such as raspberry pi, this would decrease the troubles of designing the graphical user interface. Another challenge is the size of the screen. Depending on how complex the recipe variations are would determine how complex the user interface would need to be. But a more complex interface would require a larger screen in order to have a virtual keyboard on the screen.

The next option would be to purchase a full keyboard. This would mean that a display would also have to be purchased. However, there would no longer be a requirement to have as complex a graphical user interface for the user to interact with due to not having to setup buttons that the user can interact with. Instead, the user can navigate the screen with arrow keys, the enter button, and can enter information with the character keys. Because of the range of buttons available, it would also maintain the possibility of the complexity of the stored recipes that the user can input, making it as complex or simple of potential recipes as desired. Even with keeping the potential flexibility, a complex operating system is likely not required to use the keyboard, as setting up the display can be done on a simple microcontroller. However, the real issue with this option is connecting the keyboard to the microcontroller, as even though keyboards can be as cheap as seven dollars, most microcontrollers do not read USB input. So either a keyboard that can connect to a microcontroller is needed, or a device that can translate from the USB to the microcontroller is required, as seen below in **Error! Reference source not found.** A). However, the translation device can be expensive, and can require extra components to function. So, while an operating system with this option is no longer needed, and the flexibility of complex recipes is kept, extra components are now required to make it work.

The final option would be to purchase a small, 4x4 keypad. This would mean that a display would need to be purchased, but would likely require less pins on the microcontroller, since the keypad is not complex. It would also mean that the graphical user interface for the user to interact with would not have to be as complex, since it will not have to read the input of the screen and setup interactable buttons, instead, it would rely on states, and certain inputs on the keypad would change to different states, such as the # or * keys. This decreases the difficulty of the user interface design and maintenance, but depending on how it is implemented, could also decrease the complexity of the stored recipes. This secondary effect of less complex recipes does detract from the flexibility of the overall design, but is not necessarily a negative, as a simpler, yet functionable design, is better than a complex, but unreliable system. Another effect of the smaller keypad and less complex user interface is that an operating system is likely not required, as setting up the display can be done on a simple microcontroller.

After considering how brewing recipes will be input and stored, how complex the recipes will be, and most importantly the style of user display that will be used, the touch screen display was chosen, and is discussed more below in section 5.2.4.

4.2.4. User Display Device

A necessary component for communicating with the user is the display. In order for the user to input recipes, know what recipes exist, and know the current state of the brew, they need a way to interact with the brewing device. The most important aspect of the display is making sure the user can access and modify the recipes and read the current brewing process progress. There are several different types of screens, each with their positives and negatives. Below are three possible screens.

The first display is a touch screen, as seen below in Figure 54. One of the biggest benefits of a touch screen was its dual use as both a display screen and the input device. Some of the benefits of this were that only one set of protocols and setup are needed for the input and output, rather than learning and setting up two different devices, which likely have different libraries, protocols, and requirements. However, the downside is the more complex design of the graphical user interface, as buttons would have to be coded into the display, and then reading from the buttons was required. This was tougher on a simple microcontroller unit but would be more easily accomplished if a more complex microcontroller, such as one with an operating system, is used. From an aesthetic point of view, the touch screen would provide a very nice and clean look to the design and allow the use of more graphics to enhance the user's experience. Something to be noted was that the cost of a touch screen tends to be surprisingly low for getting two devices in one. For example, a five-inch display could be purchased for less than 40 dollars. For the actual implementation of the project, a seven-inch display was used since it was only slightly more cost wise.

The next display option was a liquid crystal display screen. The benefit of this was that the system would not require as complex of a graphical user interface as the touch screen, since there would have been no buttons for the user to interact with. Instead, even though the aesthetics of the touch screen can be kept, the interaction with the display could have been done through either a keyboard or a keypad, as discussed in the input section. A secondary effect of the less complex graphical user interface was that it did not require a complex operating system, as all of the needed functions were provided in libraries already, and it would have been a matter of switching between states on the screen rather than updating existing screens. The challenge would have been determining the size of the screen needed, as they greatly increase in cost the bigger you went. If a larger screen was needed, and the decision was made to go with the liquid crystal display, one potential course of action could be to purchase several small screens, that each displayed different information to the user. One could have been for the current process or another for adjusting or adding brewing recipes. Another positive aspect of using this style of display was the flexibility in design, as it was not limited to only characters on a screen, it would have made it much easier to design a display that is pleasant to look at and use.

Figure 54:Touchscreen Display (Courtesy of Group 4)

The final potential display was a simple character display, as seen below in Figure 55. This style of display was beneficial from both a design standpoint and a cost standpoint. The character display would have been relatively simple to setup, there were lots of libraries already in existence to utilize, most are designed already for the use of self-built projects such as what we are working on, so implementing it into the design would have happened without an issue. Because of the simplicity of the character display, no complex microcontroller or operating system would have been needed to run and design it. Some prior planning on the design of the recipe storage and input would have been needed in order to determine the methodology for how to input recipes with this display, as well as the size of the display needed. These displays tended to be relatively inexpensive as well, though depending on the type of input device used, the cost might have been higher than just getting a touch screen.

Figure 55: 20x4 LCD character display (courtesy of Crystalfontz)

In conclusion, more goes into the choice of a display than simply aesthetics. A design of the user interaction and methods of entering data into the brewing system was needed to determine what style of display was required. As well as a priority of how important the style of this display, and how pleasing the display was, since often times, the more aesthetically pleasing a display, the more expensive it was. The other reason a decision on data management was required before choosing a display, was that the data management was also required for the input device choice, and since there was the possibility of choosing a display that also functioned as an input device, both options had to be considered simultaneously.

The number of displays was also a factor that needed to be considered; whether just one display would be used that the user will switch between screens to access all information, or if several displays were chosen with the potential of different styles, that can display many different informations simultaneously, such as the current brew state, the temperature of the brew, the time left in fermentation, which recipe is currently running, and modifying recipes during the brewing phase. A character display could be used for certain features, while a liquid crystal display or touch screen could be used for the main portions.

Ultimately, the touchscreen display was chosen, but in conjunction with the RA8875 driver board, as seen below in Figure 56, to interact with it, as it provides an easier design environment as we program the board, as well as an easier way to read the input from the user. There were several reasons the touchscreen display was chosen. One was aesthetics, as it was more appealing to look at. Next, it could provide a more intuitive environment for the user to interact with. Furthermore, it meant less pins to connect with the microcontroller, which can also help pinpoint issues when debugging. Finally, it provided more flexibility for creating the user interaction, as sliders can be created for adjusting time or temperature, the user can be provided with only the potential input characters needed, which could eliminate unknown results of invalid character inputs, and a more detailed interface for the current process could be designed.

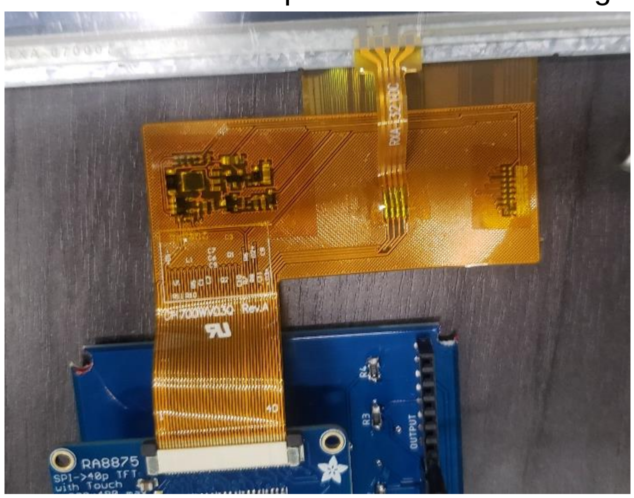


Figure 56: RA8875 Driver Board and Schematic (Courtesy of Group 4)

4.3. Data Logging

The system stored several components for each recipe. The first was whether or not they would be using any form of hops, or if they would be only using malt. This information would most easily be stored as a Boolean variable, which would reduce the total amount of memory required by the brewing system to store the recipe.

Next, would be when the malt is added to the brew. On top of the pot would be several containers to store malt in, each of these would be marked, and the user would add the ingredients they prefer into each container. Then, they would set the time for each of the containers to be opened. The hops would be done in the same fashion. This keeps the recipe flexible, while also keeping the information that needs to be stored minimal, as the data can all be stored as integers in seconds of when to open each container.

Then, should we implement adding extra ingredients during the ferment phase, there will be a Boolean value for whether the user would be adding anything, and if so, at what point during the fermentation phase they would like to add it, which would be stored as an integer.

Finally, the system would ask the user how long they would like the fermentation process to be and would store that value as an integer as well.

On the user interface side, the user would input the time as either hours or days, which would then be converted in the microcontroller to seconds, and that value would be stored as the integer time value. Then, the microcontroller would run timer modules that count up to those values, and once those values are reached, it would throw an interrupt that processes each command accordingly. For the malt and hops, it would send a signal to the container to open it. For the extra ingredient and end of fermentation, it would call a module to send a message to the user that the appropriate time has come. The modules could all be configured as needed, depending on the devices chosen to implement the physical features of the brewing system, for example, how the system would communicate with the user.

