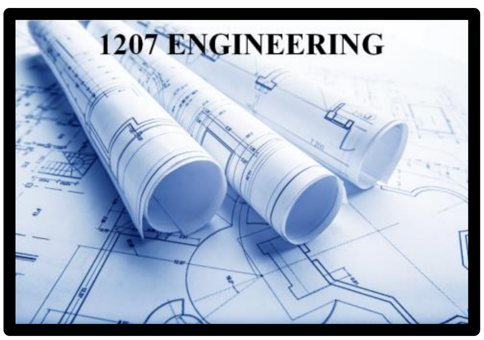
MAE 4344 – Senior Design Project
Final Report
December 9, 2022



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Introduction & Problem Description

As the world begins the transition toward more renewable forms of energy, new technologies and methods of storing energy must be developed to maximize the use of the energy being generated. One such method is the thermal energy storage (TES) tank for industrial and domestic applications.

During peak hours when wind and solar energy generation reaches its maximum output, not all of the energy is consumed and, since it is unable to be stored, it is, therefore, lost. The concept behind TES tanks is that, during these peak hours, water can be heated or cooled and stored for later use when wind and solar output falls off. Applications for the water include heating and cooling of houses and buildings and for hot and cold water supply.

For a TES system to operate at maximum efficiency, a critical issues has to be addressed: mixing. Figure 1 provides a very basic layout of the TES system. In this case, the hot water is being used for heating purposes and is pumped through the heat pump and piping system (the opposite configuration can be used as well where cold water is used for cooling purposes and heats up before returning to the tank). As this hot water passes through the system, it cools down and returns to the tank much cooler than the initial hot water temperature. If this cool water is allowed to mix with the hot water, it will lower the temperature of the hot water and make it less effective. In an ideal situation where no mixing occurs, the temperature zones in the tank would closely resemble those in Figure 1 with clearly distinct zones and a very small thermocline zone (i.e. transition zone between hot water and cool water). This distinct separation of the temperature zones is called stratification. However, this is not realistic for a tank simply filled with water, so a way to minimize mixing and maintain stratification must be developed.

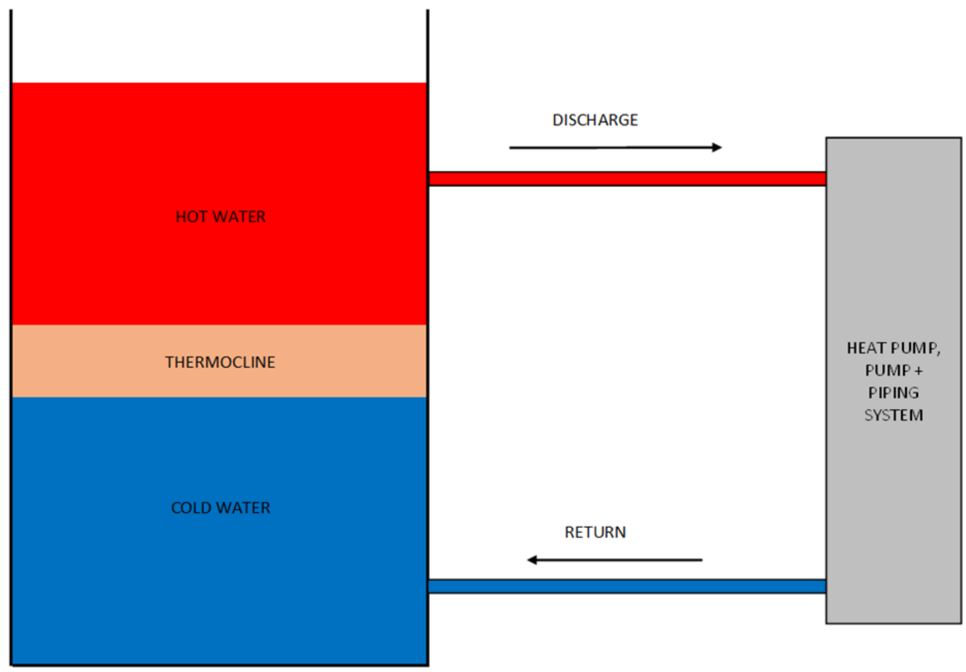


Figure 1: Elementary Diagram of TES Tank System & Temperature Zones for a Hot Water Application

Figure 2 below shows the same tank and heating system from Figure 1 only with the addition of a baffle system. The baffle configuration is entirely arbitrary for the purposes of this segment. The concept behind a baffle system is it creates somewhat of a barrier between the hot and cold zones and allows for the cooler inlet water to settle before being displaced upward. Reducing the turbulence of the inlet water and isolating it to some degree from the hot water minimizes the mixing effect and, in theory, creates a small thermocline.

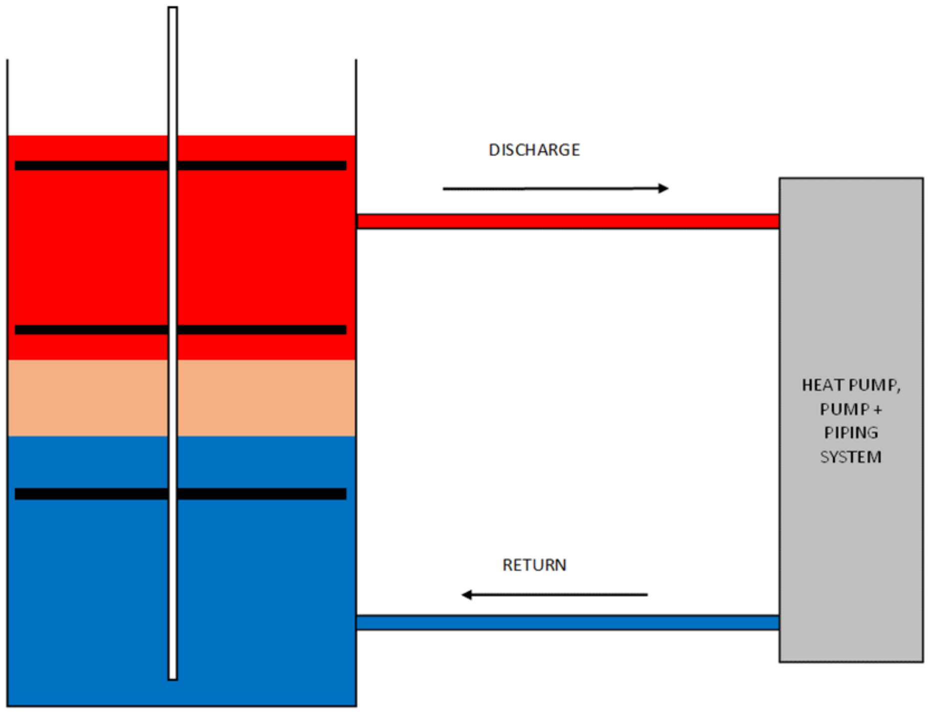


Figure 2: TES Tank with Baffle System in Place

The purpose of this project for this semester (Fall 2022) was to develop a test bed for future senior design groups to conduct tests with different baffle configurations and flows rates to determine which configuration produces the smallest thermocline and minimal overall mixing. The purpose of this project over its lifespan is threefold:

1. Design, develop, & fabricate a TES tank test bed to test baffles designs & configurations
2. Test different baffle designs & configurations under different conditions (i.e. water temperatures & flow rates)
3. Establish a strong foundation for future project development & implementation in below-ground TES systems

In an ideal setting, a tank appropriate for below-ground testing would be fabricated to begin with, but material, time, and budget constraints for this project did not allow for this. The primary differences between this system and actual TES systems are (1) the system is not connected to an actual heating/cooling system, so the effectiveness of the tank at heating/cooling a building cannot be observed; (2) the system is tested above-ground, so the effect of geothermal insulation is not observed; and (3) the project was limited to using commercial-off-the-shelf (COTS) components and no specially-fabricated components were employed.

Engineering Principles

Given the nature of this project, it was required that a working knowledge of (1) heat transfer, (2) thermal fluids design, (3) fluid mechanics, and (4) data acquisition be had in order to properly and effectively develop, test, and analyze the system.

The tank is composed of relatively thin-walled high-density polyethylene (HDPE), which creates a small conductive medium between the working fluid and the primary insulator, air. As a way of adding additional insulation to the tank and, thus, minimize heat transfer, reflective roll insulation was added to the exterior of the tank.

In order to heat and cool the working fluid, a heat exchanger was tied into the plumbing and can be connected to a local tap for hot or cold water supply. The heat exchanger is a manufactured product that has been specifically engineered for this kind of application.

Since the entire system is intended to serve as a test bed for optimizing baffle configuration, there are no designed flow rates. Flow rate will be altered over the course of the testing phase in order to determine if one flow rate is preferable to another with the baffle configuration being tested at that time.

The means of analyzing the effectiveness of the baffles and corresponding flow rates is a data acquisition (DAQ) system comprised of an Arduino connected to ten temperature sensors at various depths in the tank as well as a flow meter downstream from the pump. Flow rate can also be recorded manually by timing the cumulative gallons pumped from the flow meter.

Environmental, Health, & Safety (EHS) & Other Considerations

This project has significant environmental, health, and safety implications. With regards to environmental implications, this project is specifically designed to take advantage of renewable energy, which, if widely implemented, could generate a decent reduction in fossil fuel consumption. The end goal is to use renewable energy during nonpeak hours of the day to charge a battery in the form of a consumer-side TES water tank. This energy would be used during peak hours to help shave the peak from the power grid curve. In addition to this, the system, once deemed field-ready, will largely rely on geothermal insulation to maintain the water temperatures in the tank.

With regard to health, there are no significant concerns with the components or the system as a whole. Water, from the City of Stillwater's municipal water supply, is the working fluid for this system. Aside from base load power supplying energy to the pump and DAQ, the design generates zero emissions. And lastly, the system, if successful, would benefit the health of its users by providing heating and cooling services to people, providing better living conditions in the form of the temperatures they are living and working in.

Much like the health concerns of this project, the safety concerns are minimal as well. Possible safety concerns include spills, overhead falling objects, ladder safety, and electrocution. Since water is, again, the working fluid for this design, spills would have a minor impact, especially since containment is being used as a precaution and there is a floor drain present in the testing space to immediately evacuate the water. In terms of overhead falling objects, ensuring there is no one below any components that are being hoisted will help to mitigate this concern as well as wearing hardhats. With regard to ladder safety, having a teammate present to hold the ladder steady as well as taking ladder safety training prior to any ladder use to understand the dangers associated with ladders will help to minimize this issue. Lastly, the pump and DAQ system will be plugged into 120V wall outlets, so appropriate precautionary measures should be taken to ensure the setup and components are safe. A ground fault circuit interrupter (GFCI) is included in the project, so this should be included in the electrical setup.

In addition to EHS considerations, the sustainability, societal, and global implications of the design must be taken into account. Since the intention of the design is to rely primarily on renewable energy, the non-reliance on fossil fuel-based power sources adds considerably to the sustainability of the system. On top of this, the design is made up of components with long lifespans and with the potential for repurposing after they have exceeded their lifespans.

In terms of the societal impacts of the design, if renewable energy use can be maximized, then the energy savings to consumers could be substantial. Another added plus to this would be that consumers could rely more heavily on renewable energy sources and achieve a greater sense of energy independence if fossil fuel use can be reduced.

The final consideration is the impact this design could have on the world. There is a direct correlation between energy consumption and quality of life. If more energy can be used, stored, and made available to the world, then it is believed the global standard of living could be improved.

Stakeholders

The primary stakeholders in this project include:

1. Project investors/supporters
2. The research community
3. Utility & service companies
4. Individuals
5. Households
6. Communities
7. Governments
8. Industry

The project investors/supporters are, namely, Dr. Bach & Dr. Spitler, the Center for Integrated Building Systems (CIBS), and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). The research community includes CIBS, ASHRAE, Oklahoma State University, and a number of unnamed organizations. Utility and service companies would have an interest in this because it could have a direct impact on the power grid if implemented on a large scale. As mentioned in the societal considerations, individuals, households, and communities could see lower utility costs if the design is used. Governments, more specifically entities such as the U.S Department of Energy, may have to regulate the product and/or analyze the macroscopic impacts of the design on national energy consumption and other related items. Lastly, if implemented on a large scale, repairs and other services will likely open up supporting industrial opportunities as well as a global opportunities if companies decide to use the product across the world.

Stakeholder Involvement

A critical aspect of having stakeholders is that the stakeholders be involved in the design and testing of the TES tank. Since Dr. Bach and Dr. Spitler are the principal investigators for this project, it was relatively easy to keep them in-touch with new developments. Constant communication was maintained with them to throughout the course of this semester to ensure their requirements and standards were met.

Engineering Codes, Standards, and Guidelines

A couple of the engineering codes and standards that apply to our design include ASHRAE 34 and ASHRAE 41. ASHRAE 37 is the design standard for installation of heat pumps and heat exchangers. Our design has a heat exchanger placed between the pump and the tank, so this section of ASHRAE will be used. ASHRAE 41 is the standard methods for measurement including both temperature and flow rate measurement. Temperature and flow rate measurement are crucial to our design. The temperature measurements will be used to discover the thermocline and the flow rate will be altered to optimize the thermocline. ASHRAE 41 is a key part to the testing and validation of the design.

In addition to these two engineering codes, ASHRAE STD RP-1719 was considered, which is a design guide for cool thermal storage units. While this document is simply a design guide, it will likely be heavily used to create an efficient thermal energy storage unit.

Knowledge Acquisition

Because the team this semester only consisted of two people, it was crucial that knowledge gaps be recognized and sources of information identified to fill those gaps. Some sources of knowledge included professors and staff (particularly Dr. Bach and Dr. Spitler), literature, and industry contacts.

The major knowledge gaps that had been recognized included data acquisition, instrumentation, and fabrication. Plans were made to fill these knowledge gaps by finding mentors and resources to guide the team through the project. The plan to fill the data acquisition knowledge gaps was to attend future LabVIEW sessions that may be provided, seek advice from Dr. Rowland and Dr. Bach, and use any student help that we could while setting up the DAQ system.

To ensure that the instrumentation setup was correct, the team sought the counsel from Dr. Bach as well as his TA, Pouria. We also sought assistance from John Gage and Dr. Conner with regards to the actual fabrication of our baffles. Figure 3 outlines the team's knowledge acquisition plan that was executed over the course of the project.

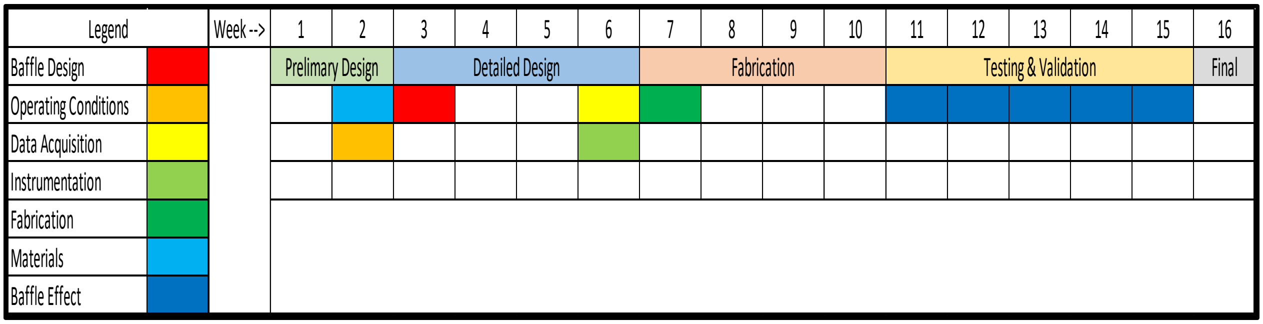


Figure 3: Knowledge Acquisition Plan

Detailed Design

<u>Concept Generation</u>

In preparation for the preliminary design review, four concepts for the TES tank were generated. In order to determine the best possible selection, a decision matrix (<u>Figure 4</u>) was developed to analyze the concepts. Initial parameters for the project included but were not limited to:

1. 180-gallon tank
2. Able to be deployed in 3-foot diameter x 10-foot deep hole for geothermal insulation
3. 1.0-10.0 GPM flow rate range
4. $1,000-1,300 budget

The oil drum concept was ranked lowest due to its material (steel) having a tendency to corrode in subsurface conditions and because the steps that had to be taken in order to fabricate it were extensive. The PVC tank, in theory, was a decent concept because the tank could be constructed somewhat easily and to the appropriate dimensions. The price tag and lead times, ultimately, prevented this design from being realized. The 200-gallon and 300-gallon tanks were essentially identical in terms of material and material properties. Convenience and cost ultimately led the team to select the 300-gallon tank (<u>Image 1</u> & <u>Image 2</u>) because the tank was already available on campus and there would be no cost to use it.

		Oil Drum Tank		200-Gal Tank		300-Gal Tank		PVC Tank	
Criteria	**Weight**	Score	Total	Score	Total	Score	Total	Score	Total
Cost	4	2	8	3	12	5	20	1	4
Lead Times	5	3	15	4	20	5	25	1	5
Ease of Fabrication	3	1	3	5	15	5	15	3	9
Appropriate Size	4	5	20	5	20	5	20	5	20
Field Deployable	4	1	4	3	12	3	12	5	20
Materials	4	1	4	5	20	5	20	4	16
Able to be modified	4	3	12	4	16	4	16	4	16
Mobility	3	4	12	4	12	4	12	4	12
Total Scores		78		127		140		102	

Figure 4: Decision Matrix for Tank Selection

Image 1: 300-Gallon Ace Roto-Mold Tank

Image 2: Top of 300-Gallon Ace Roto-Mold Tank

After selecting a tank, the heating & cooling mechanism had to be addressed. Dr. Bach made the team aware of a Danfoss micro plate heat exchanger (Image 3) that was available for use. To heat the fluid in the tank, hot water from the tap could be plumbed into the heat exchanger and then the fluid in the tank pumped through the heat exchanger and then back into the tank. For a cooling effect, cold water from the tap would be plumbed into the heat exchanger.

The next issue that had to be addressed was how to connect the pump to the heat exchanger and then the heat exchanger to the flow cross. The team proposed the design shown in Image 4 which consists of PVC components attached to the heat exchanger connections. The heat exchanger has 2-in connections which eventually had to be reduced to fit 1-in diameter PVC tubing. This was achieved by using PVC reducers, which can be seen in the final design in Image 5.