5. Structure

A strong foundation was required for proper operation and safety of the design. It was critical to have the structure designed to support the flow of our product. It was critical to have the mash kettle above the boil kettle since we utilized a gravity fed system to go from the mash kettle to the boil kettle. It made sense to build a system that started at the top, moved water horizontally to the mash kettle since this cycle is controlled by a pump, followed by a downward vertical cycle that took the product from the mash kettle to the boil kettle and finished with another horizontal cycle that took the wort from the boil kettle to the fermenter. This design allowed the product to flow in a manner that helped keep the size of the overall system more compact than simply laying everything out in a line on the floor of the work area. Structurally the system was considered minor. It never had much more than 100lbs on the top shelf and therefore 1.5" aluminum tubing was more than capable of handling the load.

The vibrations from the pumps are relatively small and therefore we didn't need to be concerned with vibration of the unit. The main concern we had was simply having a pot reach the edge of the stand and topple over. This was a huge concern as the mash kettle on the top shelf can get as hot as 170 degrees F and the temperature of the boil kettle reached 212 degrees. To prevent the kettle from going over the edge a simple .75" lip was added to all the shelves to prevent any item from slipping over the side. The structural system was be made from 1.5" aluminum tubing welded together in two different stands. The fermenting stand, as seen in Figure 57 A), had four legs and bracing on three sides of the bottom of the stand. The front will be left open to slide the fermenter in and out without obstruction. The top of the stand had 4 braces to support the load of the water reservoir, water tanks, and control panel located directly above the fermenter. The kettle portion of the stand seen in Figure 57 B) had two upright members with four braces located at the bottom of the stand and four more at the top of the stand.

The kettle stand attached to the fermenting stand via bolts. Two bolts went through 'L' brackets welded on the bottom side of the top support. The bottom was connected by the shelf that was added to the bottom of the kettle stand. The shelf bolted through the .75 lip to the two-upright post of the kettle stand and through the .75" of the lift of the shelf to the uprights of the fermenting stand. These bolts will make it easier to assemble and disassemble the stand for relocation purposes. The bottom shelf located on the kettle stand will be made in one solid piece with the .75" lip turning up accomplished with a break or welded on if breaking all sides is not feasible. The top shelf was made in two parts. The top kettle shelf was made with 3 of the 4 sides turned up .75" but the fourth side facing the fermenting stand was not be broke up. The top shelf above the fermenter was likewise broke on 3 of the 4 sides. The open side faced the kettle stand. This provided for a .75" lip around the entire top shelf joining both the kettle and fermenter top shelf together.

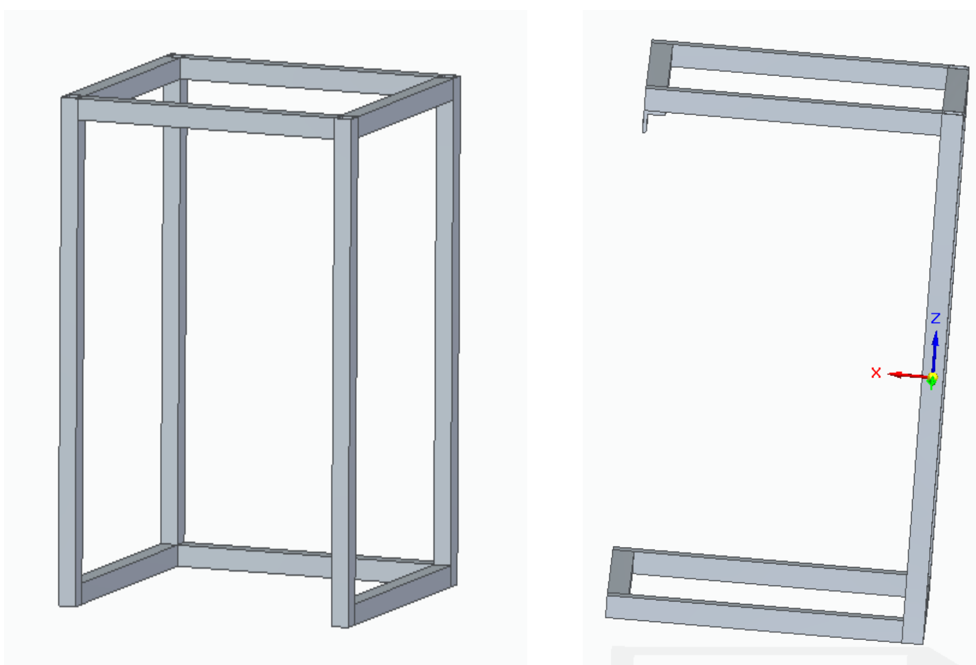


Figure 57: A) Fermenting Stand B) Kettle Stand

6. Wiring Diagrams

Thought must be put into wiring the Keur-Keg. Putting adequate time and thought into the wiring process will ensure proper function from the beginning and allow you to design a clean looking and safe system.

Creating an electrically safe system is one of our most important tasks. For example, the actuators worked on the basis of reversing polarity in order to move the piston in and out. The relays needed to be wired in such a way that they are interlocked so that if any mishap occurs, we would not send 12V positive to the same wire lead as 12V negative at the same time. Of course, that can be accomplished with code, but often times there is a maintenance menu that will allow you to bypass code and turn relays on and off for testing. Wiring devices in a way that will mechanically prevent them from being energized at the same time is always a best practice and often required to keep a system electrically safe. As seen in Figure 58, by applying the positive and negative voltages to the normally open and normally closed contacts and operating both contacts with the same output from the MCU we have achieved a mechanical interlock that would not allow the leads on the actuator to see a short between the 12 volt positive and negative feeds.

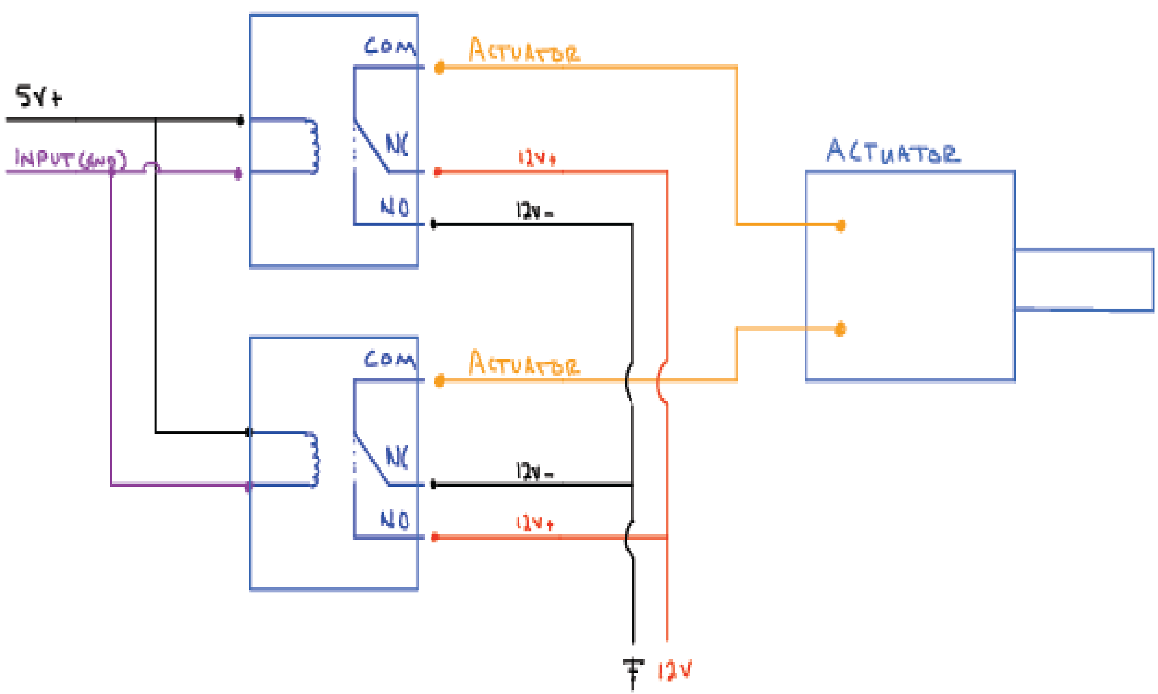


Figure 58: Interlocked Relays to Operate Actuator

6.1. Basic Wiring Layout

The basic wiring layout shown in Figure 59, shows the basic component layout and which components need 120 volt signal, seen in red, or low voltage power or signal, seen in blue. Where all of the wires come together does not depict a wire connection but simply a harness where all wires are run at the same location. This was done to keep the wiring diagram simple and easy to understand.

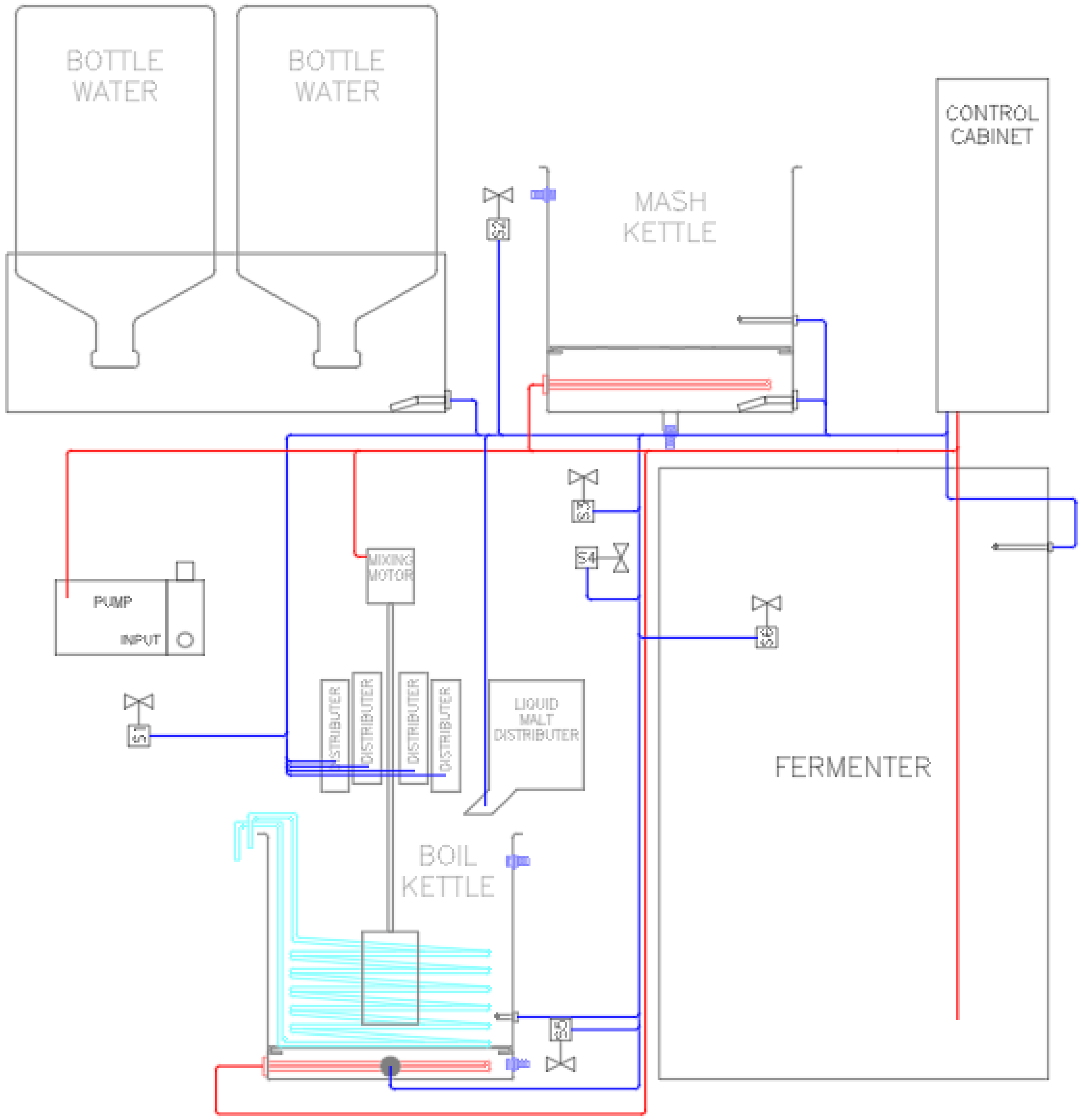


Figure 59: Basic Wiring Layout. Blue wire are low voltage. Red Wiring is High Voltage.

6.2. Wiring Diagram

The following, Figure 60 shows part 1 of the wiring diagram that was followed when the product was being wired all together.

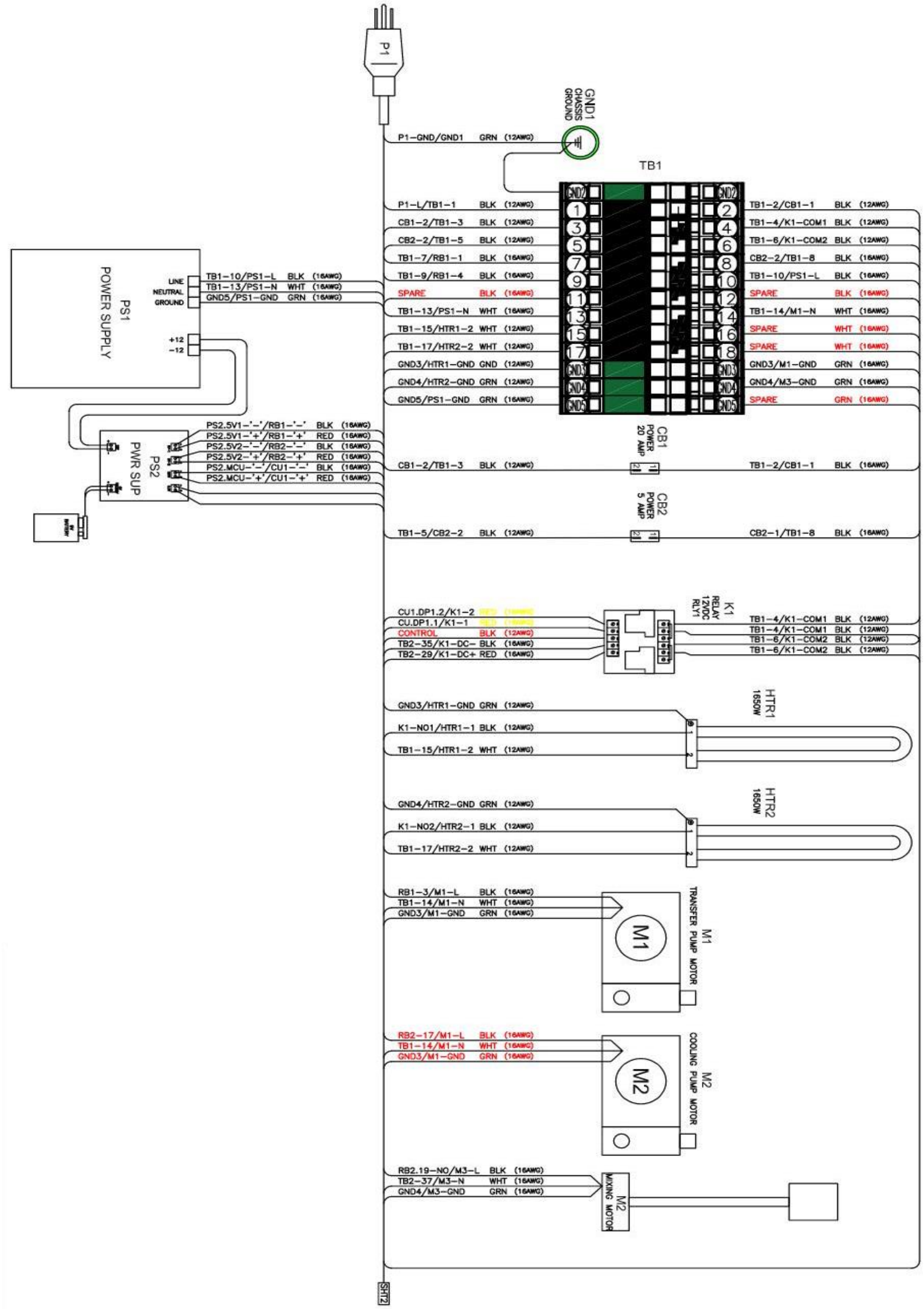


Figure 60: Wiring Diagram Part 1

The following Figure 61 shows part 2 of the wiring diagram that was followed when the product was being wired all together.