Image 3: Danfoss Micro Plate Heat Exchanger

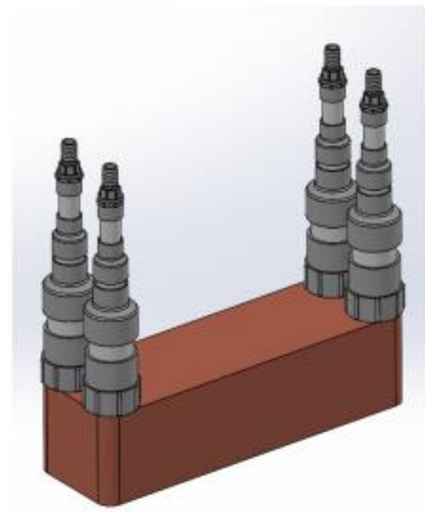


Image 4: Heat Exchanger Connection Design

Image 5: Final Heat Exchanger Design

In order to drive the system, a pump of adequate size had to be selected. Dr. Bach recommended reaching out to Dr. Rowland at the ENDEAVOR lab to see if there may be an extra pump on-hand. After contacting Dr. Rowland and browsing through some options, a Jebao DCP-20,000 (Image 6) was selected (head loss calculations and pump curves will be provided in a later section). The pump would be connected to the discharge side of the flow cross (discussed later) and to the inlet side of the heat exchanger. Because of this, an adapter system had to be developed in order to connect the pump to these two points. The original design can be seen Figure 5. However, given some hesitations about the pump, the team decided to pursue another option, a Viridian variable flow pump (Image 10). This pump was provided by Dr. Bach and will be discussed later on in the engineering analysis section of this report. The connections for this pump are simply ¾-in hose fittings, so no assembly had to be constructed in order to integrate the pump into the system.

Image 6: Jebao DCP-20,000 Pump

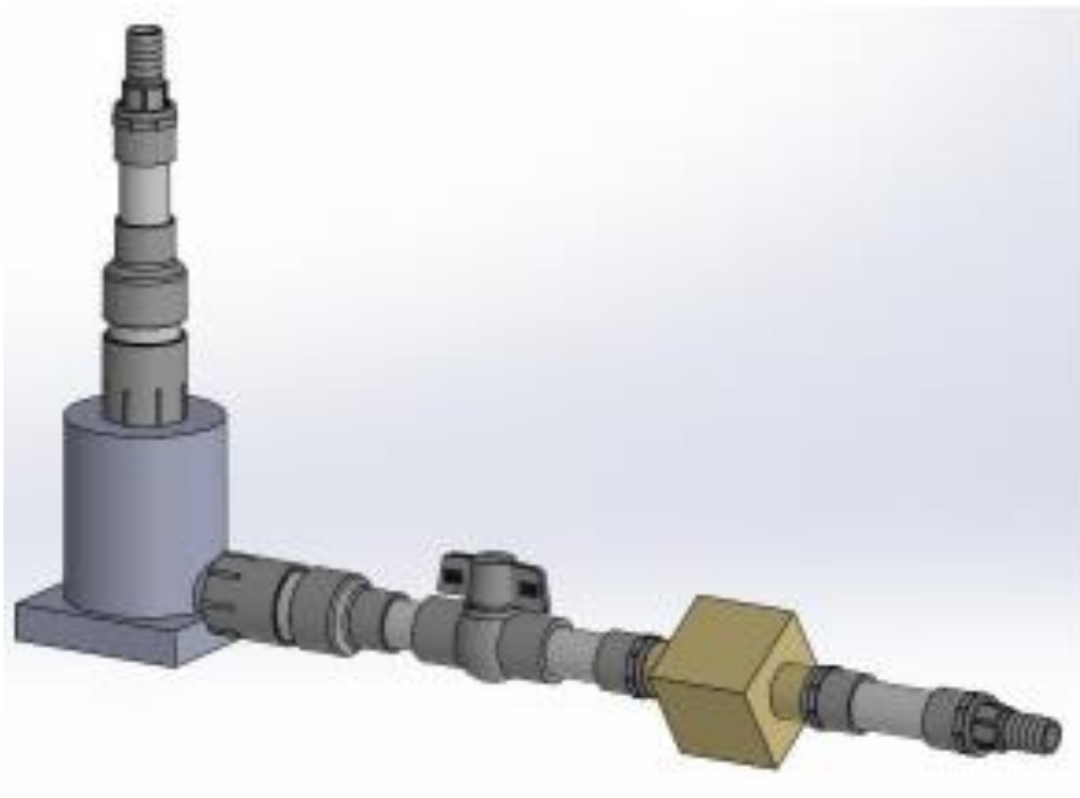


Figure 5: Original Pump Design

The TES system needs to be able to discharge both hot and cold water. Because of this, a method of reversing the flow direction without changing the pump setup had to be developed. Figure 6 & Figure 7 provide a basic visualization of how this will be achieved.

In Figure 6, the cold water is being discharged to be used for cooling applications. A simple flow loop can be configured by simply opening valves 2 & 5 and closing valves 1, 3, 4, & 6. Cold water passes through valve 5, into the pump, on to the heat exchanger, through valve 2, and back into the tank.

In order to discharge hot water, the configuration changes. Figure 7 shows that if valves 2 & 5 are closed and valves 1, 3, 4, & 6 are opened, the flow will cross, allowing the hot water to enter the pump, pass through the heat exchanger, and then cross back over to the cold water inlet.