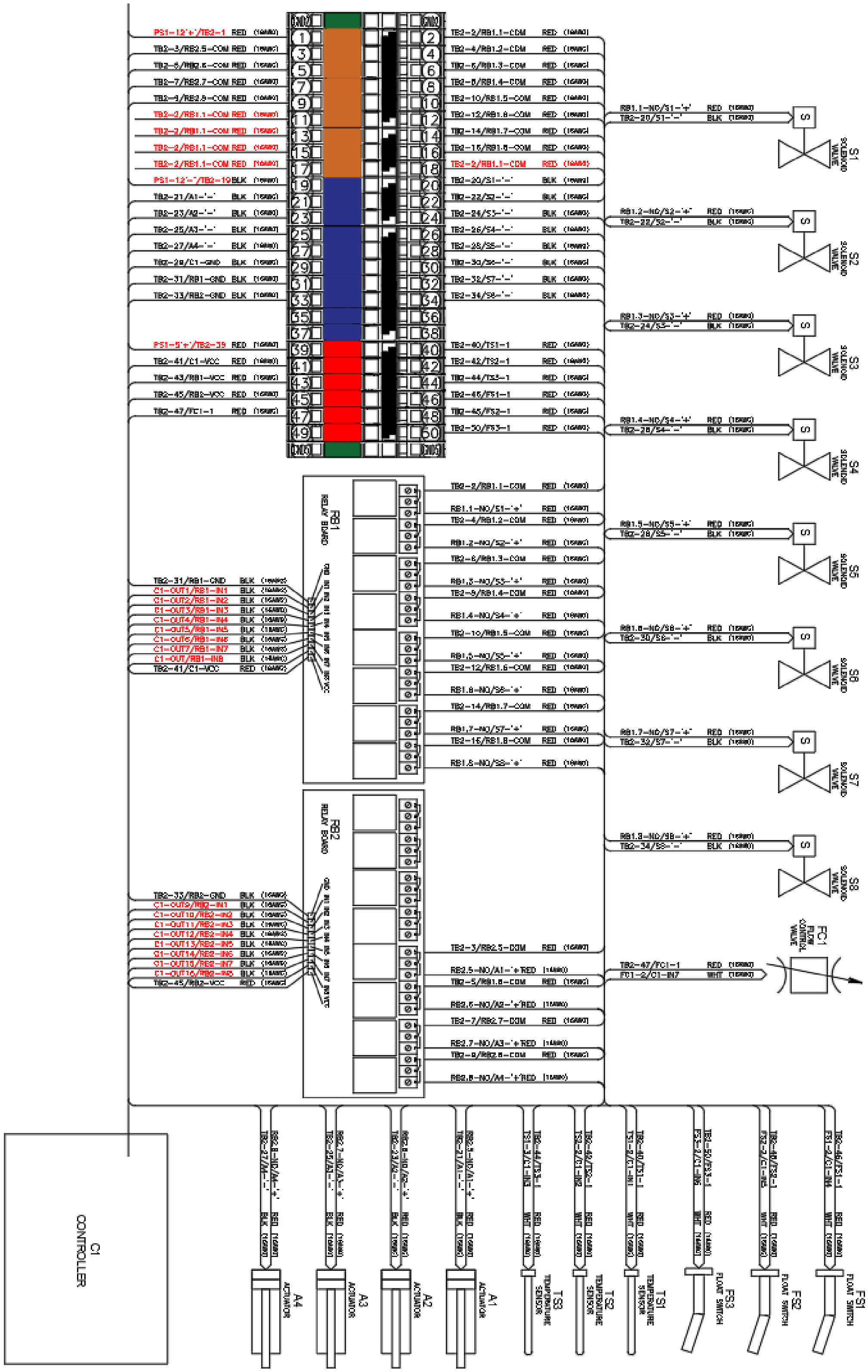


Figure 61: Wiring Diagram Part 2

7. Recipes

An important part of consistent brewing is saving the recipes. In order to have the proper data structure to store the recipes, it was required to know the types of ingredients, as well as how many variants of these ingredients were possible and when to add them. Using https://beerandbrewing.com/beer-recipes/ 30 recipes were pulled and recorded the data for the recipes. The required ingredients to brew were: malt and/or grain, hops, yeast, and any extra flavoring.

On average, recipes call for 4 different types of grains and/or malt, with most recipes having an even mix of the two, and the max being 11 in one recipe. The average different types of hops required for each recipe was 5, with a max of 18. A challenge that was realized as the data unfolded is that the hops are not always added on the same day. In fact, 57% of recipes add hops both on the brew day, as well as at varying times over the next 4 weeks. Only 1 recipe required 2 different types of yeast, but all of them were added on the brew day.

Another aspect that was considered, as a possible stretch goal, was the addition of extra flavoring. Some recipes called for adding ingredients like peppers during the hops phase, or hibiscus part way through the fermentation period. The biggest issues here are the wide variety of ingredients, their shapes, storage needs, and when to add them. If they were all required to be added on brew day, many of these issues would be resolved. However, since some go in during the fermentation process, having a way to store them, should they be perishable, would be required, as well as a way to insert them into the brew during the time the brew is sealed off.

8. Prototype Testing and Evaluation

8.1. Hardware Testing and Evaluation

Testing was completed both on the work bench and as a completed system. Each piece that could be tested for functionality on the bench was tested before using in our project. Once the project was put together each component was tested as a system making certain that each component functioned as it should and as it was expected. Any components that did not pass the workbench test was replaced with a part that worked. If a part did not function as expected in the completed prototype, then that part was replaced with a working component or changed it to one that better fits the purpose it was needed for in the project. The project was evaluated during the testing of the complete system. We ran the system thoroughly using water and other household food items to test the functionality of the build before attempting the first beer brewing process.

8.1.1. Breadboard and Development Board Testing and Evaluation

Before a PCB is designed, a breadboard was used to test whether all components are worked as expected, as well as their compatibility with each other. The breadboard was used with external wiring that would represent the inlaid wires of the PCB, providing an environment that allowed for quick modifications to the design for testing purposes, ensuring a working design, without needing to fabricate several different PCBs that have only slight changes.

8.1.2. PCB Testing and Evaluation

For our PCB did functional testing and some physical tests. This simulated how the PCB would operate within the scope of our project. We tested the two PCBs separately; one to house the power supply system and the other to house the microcontroller and control signal. For each PCB we used the power supply and the multimeter in the senior design lab to ensure that proper voltages and currents were getting to where they need to. In addition, we tested to make sure every conductor line on the PCB passes a continuity test with the multimeter provided in the senior design lab.

We also visually inspected the PCBs to ensure that there was nothing missing or broken on them. If we were able to get more that one of each of our PCBs then we will provide a do a flexibility test on PCB to see how far they flex before they break. We would do this in the Manufacturing or TI Lab by clamping two opposing sides of the PCB and gently start twisting and then measure the angle at which the torsion is too much for the PCB.

The final and most important test we did was testing of both PCBs working with all the other equipment. We had basic programs that ran on the MCU PCB to make sure it followed the proper sequence of results according to the software flow diagrams. We to made sure that when the MCU sent a signal that it occurred at the proper voltage and the correct amount of current by measuring both with the multimeter provided in the senior design lab. In addition, did a test where the maximum amount of settings are on that would create a large load on the MCU and the power supply system to ensure that the MCU PCB functions properly and switches off the necessary parts to keep the system from exceeding its load limits.

8.1.3. Microcontroller Testing and Evaluation

Due to the large number of pins on the microcontroller, it was important to test that the pins that were used functioned as intended. Once the board was designed and what pins are being used was known, those pins were connected to testing devices, and a segment of code was be written to ensure they were functioning correctly. For example, digital I/O pins were connected to an LED to ensure they were sending signals correctly and connected to a button to ensure they were receiving signals correctly. To ensure communication between pins, one digital I/O was connected to a button, that when pressed would activate another digital I/O that was connected to an LED, if the LED did not turn on, it meant that one of the two pins was not working. To ensure that the internal timers were accurate, an already tested digital I/O pin was connected to an LED, and a segment of code would run that flashed the LED continuously over a period of time, a stopwatch was used to compare the expected times with the actual times to get an understanding of the accuracy of the timers.

8.1.4. Power Supply Testing and Evaluation

Since the power supply will be on its own separate PCB, it needed an electronic load to simulate the maximum loads that it would be handling when in actual operation at the 24VDC power supply, 12VDC power supply and the 5VDC power supply. First, the efficiency of each power supply was measured by the input output voltage and the input output current. This was to make sure that the voltage in, voltage out, current in, and current out are the expected values. Different voltage ins were be chosen to test at: the first was a value below the expected voltage in, next was the expected voltage in, and lastly, test at a voltage higher than expected. At those voltage ins it was further subdivided and tested at differing current outs, at least five values with the middle value being the expected current out and the other values being above and below the expected values. By testing at the extremes then observations can be made if there are any limits that cause instability that should be avoided. Then designed power supplies, 24VDC, 12VDC and 5VDC, would be connected to the power supply provided in the senior design lab to control the input voltage and output current. With 2 multimeters in the senior design lab, the voltage in, voltage out, current in, and current out can be measured simultaneously at the different inputs and outputs. All these measurements were recorded so that the results can be observed on a graph. The efficiency values from testing should match or come close to those determined in WEBENCH®. If the values did not match or come close, then retesting and troubleshooting of the circuit must commenced. This testing plan was slightly changed to test the 12VDC power supply that was bought and then each 5VDC circuit and the 3.3VDC circuit.

Then testing for stability of the power supplies followed. Similar to testing for efficiency, a DC power supply was needed like the one’s found in the senior design lab connected to the power supply that was designed. Then a 50-ohm test resistor will be connected to the feedback loop of the voltage regulator. Then a spectrum analyzer and isolation transformer will be connected to the power supply being tested. The multimeter will need to be connected at the inputs and outputs to ensure that the value is correct. Once again, testing at the extremes and nominal input values must occur. Then the testing at the different values must happen so that the bode plot that is created by the spectrum analyzer on the computer can be observed. On the bode plot, little to no change should be observed in the phase margin at the different output values in order to prove that the power supply is stable. This section was not used in the actual testing of the power supply, but is good practice to do so.

The next aspect of the power supply that will be tested is noise in the senior design lab: switching ripple noise and switching transient noise. For this test a multimeter will be needed to measure input and output currents and voltages. An oscilloscope will also be needed to determine if there is any noise. Limiting the bandwidth on the oscilloscope is crucial for noise measurements since the lab has a lot of electrical equipment that will contribute to the noise seen on the oscilloscope. By limiting the bandwidth to lower frequencies, than we can see if our power supply is noisy. First, a probe from the oscilloscope will be used to measure across the output capacitor and pause the sweep so that ripple noise that is occurring can be observed. This value will be determined by measuring the peak to peak value for the voltage that is seen on the oscilloscope screen. Now to test for switching transient noise, the bandwidth limitation is removed on the oscilloscope. Then a a probe is taken to measure at the output of the power supply. On the oscilloscope ripple voltage will be observed. However, personal judgment must be used to determine if the noise is caused by the power supply circuit or simply just noise from something else. This aspect of the power supply was also not tested, but would be good practice to do so.

8.1.5. Sensor Testing and Evaluation

Temperature testing was completed using a calibrated digital thermometer. Verification was made that the temperature being displayed on the screen was within tolerance of the actual temperature observed on the digital thermometer. The temperatures were verified for accuracy between 140 and 212 degrees F for the sensors being placed in the mash and boil kettle by heating water up and checking the temperature on the screen against the temperature on the digital display. The temperature sensor located in the fermenting fridge was tested between 33 and 70 but setting the fermenting temperature on the controller and visually inspecting the temperature being read by the digital meter.

The float switches were bench tested to be certain they operate correctly before installing in the project. On the bench and when installed in the project the switches were tested using a simple continuity meter. When the switch was down there was no continuity. When the switch was level with its base there was continuity that can be seen on the meter.

8.1.6. Mechanical Components Testing and Evaluation

Solenoid testing was completed both on the benchtop and in the project. Simple benchtop testing ensured that the solenoid worked from the very beginning. Using a 12V DC power supply each solenoid was connected directly to the power supply so that each solenoid was visually inspected for operation. When connected to the system we ensured that each solenoid operates as expected by visually inspecting that the fluid was coming out of the solenoid at the proper time.

Actuator testing was accomplished on the benchtop for preinstallation inspection. The actuators were connected to a 12V DC power supply and visually inspected for proper operation. When the actuator was installed on the project a visual inspection during the expected time of operation will suffice for testing proper function.

8.1.7. Heater Testing and Evaluation

The heater was tested on the bench using resistive measurements. The 1650-watt heater should read 8.7 ohms. When we installed the heater in a kettle, we tested the functionality of the heater using a simple amp probe. When the heater was commanded on, we had a voltage of 120V and had a amperage reading of approximately 13.75 amps.

8.1.8. Transfer and Wort Chiller Pump Testing and Evaluation

The transfer pump was tested before installation by simply connecting a hose to the inlet end and sticking the hose in a 5-gallon bucket of water. We connected 120V to the pump using a extension cord with the word cap removed on one end. When the pump turned on, we verified that it self-primed and transferred the water from one bucket to another. Once the pump was installed on the project, we visually verified that it was operating as expected for each cycle the pump is required for.

8.1.9. Testing and Evaluation of Low Water in Reservoir

The low water alert for the reservoir was checked allowing the water to run low so that the float switch trips sending a signal to the MCU to stop the water pump from running. We verified this in the initial filing stage where a specific amount of water was to reach the mash kettle before the heating process begins. We monitored with the pump and checked with a multimeter that the pump shut off when the reservoir sent a low water signal.

8.1.10. Mash Kettle Testing and Evaluation

If the water in the mash kettle did not reach the minimum level, then the heater should not turn on. This was verified by transferring water to the mash kettle but disconnecting the bottom hose, so all the water flowed out of the mash kettle. Checking with a multimeter we should never saw the heating element come on. If the mash kettle became full the heater and circulation pump turned on. We then checked that when the water dropped below the minimum water level that the heater and circulation pump shut down. This will be accomplished allowing the mash kettle to fill with water and allowing the heater and pump to come on but then during the cycle remove the bottom hose allowing water to leave the mash kettle. Using a voltmeter watched for the voltage to be removed from the heater and we visually and audibly observed here the circulation pump shut down as the water went below the minimum water lever.

8.1.11. Boil Kettle Testing and Evaluation

If the water in the boil kettle does not reach the minimum level then the heater should not turn on . This was verified by transferring water to the boil kettle but disconnected the bottom hose, so all the water flowed out of the boil kettle. Checking with a multimeter we never saw the heating element come on. We verified the heater turned off if the water dropped to low by filling the boiling kettle up and allowing the heater to turn on. Once the heater was on then we removed the water by opening the bottom valve and allowing the water to leave the boil kettle. Using a multimeter, we observed that once the water drops below the minimum water lever the heater shuts down.

8.1.12. Testing and Evaluating the Fermenter

The fermenter kept our product at a specific temperature for the duration of the fermenting cycle. We tested this function by bringing the fermenter up to temperature. We verified the temperature never dropped below a specific temperature by making sure the fermenter came on when the temperature rose to a specific set point and that it turned off when it dropped down to another specified point. If equipped with a alarm then the system can be tested that the alarm goes off if the temperature rose above a specific temperature for more than 3 minutes. This was tested by simply opening the door to the fermenter and letting the temperature rise until the max time is reached and the temperature increased. Since no alarm was installed the alarm did not go off. If testing where it is cold out, simply place your hand around the temperature sensor for the 3 minute period.

8.2. Software Testing and Evaluation

Testing was an important part of coding. One of the first steps to take, regardless of what portion was being tested, was to test early and often. It is in bad form, and causes many problems, to wait until all the code has been written to start testing and debugging, instead, small tests were run along the entire process to ensure that every new bit of software worked well with the rest and performs as expected.

8.2.1. IDE Used

Because the chosen microcontroller, the ATmega2560, has support from the Arduino community and compatibility with other Arduino products, the Arduino Software Integrated Development Environment will be used for designing the code. This IDE allows for code to be written in C and C++, and since C is a language required for all electrical and computer engineers to know at the University of Central Florida, this means the entire team will have an easier time reading and understanding the code should there be any questions. The Arduino IDE is also able to be run on any of the main operating systems (Windows, Mac, and Linux) so the project will have support for coding no matter what computer is used to code on. Furthermore, since the IDE is designed for the chosen microcontroller, uploading code to the device is streamlined, and should provide little to no problems. Finally, there is a large community around this software, meaning a vast amount of support and already designed modules for similar products can easily be found.

8.2.2. Testing Procedure

Since the project is based upon creating a product that takes several hours of constant work to produce, for most of the early tests, the time was scaled down significantly to ensure that the steps are occurring in proper order, and with the correct outputs, without wasting time.

Also, because the code will be created at the same time as the physical hardware, a secondary method of testing will be needed. To do this, a board with the ATmega2560 already on it will be purchased, that can then be used to ensure that the design works, before designing and building a printed circuit board. To do this, the Arduino Mega 2560 REV3 will be used.

Initially, until the sensors are working, the code will be tested using hardcoded values for the sensors that change over time, and small LEDs to represent the outputs, such as when messages would be sent to the user, when a heater would be turned on, when a pump is activated, or when an ingredient is added. There will also be small buttons that can be used to simulate user input from the touch screen.

8.2.3. Simulated Testing and Evaluation

Required components:

- Arduino Mega 2560 REV3
- Connecting cable for Arduino
- 15 LEDs
- 2 Small Buttons
- 2 Stop Watches
- 1 computer

As seen above in Figure 31: Overview Flow Diagram, there are 7 different phases the product will run through, which helps to segregate the testing initially. To simulate this, there will be 7 LEDs, one for each phase, and whenever the system enters a phase, the corresponding LED will turn on, and whenever the system exits a phase, the corresponding LED will turn off. There will also be an LED to simulate the user display, such that whenever it turns on, it simulates a message of some kind being displayed to a user. Similarly, there will be an LED to simulate turning on and off the pumps, heaters, gravity feeder, mixer, two for the valves, and one to also show when we are adding ingredients

For the User Phase, it will start by activating the User LED, and then by flashing the Display LED to inform the tester that the user has been asked whether they want to manage recipes or not, the tester will then have two buttons they can press, the first will be for yes, and will activate the Recipe LED and turn off the User LED, the second button will be for no, and will flash the Display LED to simulate asking the user to select a recipe. At this stage, there will be two recipes the user can select from, the tester will have this written down to monitor whether it follows the recipe correctly, they will then select one of them by pressing one of the two buttons, and the Display LED will flash to show that the user has been asked whether all ingredients have been loaded, if the tester presses the button for no, the Display LED will flash again, showing a repeat of the same question, if the button for yes is pressed, the device will switch from the User Phase to the Grain Phase, switching on and off the appropriate LEDs.

In the Recipe Phase, the Display LED will turn on to show that the user is being asked what they would like to do. At this point however, since the device cannot show the actual recipes on the touch screen display, or modify them at the beginning stages, the system will simply have the first button modify the flashing speed of an LED, and the second button will take us back to the User Phase. Later on, however, if the touch screen display is still not working, the system will interact with this phase via a computer and a terminal, allowing the tester to simulate adding and modifying recipes.