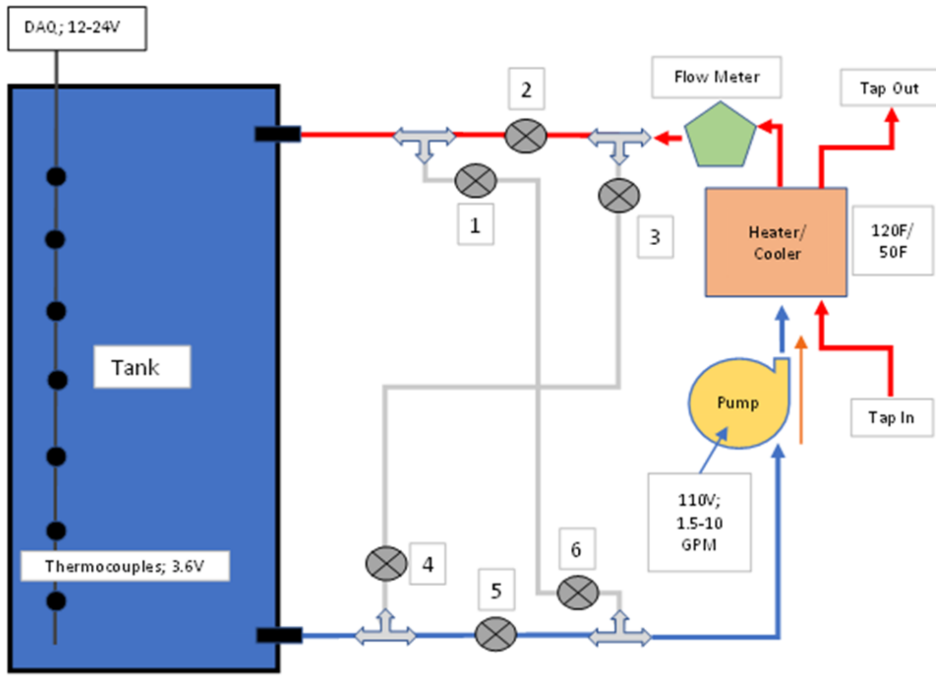


Figure 6: Cold Water Discharge Flow Loop Configuration

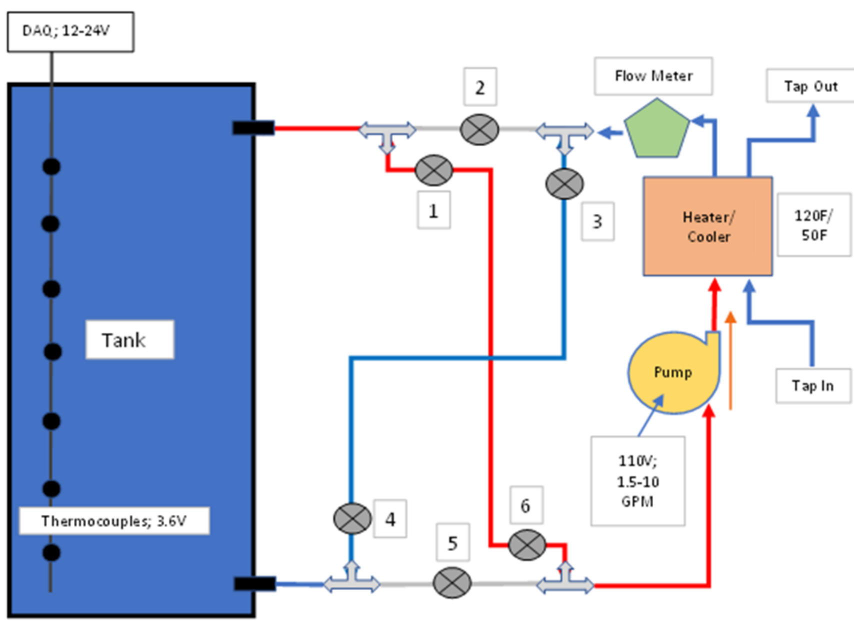


Figure 7: Hot Water Discharge Flow Loop Configuration

The mechanism that was designed to cross the flows is appropriately called the flow cross. Using the diagrams in Figure 6 & Figure 7 as references, the design was realized in SolidWorks using model PVC components readily available at Lowe's (Figure 8) and then fabricated (Image 7).