One the Grain Phase starts, the tester will activate a stopwatch to compare the expected timing of the recipe with the actual times. The system will turn on the first Valve LED, then turn on the Pump LED. After a period of time, once the hardcoded values read that the container is full, the Pump LED will turn off, and the two Valve LEDs will toggle, then the Heater LED will turn off, and the two Valve LEDs will toggle once more. Next, the Pump LED will turn on and the tester will start the second stopwatch for the brewing time. They should then see the Heater LED toggle on and off during this time until the timer expires, at which point the tester will compare the expected time with the actual time. Both the Heater LED and Pump LED should turn off, and the Gravity LED should turn on as the device switches from the Grain Phase to the Malt Phase. The rest of the phases will all be tested in very similar ways to the Grain phase.

8.2.4. Physical Testing and Evaluation

Physical testing was done very similarly to the simulated testing, in that the process was be sped up at the start, and once the basics were verified as working, we expanded the time constraints until all but the fermentation time period matched the real time limit.

8.3. Testing Results

The following Table 26 shows the results during testing of individual parts of the product and the combined systems. After troubleshooting and error corrections everything worked as it should for the automated beer brewer to work properly.

Table 26: Testing Results

Test	Outcome
Max Current of System	14 A
Memory Storage of Recipes	25 Recipes
Email	Sent and Received
WiFi	Connects
User interface	Reads input and displays properly
Functions	Communicate and run properly
Temperature Control	±5 F
Flow Control	±2%
Power Supply	Tested to full load
PCB Test	All input and outputs full function
Pumps	Proper flow
Float Switch	Properly operate
Relay Boards	Proper switching

9. Facilities and Equipment

9.1. Facilities

Most of the work for the project will take place at two locations, team members' houses, and the University of Central Florida. Several team members have large spaces and the required tools for working on the larger portions of the project, such as the frame and housing, wiring, housing unit for the power supply, and so on. Much of the programming will be done in the homes as well. For what cannot be done at home, UCF offers a space for students to work on their projects, this can be found on campus in Engineering Building 1, Room 456. This is where the majority of the testing will take place for the breadboard, voltage, current, and anything else that requires the use of expensive electrical testing equipment.

9.2. Equipment

Most of the work for the project will take place at two locations, team members' houses, and the University of Central Florida. Several team members have large spaces and the required tools for working on the larger portions of the project, such as the frame and housing, wiring, housing unit for the power supply, and so on. Much of the programming will be done in the homes as well. For what cannot be done at home, UCF offers a space for students to work on their projects, this can be found on campus in Engineering Building 1, Room 456. This is where the majority of the testing will take place for the breadboard, voltage, current, and anything else that requires the use of expensive electrical testing equipment.

9.3. Suppliers

While most of the parts will be purchased or built in house, the only part that will be sent out to be designed and constructed elsewhere will be the PCB. The PCB will be sent to Quality Manufacturing Services Inc, a company that is known for frequently assisting students of UCF. For a list of further suppliers, see Bill of Materials in Section 10.

10. Parts (Bill of Materials)

Below is the bill of materials for the design of the brewing system on Tables 27 through 37. It is separated into the different subsystems that make up the automated brewing system. Each table consists of the parts, quantity order, the part number, a description of the product, the manufacturer, the vendor that supplied the component, and finally the cost.

Table 27: BOM Mash and Boil Kettle

Mash and Boil Kettle						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	2	ST-32	32 Quart SS Stockpot w/ steamer rack	Gas One	Amazon	$59.99
2	3	Sensor Float Switch	DerBlue Aquarium Wired Liquid Water Level Sensor Float Switch	DerBlue	Amazon	$11.99
3	2	DERNORD-13	120v 1650w low Watt Density Screw in Foldback Water Heater Element	DERNORD	Amazon	$21.99
4	2	4452K116	1" SS 1/2 Coupling	McMaster Carr	McMaster Carr	$12.83

Table 28: BOM Fermenting Unit

Fermenting Unit						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	N/A	Mini refrigerator	Frigidare	Kevin Ruzich	$0.00
2	1	N/A	7 Gallon Stainless Steel Fermenter (Portless)	Chapman	Amazon	$122.52
3	1	N/A	Drilled Rubber Stopper #10 Set of 3	Home Brew Ohio	Amazon	$8.26
4	1	N/A	3 Piece Airlock (Pack of 3)	Social Home Brew	Amazon	$7.03
5	1	200F	Polypropylene Cam & Groove Fitting, 2" Male Adapter x NPT Male	Banjo	Amazon	$10.90
6	1	200D	Polypropylene Cam & Groove Fitting, 2" Female Coupler x NPT Female	Banjo	Amazon	$20.40
7	1	N/A	Beverage dispenser spigot	Lyty	Amazon	$13.55

Table 29: BOM Water and Fluid Transfer System

Water and Fluid Transfer System						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	N/A	2 5-gallon water jugs	LavoHome	Amazon	$39.95
2	2	038270-103	Oasis waterguard 7 assembly	Oasis	Amazon	$39.86
3	2	N/A	1/2" Inner diameter food grade PVC vinal tubing	Hosetool	Amazon	$11.99
4	4	N/A	Stainless Steel Quick Disconnect Set - Beer Brewing Connector Kit (Barb Male/MPT Female)	Dernord	Amazon	$14.69
5	1	N/A	15 Pairs of plastic quick disconnect	Link Tech	Link Tech	$247.65
6	6	GRSV-04	1/2" DC 12V Solenoid Valve N/C Normally Closed	Grodia	Amazin	$10.19
7	1	N/A	Hose claps 20 pc	N/A	Amazon	$7.59
8	2	N/A	1/2" Check valve	Zurn	Amazon	$7.34
9	1	T-0500	5 Gallon Fresh Water Holding Tank NSF Approved	Class A Customs	Amazon	$37.20
10	1	N/A	5-gallon jug caps (9)	Huele	Amazon	$10.69
11	1	TBD	Water Pump	Shurflo	Amazon	$120.00

Table 30: BOM Malt and Hops Dispensing Unit

Malt and Hops Dispensing Unit						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	4	6101	PVC Gate Valve, White, 1-1/2" Slip	Valterra	Amazon	$13.74
2	4	2inchActuator	2'' Stroke Heavy Duty Linear Actuator	New Jia Qun	Amazon	$28.00
3	1	N/A	PVC Pipe Sch. 40 1 1/2 Inch. 4 ft	Ventral	Amazon	$14.88
4	1	GR9863	Homend DC12V 10inch Stroke Linear Actuator	Homend	Amazon	$40.95
5	1	N/A	6" PVC 2ft	Home Depot	Home Depot	$8.97
6	1	70156	Pipe Cap, 6 in, Hub, SCH 40, PVC, 6"	Genova	Amazon	$18.73
7	1	F01550D	Adapter, Schedule 40, 1" Slip x NPT Female	Nibco	Amazon	$6.64
8	1	GRSV-1	1" DC 12V Solenoid Valve N/C Normally Closed	Grodia	Amazon	$11.99

Table 31: BOM Cooling System

Cooling System						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	GIDDS203326	Copper Tubing 1/2" x 25'	Mueller	Amazon	$32.04
2	1	TBD	Cooling Pump	Shurflo	Amazon	$80.00
3	1	N/A	Stirring Motor	Bringsmart	Amazon	$23.77
4	1	N/A	Mixing Head	Allway	Amazon	$8.18

Table 32: BOM Control Cabinet and Electrical Equipment

Control Cabinet and Electrical Equipment						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	AHE18x18x6	NEMA 1 Hinged Cover Pull Box	Nvent	Zoro	$50.00
2	1	N/A	16 Channel Relay Module	Walfront	Amazon	$28.89
3	1	SLA-5VDC-SL-C	30A two-way 2-way relay module	Knacro	Amazon	$12.20
4	1	N/A	2pcs 8 Channel DC 5V Relay Module	Huayao	Amazon	$13.99
5	1	3/8-16 Rod Coupling	Pack of 5 3/8"-16 Rod coupling	Hillman Group	Amazon	$6.85
6	4	3/8-16	Bolts for backplate		Fastnal	$1.50
7	8	3/8	Lockwashers		Fastnal	$0.25
8	4	3/8-16	All thread Studs		Fastnal	$1.00
9	4	3/8	Fender Washers		Fastnal	$0.25
10	4	3/8	Nuts		Fastnal	$0.35
11	1	GCA20	Inline GFCI	Leviton	Amazon	$24.39
12	1	Nema 5-20P	Cord for plugging unit in		Amazon	$19.99
13	1	1.26Wx 1D	Wire Duct 6 foot long	Panduit	Amazon	$36.01

Table 33: BOM PCB

PCB Testing						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	N/A	Development Board	Arduino	Amazon	$30.74
2	1	N/A	Touch Screen Chip	Adafruit	Digi-Key	$34.95
3	1	N/A	WiFi Module	HiLetgo	Sparkfun	$6.95
4	1	N/A	Touch Screen	EastRising	BuyDisplay	$37.41