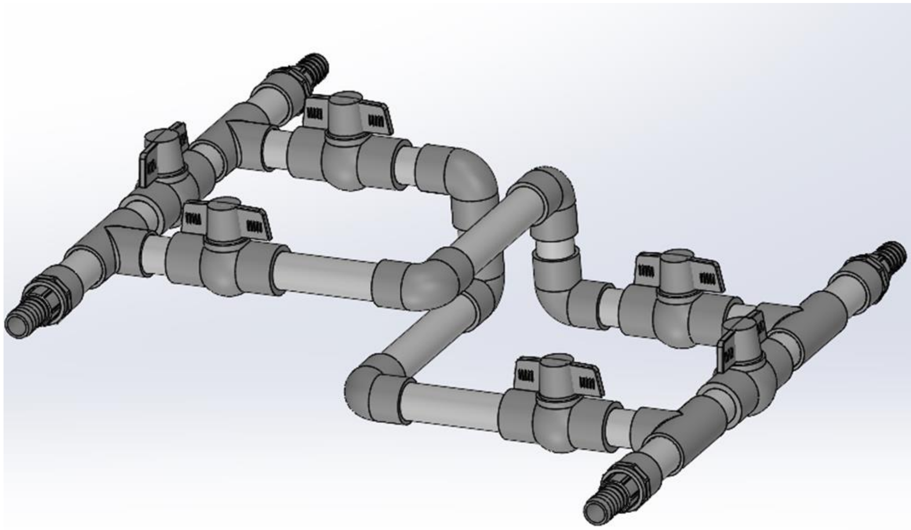


Figure 8: SolidWorks Rendering of Flow Cross

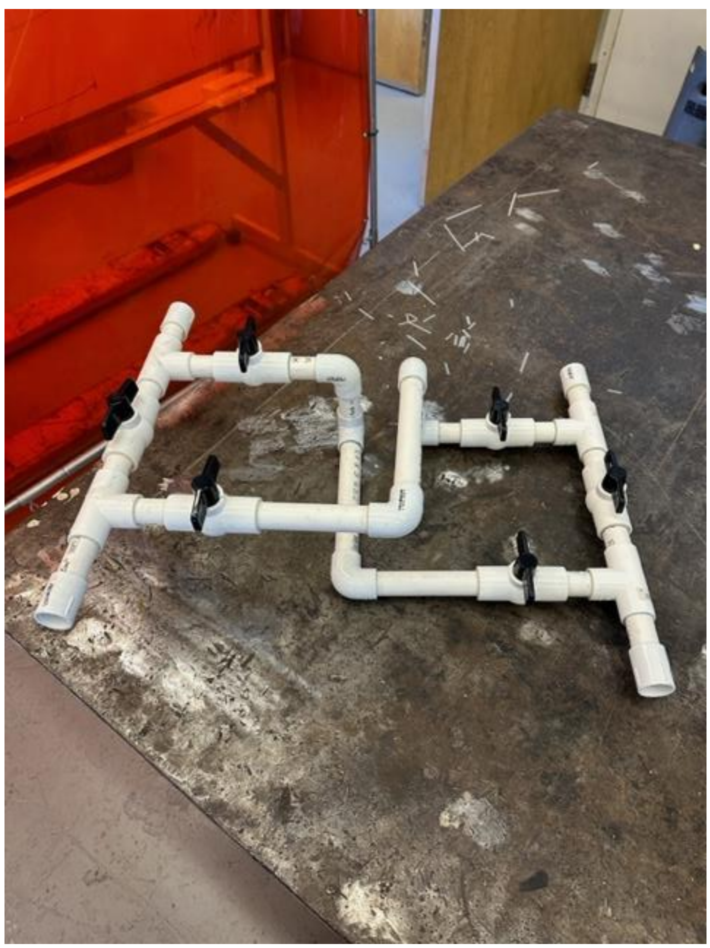


Image 7: Flow Cross Minus Hose Connections

In order to circulate water in and out of the tank, an inlet/outlet system had to be developed to pump water into the hot and cold zones. Early ideas included inlet ports at the top and bottom of the tank, but after receiving some advice from Dr. Seeton, a new concept was developed which would allow water to be pumped in and out through the top of the tank. This concept employs dip tubes (Figure 9) which extend from the top of the tank into the hot and cold regions. Originally, is was intended for these dip tubes to be connected to the lid of the tank, however, after realizing the difficultly of involving the tank lid in the insertion and removal of the baffle system, the team elected to abandon this concept in favor of leaving the top of the tank open-ended for easy access (Image 8). Valves at the tops of the dip tubes allow them to be isolated, mitigating the hazard of a siphon developing while also keeping the system primed when it is not in use. PVC tubing connects the dip tubes to the flow cross.

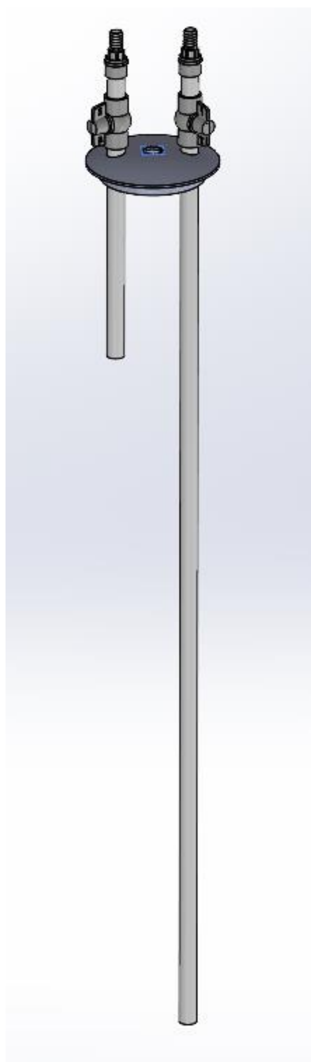


Figure 9: Dip Tube Design

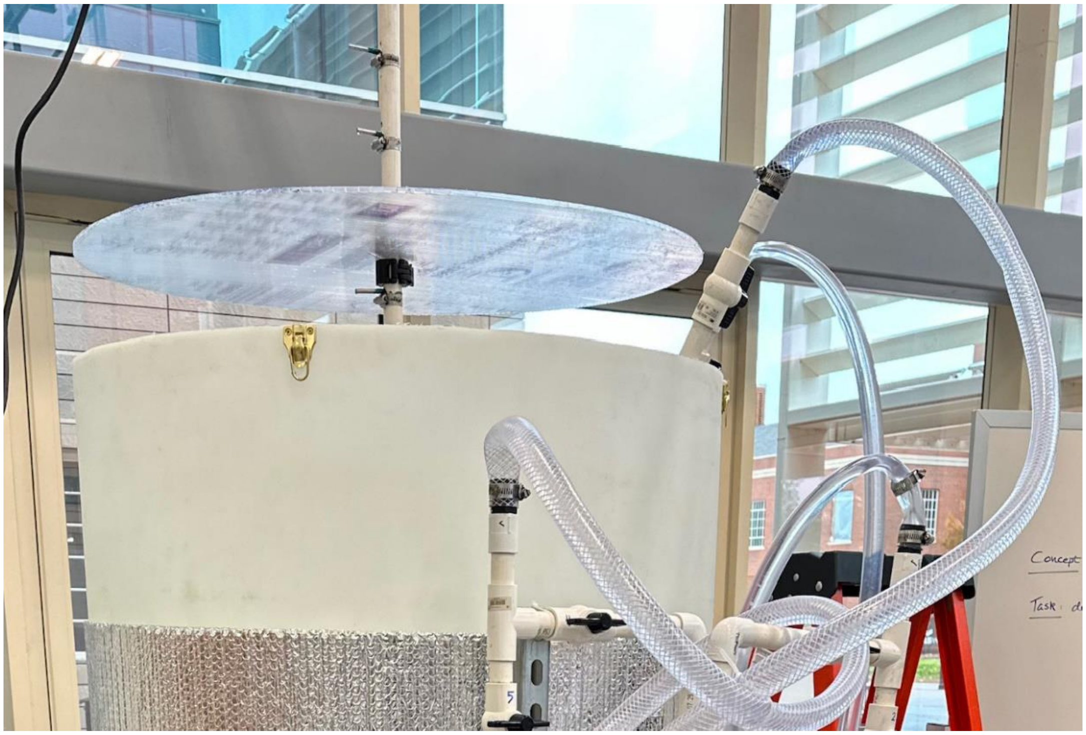


Image 8: Dip Tubes in Open Top Tank

The next component that will be addressed is the baffle system. Based on concepts found in literature (*An Experimental Study of Stratified Thermal Energy Storage Under Variable Inlet Temperature Conditions*, Abu-Hamdam, 1986), two primary baffle configurations are recommended for testing: perforated and non-perforated (Figure 11). The perforated baffles allow water to pass through them whereas the non-perforated baffles are simply a disk than allows water to flow past its edges. The baffles are not flush with the inside of the tank, which allows for water to pass by the edges of both baffle types. With regard to perforated baffles, different perforation sizes should be trialed to determine if one perforation size performs better than another.

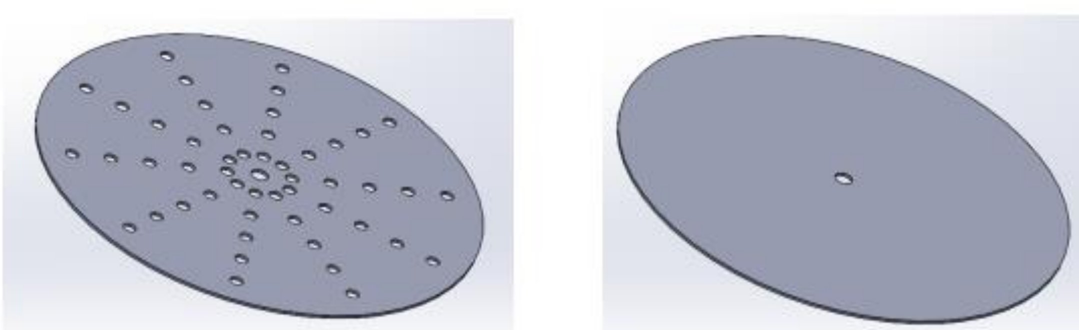


Figure 10: Perforated (left) and Non-Perforated (right) Baffles

Initially, the final assembly was thought to resemble Figure 12. But, after some discussion halfway through the semester, the team pivoted to focus on packaging the system in a way that could easily be moved. The result was the configuration shown in Image 9. Note: all engineering drawings are available at end of report.