Table 34: BOM PCB

PCB						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	3	96M1143	CERAMIC CAPACITOR 22PF 50V	AVX	Arrow	$0.01
2	11	68R4839	CERAMIC CAPACITOR	YAGEO	Arrow	$0.01
3	2	68R4839	CERAMIC CAPACITOR	YAGEO	Arrow	$0.01
4	1	89F4578	JUMPER	BERG ELECTRONICS	Arrow	$0.10
5	1	18M4786	FUSE	LITTELFUSE	Arrow	$0.21
6	2	91B8548	FEET	3M	Arrow	$0.05
7	1	unknown	8-bit Microcontrollers	Microchip Technology / Atmel	Arrow	$12.20
8	1	68T2601	8 BIT MICROCONTROLLER MCU	MICROCHIP	Arrow	$2.09
9	1	23X6027	Fixed LDO Voltage Regulator	ANALOG DEVICES	Arrow	$0.98
10	1	96W2925	OP AMP	TEXAS INSTRUMENTS	Arrow	$0.24
11	2	12C1945	MICROCONTROLLER MCU	MICROCHIP	Arrow	$2.89
12	3	57AC7888	TERMINAL	AMP	Arrow	$0.11
13	1	41Y1379	FERRITE	BOURNS	Arrow	$0.02
14	1	55AC2390	IND CHIP 10UH	MURATA	Arrow	$0.05
15	1	09J9301	LED	LUMEX INC.	Arrow	$0.16
16	2	82AC9527	CAP	SAMSUNG ELECTRO-MECHANICS	Arrow	$0.24
17	2	52W1067	RES	PANASONIC	Arrow	$0.01
18	1	11X9320	RKWTS 4-288/2 M	LUMBERG AUTOMATION	Arrow	$15.78
19	2	94X1379	SURFACE MOUNT THICK FILM RESISTOR	MULTICOMP	Arrow	$0.01
20	1	64R5449	RES	PANASONIC	Arrow	$0.02
21	2	64R5247	RES	PANASONIC	Arrow	$0.01
22	2	55H2736	FEMALE DISCONNECT	MOLEX	Arrow	$0.30
23	1	84R5710	CRYSTAL	TXC	Arrow	$0.53

Table 35: Power Supply 24VDC to 12VDC

Power Supply 24VDC to 12VDC						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	GRM2165C1H102JA01J	Cap-1nF	MuRata	Arrow	$0.02
2	1	C2012X5R1V156M125AC	Cap-5uF	TDK	Arrow	$0.23
3	3	293D106X9063E2TE3	Cap-10uF	Vishay-Sprague	Arrow	$3.42
4	1	TMK212BJ474KD-T	Cap-470nF	Taiyo Yuden	Arrow	$0.02
5	1	SS14FL	VFatIo-0.55V	Fairchild Semiconductor	Arrow	$0.04
6	1	NPI52W8R2MTRF	L-8.2uH	NIC Components	Arrow	$0.26
7	1	SI4401BDY	VdsMax--40V	Vishay-Siliconix	Arrow	$0.69
8	1	ERJ-6ENF1431V	Resistance-1.43kOhm	Panasonic	Arrow	$0.01
9	1	CRCW0805549RFKEA	Resistance-549Ohm	Vishay-Dale	Arrow	$0.01
10	1	CRCW080510K0FKEA	Resistance-10kOhm	Vishay-Dale	Arrow	$0.01
11	1	CSR1206FK10L0	Resistance-0.01Ohm	Stackpole Electronics Inc	Arrow	$0.12
12	1	ERJ-6ENF7153V	Resistance-715kOhm	Panasonic	Arrow	$0.01
13	1	LM25085MY/NOPB	PFET Buck Controller	Texas Instruments	Arrow	$0.70
14	1	C0805C273K5RACTU	Cap-27nF	Kemet	Arrow	$0.02
15	1	F1-93U	Transformer	Triad Magnetics	Arrow	$30.64
16	1	BR62	Rectifier Bridge	Rectron	Arrow	$0.95
17	1	EEEHD1A682AM	Cap-6800uF	Panasonic	Arrow	$2.43

Table 36: BOM Power Supply 24VDC to 12VDC

Power Supply 24VDC to 12VDC						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	CL21C121JBANNNC	Cap-120pF	Samsung Electro-Mechanics	Arrow	$0.01
2	1	GRM31CR61H225KA88L	Cap-2.2uF	MuRata	Arrow	$0.10
3	1	XFL4012-121MEB	L-120nH	Coilcraft	Arrow	$0.53
4	1	ECPU1C474MA5	Cap-470nF	Panasonic	Arrow	$0.20
5	1	C3216X5R1H106K160AB	Cap-10uF	TDK	Arrow	$0.30
6	1	CGA4F2C0G1H153J085AA	Cap-15nF	TDK	Arrow	$0.07
7	1	NPI52P7R8MTRF	L-7.8uH	NIC Components	Arrow	$0.36
8	1	FDD8647L	VdsMax-40V	Fairchild Semiconductor	Arrow	$0.57
9	1	CRCW080510K0FKEA	Resistance-10kOhm	Vishay-Dale	Arrow	$0.01
10	1	ERJ-6ENF1913V	Resistance-191kOhm	Panasonic	Arrow	$0.01
11	1	CRCW08051K15FKEA	Resistance-1.15kOhm	Vishay-Dale	Arrow	$0.01
12	1	LM3150MH/NOPB	Voltage Regulator	Texas Instruments	Arrow	$1.62
13	2	CKG57NX5R1H226M500JH	Cap-22uF	TDK	Arrow	$2.02
14	1	C0805C104M5RACTU	Cap-100nF	Kemet	Arrow	$0.01
15	1	EMK212BJ225KG-T	Cap-2.2uF	Taiyo Yuden	Arrow	$0.03
16	1	CSD18537NQ5A	VdsMax-60V	Texas Instruments	Arrow	$0.30
17	1	ERJ-6ENF1913V	Resistance-191kOhm	Panasonic	Arrow	$0.01

Table 37: BOM 24VDC to 5VDC

Power Supply 24VDC to 5VDC						
Item #	**Order Qty**	**Part #**	**Description**	**Manufacturer**	**Vendor**	**Cost**
1	1	C0805C104M5RACTU	Cap-100nF	Kemet	Arrow	$0.01
2	1	C2012C0G1H822K060AA	Cap-8.2nF	TDK	Arrow	$0.05
3	1	CL21C221JBANNNC	Cap-220pF	Samsung Electro-Mechanics	Arrow	$0.01
4	1	50SVPF10M	Cap-10uF	Panasonic	Arrow	$0.41
5	1	C0805C104M5RACTU	Cap-100nF	Kemet	Arrow	$0.01
6	3	GRM31CR61C106KA88L	Cap-10uF	MuRata	Arrow	$0.08
7	1	SRN8040-8R2Y	L-8.2uH	Bourns	Arrow	$0.27
8	1	ERJ-6ENF2741V	Resistance-2.74kOhm	Panasonic	Arrow	$0.01
9	1	CRCW080519K1FKEA	Resistance-19.1kOhm	Vishay-Dale	Arrow	$0.01
10	1	CRCW0805100KFKEA	Resistance-100kOhm	Vishay-Dale	Arrow	$0.01
11	1	CRCW0805100KFKEA	Resistance-100kOhm	Vishay-Dale	Arrow	$0.01
12	1	TPS54334DRCR	Voltage Regulator	Texas Instruments	Arrow	$0.90
13	1	C0805C225K8RACTU	Cap-2.2uF	Kemet	Arrow	$0.04
14	1	NLCV32T-R10M-PFR	L-100nH	TDK	Arrow	$0.10

11. Administrative Content

11.1. Milestone Discussion

Initial project milestone for both semesters

The first two weeks of the summer semester should be picking an idea for the project, learning the process of brewing beer, determining what needs to be automated for our design, doing research on what components are needed, and determining operation and cost. The next two weeks will be going in further detail with the design and parts needed for power, control, and automation. This process will include detailed schematics for the PCB and power supply, generic step-by-step process for the entire project, and final production output of the system up to the bottling or kegging process. The next month will include a more detailed step-by-step process and how each component interacts with the next component as well as what the control unit will read and control such as heating, cooling, motor and pump control, temperature sensors, and any other automation needed. Each step will include what is supposed to happen, specific timing process, and detailed description of parts needed and what each part does. The board layout for the PCB should be completed and the power supply. The last month of the semester will include finalizing the design and process, reviewing the research and paper, and making sure nothing else needs to be added or removed from the design. At this point we should be ready to order parts and start building the project.

The next semester will consist of ordering parts, assembling the project, connecting the power supply and PCB, writing all the code needed for automation, testing everything for proper operation, and successfully complete the entire brew process before demonstration. The idea is to have the entire project built, including the power supply, PCB, and all attaching components in the first month. All of the coding should also be complete in this first month. This will allow us to test sooner and fix any issues we may have in the second month and add or remove features to the design if needed. At this point we should have a fully functional and working project. Since the process takes time to complete 1 cycle, we would have to start testing final operation in the third month. This will allow us to be completed and fix any final bugs in the system if any. We would like the project to be completed in the third month. Every two weeks should be a good check point for both semesters as a checkpoint to see where we are at for the project and how much was done and that needs to be done to meet these goals. Any modifications to the process should also be completed and updated every two weeks.