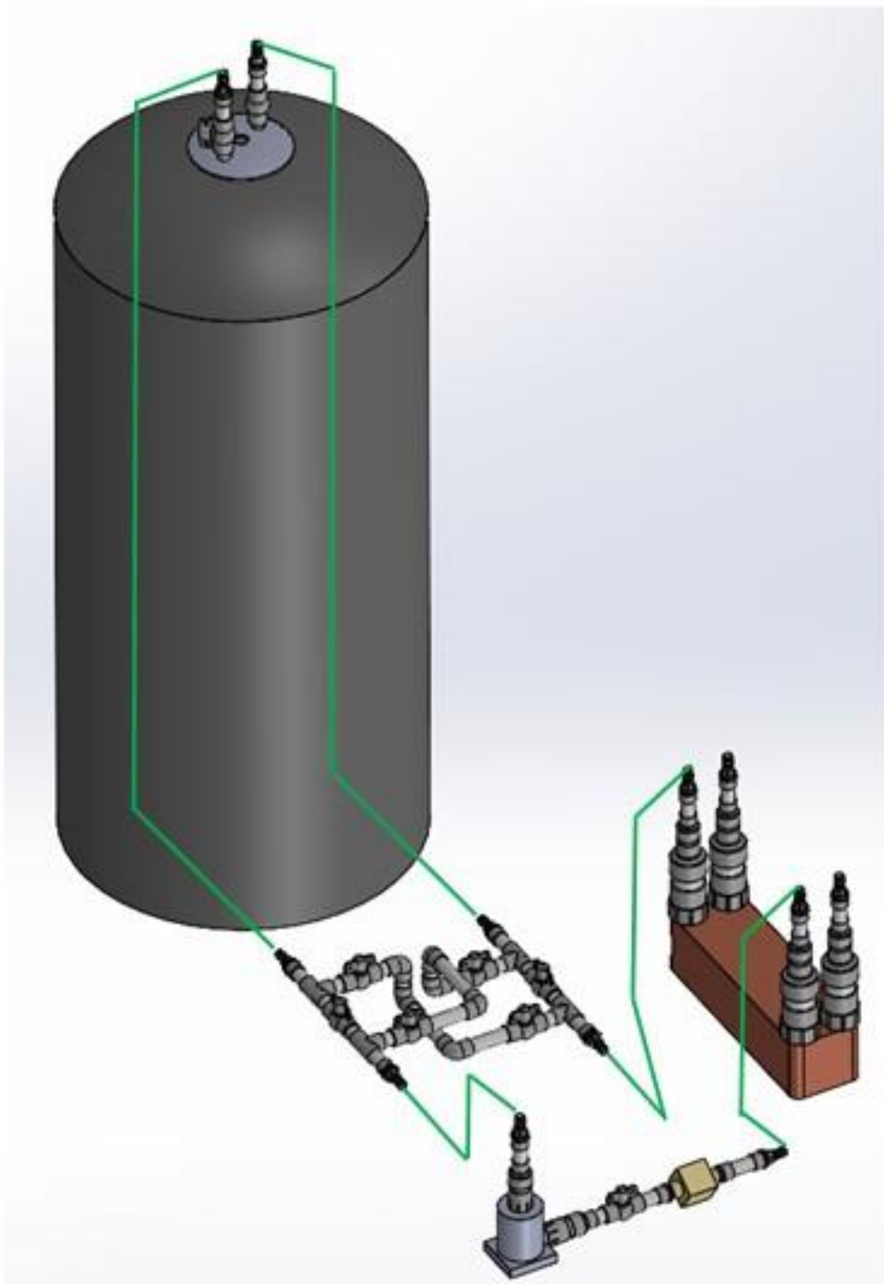


Figure 11: Full Assembly

Image 9: Final System Configuration

To collect data during testing, the team decided to use temperature sensors connected to an Arduino that would then read out to a computer. Each temperature sensor is a DS18B20 and was initially about 2 feet long. These cords have three wires: one ground connects to ground, one connects to 5 volts, and one connects to the data output. Temperature sensors were installed along the length of the shaft holding the baffles. The sensors were soldered to extension wiring that was run through the length of the shaft and out the top to an electrical box that contains the Arduino and breadboards. A 20-foot USB adapter cable was then attached to the Arduino so it could be connected to a computer. The setup is visible in Image 10.

The colors of the wires that correlate to their function are as follows:

Black – ground
Red – 5 Volt
Clear – Data output

The team was guided to use breadboards for the instrumentation for a good reason: they are simple and cheap, and, if errors are made, it is very simple to fix. However, the team overlooked the fact that the connections in a breadboard are insecure, and the wires can pop out when moving the instrumentation pole, which is not easily fixed. The team discovered this issue too late into the semester to change the system. Therefore, the team would encourage future semesters to use a PCB board instead with much more solid connections so that this is not an issue. Note: the Arduino code to operate the instrumentation is saved to the team files.

Image 10: Baffle Shaft Setup with Temperature Sensors and Instrumentation Box

Electrical Diagram

The electrical diagram (Figure 13) is very simple and can be found below. The flow meter, which will need to be connected by a future project team, is connected to the Arduino which in turn is connected to computer connected to a 120V wall source. The pump is also connected to a 120V wall source. The heat exchanger requires no electrical power.