- **5/13/2019** Semester begins. Gather team together and start research on projects.
- **5/27/2019** Project decided on and research on idea and operation completed. Block diagrams, cost, parts needed, and basic drawing completed.
- **6/10/2019** Further details on operation, schematics, and parts needed
- **6/24/2019** Step-by-step design specifications for operation should be completed

- **7/8/2019** Coding, PCB schematic and board layout, and power supply design specifications complete
- **7/22/2019** Final project report should be completed and parts should be ready to order and assembled.
- **8/26/2019** Parts should be ordered and assembly of the project should begin
- **9/9/2019** PCB, power supply, and brew components need to be assembled and completed.
- **9/23/2019** Coding is to be completed and testing of individual component operation
- **10/7/2019** Initial testing and modifications completed if any
- **10/21/2019** Final tweaks to project and all operations to be tested at this time.
- **11/4/2019** Testing and operating
- **11/18/2019** Testing and operating
- **11/21/2019** Final presentation and demonstration
- **11/25/2019** Senior Design Showcase
- **12/4/2019** Final documentation

Appendix A: References

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Appendix B: Copyright Permissions

From: Ricky <Ricky.ye@dfrobot.com>
Sent: Saturday, June 22, 2019 8:47 AM
To: Jason Carlisle <jlcarlisle@Knights.ucf.edu>; Manufacturing Service <Manufacture@dfrobot.com>
Cc: Jason Carlisle <jlcarlisle@Knights.ucf.edu>
Subject: Re: Copyright

Dear Jason:

Please feel free to use our pictures for your projects.

best

Ricky

获取 Outlook for iOS

发件人: Jason Carlisle <jlcarlisle@Knights.ucf.edu>
发送时间: Saturday, June 22, 2019 8:16:54 PM
收件人: Manufacturing Service
抄送: Jason Carlisle
主题: Copyright

Hello DFROBOT,

I am an electrical engineering student at the University of Central Florida. I am part of senior design group consisting of four members. We are currently working on a design and report for our senior design project that will attempt to fully automate a brewing process. We have looked through several designs and would like to reference some pictures from your website in our document in which we will compare technologies and hardware. We will of course give credit to you or your website for images that we use. Thank you for your support in helping us further our graduation project.

We would be using pictures like the one shown below and we may choose to purchase one from your store to use in our project. We will not negatively depict anything on your site. Thank you in advance for the support.

Jason L. Carlisle EE

University of Central Florida

Copyright Permission

KR Kyle Rits
Today, 2:22 PM
sales@crystalfontz.com

Reply all

Good Afternoon,
My name is Kyle Rits, I am a computer engineering student at the University of Central Florida, and I am currently working on Senior Design, which is our capstone course for engineers. For our project, we are building and designing an automated brewing system. As part of the course, we are required to write a technical document cataloging our research, design, and parts. Can we have your permission to include some information and pictures from your website. Specifically the following:
https://www.crystalfontz.com/product/cfah2004dtmiet-character-display-20x4

20x4 Parallel Character LCD (CFAH2004DTMIET)

www.crystalfontz.com

Part Number: CFAH2004D-TMI-ET 20x4 character LCD module, White characters on a blue background, LED backlight.

However, I know as we get further along in the project, we made need more from the website. We would cite your company website as a source for any copyrighted pictures or information in the report.
Thank you very much,
Kyle Rits

Copyright Permission

BC Brent Crosby <brent@crystalfontz.com>
Today, 1:09 PM
Kyle Rits; Alicia Moore <sales@crystalfontz.com>; Deb Adair <deb@crystalfontz.com>; Jean Agte <jean@crystalfontz.com>; Trevin Jorgenson <trevin@crystalfontz.com>; +1 more

Reply all

To help protect your privacy, some content in this message has been blocked. To re-enable the blocked features, click here.

To always show content from this sender, click here.

Action Items

Kyle:

Sounds like a fun project.

Yes, you have our permission to use any material from our site about that display in your project. Yes, you may cite our website and datasheets.

We always appreciate links back to our site (from a video description or project web page, for example) but that is not required.

We would also love to see pictures of your project . . . perhaps we could feature your project in our blog ?

Please let us know.

-Brent

Crystalfontz
12412 East Saltese Avenue
Spokane Valley, WA 99216

Brent Crosby
brent@crystalfontz.com
www.crystalfontz.com
509.892.1200

Please rate my support.

ISO 9001:2015

Hey Laura,

That is perfectly fine! Thanks so much for the heads up. Best of luck on your project.

Best Regards,
Tech Support Team

Tech Support | **DFRobot**

Follow us on twitter to find out about coupons, promotions, projects, and cool happenings in the electronics world! Also, check out our Youtube channel for guides, tutorials, and general silliness.

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上海市浦东新区亮秀路 112 号 Y1 座 615 室

From: Laura Hoshino <hoshinol@knights.ucf.edu>
Sent: Monday, November 11, 2019 07:55 AM
To: Tech Support <techsupport@dfrobot.com>
Subject: Picture Usage Permission:Gravity: Analog pH Sensor / Meter Pro Kit For Arduino

Hello,

I am a senior electrical engineering student at the University of Central Florida in Orlando, Florida. I am currently in Senior Design (a capstone course for engineers) with a group. For our final engineering project, we decided to make an automated beer brewer. I would like permission to use a picture from your website to feature in our Senior Engineering research paper as a component that we considered using. This is the picture I would like to use:
https://www.dfrobot.com/product-1110.html

I would of course cite your company as a source in our final paper.

Thank you very much,

Laura Hoshino

Product details inquiry from Amazon customer Laura Hoshino

yeeco - Amazon Marketplace <rbqf0b9tw69ngcp@marketplace.amazon.
To Laura Hoshino

Reply | Reply All | Forward | ...

Tue 11/12/2019 9:47 PM

If there are problems with how this message is displayed, click here to view it in a web browser.
Click here to download pictures. To help protect your privacy, Outlook prevented automatic download of some pictures in this message.

Right-click or tap and hold here t...

You have received a message from the Amazon Seller - yeeco

Hi,
Yes~ you could use these pictures !
Wish you all the best !

Did this solve your problem?

Yes | No

Report suspicious activity

Right-click or tap and hold here t...

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Your e-mail to yeeco

Amazon.com <auto-communication@amazon.com>
To Laura Hoshino

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Tue 11/12/2019 9:35 PM

Here is a copy of the e-mail that you sent to yeeco. No further action is required on your part. Seller will communicate to you if there are any questions or comments.

------------- Begin message -------------

Hello,

I am a senior electrical engineering student at the University of Central Florida in Orlando, Florida. I am currently in Senior Design (a capstone course for engineers) with a group. For our final engineering project, we decided to make an automated beer brewer. I would like permission to use a picture of your product to feature in our Senior Engineering research paper as a component that we considered using. This is the component's pictures I would like to use:

Yeeco 30A High Current Relay Output Relay Control Module Power Switch Normally Open Normally Closed 5V DC Electric Current Amp Transfer for Cooler/Heater Cooler Heater Refit Water Heater Control

I would of course cite your company as a source in our final paper.

Thank you very much,

------------- End message -------------

Product details inquiry from Amazon customer Laura Hoshino

HY Hua Yao - Amazon Marketplace <qqzcbfjp756zcg2@marketplace.amazo
To Laura Hoshino

Reply | Reply All | Forward | ...

Thu 11/14/2019 9:07 AM

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Click here to download pictures. To help protect your privacy, Outlook prevented automatic download of some pictures in this message.

Right-click or tap and hold here t...

You have received a message from the Amazon Seller - Hua Yao

Hello Classmate
I agree Good luck

Did this solve your problem?

Yes | No

Report suspicious activity

Right-click or tap and hold here t...

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Your e-mail to Hua Yao

Amazon.com <auto-communication@amazon.com>
To Laura Hoshino

Reply | Reply All | Forward | ...

Tue 11/12/2019 10:13 PM

Here is a copy of the e-mail that you sent to Hua Yao. No further action is required on your part. Seller will communicate to you if there are any questions or comments.

------------- Begin message -------------

Hello,

I am a senior electrical engineering student at the University of Central Florida in Orlando, Florida. I am currently in Senior Design (a capstone course for engineers) with a group. For our final engineering project, we decided to make an automated beer brewer. I would like permission to use a picture of your product to feature in our Senior Engineering research paper as a component that we considered using. This is the component's pictures I would like to use:

Huayao 2pcs 8 Channel DC 5V Relay Module with Optocoupler for Arduino UNO R3 MEGA 2560 1280 DSP ARM PIC AVR STM32 Raspberry Pi

I would of course cite your company as a source in our final paper.

Thank you very much,

------------- End message -------------

For Your Information: To help protect the trust and safety of our marketplace, and to help arbitrate potential disputes, we retain all messages