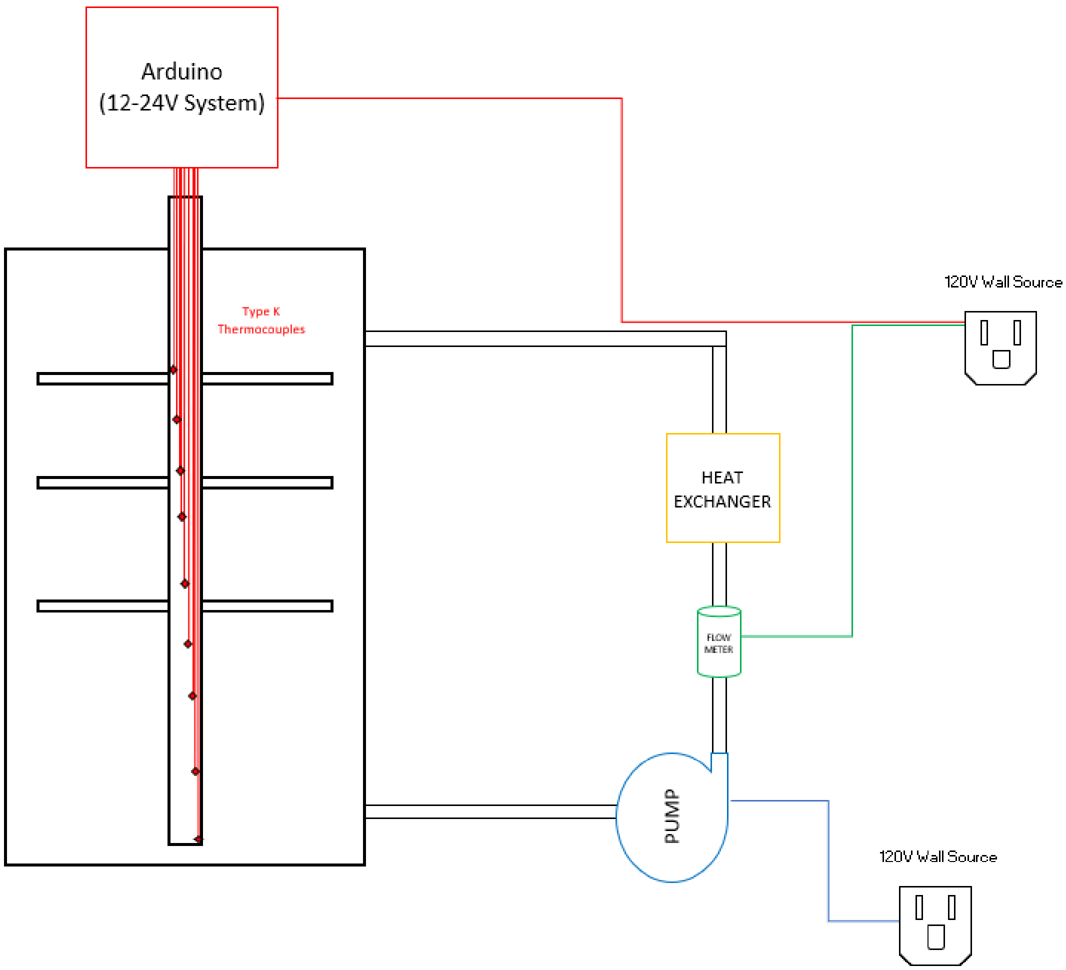


Figure 12: Electrical Diagram

Engineering Analysis

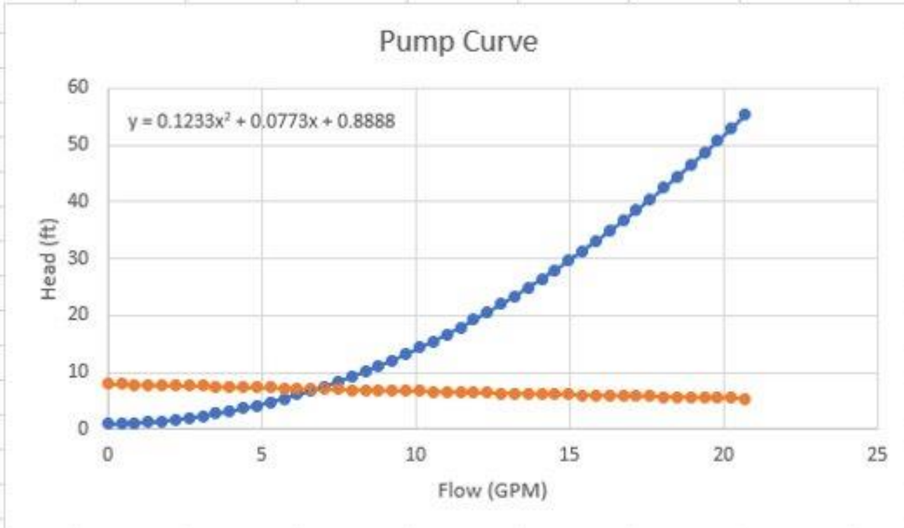
Head Loss & Pump Selection

The individual components of the system were tallied up and the head loss through each of component calculated for various flow rates between 1 GPM and 10 GPM. Table 1 and Table 2 outline the steps and parameters used to determine the head loss while also providing the approximate range of the system head loss from 1-10 GPM, Table 1 being the calculations for 1 GPM flow rate and Table 2 being the calculations for 10 GPM flow rate.

The same process outlined in the tables was carried out for 1-in diameter and ½-in diameter systems. The ½-in diameter system had too much head loss, whereas the 1-in system worked, but the components were expensive. The head loss for the ¾-in system was calculated and was deemed acceptable. This allowed for cost savings by using ¾-in components rather than 1-in components. In addition to using ¾-in components, 1-in ID PVC tubing was used to connect the various system components This tubing is relatively inexpensive and also helps to reduce the head loss of the system.

With the help of Dr. Bach, the head loss through the heat exchanger at flow rate between 1-10 GPM was found using Danfoss's Hexact software. Adding this head loss to the calculated head losses from using the formulas in Table 1 and Table 2, a design curve was generated for the Jebao pump (Image 12) with a design point of 13.85 feet of head at 10 GPM. There was an issue, however, with the Jebao pump's pump curve. The pump curve was absent for rates below 35 GPM (the curve in Image 12 was developed using a plotting software to project the curve down to lower flow rates). So, under the advisement of Dr. Fisher, the team looked to an alternative pump, a Taco Viridian VR 3452 (Image 11) whose pump curve is given in Image 13. The calculated design points falls well within the pump's capability, so this is the pump the team decided to move forward with.

Image 11: Viridian Pump



L/Hr	GPM	3rd Order	2nd Order	Design
1500	6.604438	8.092107	7.1225	6.777497
1600	7.044734	8.091308	7.0656	7.552525
1700	7.48503	8.090509	7.0089	8.375358

Image 12: Jebao DCP-20000 Pump Curve for 3/4-in System

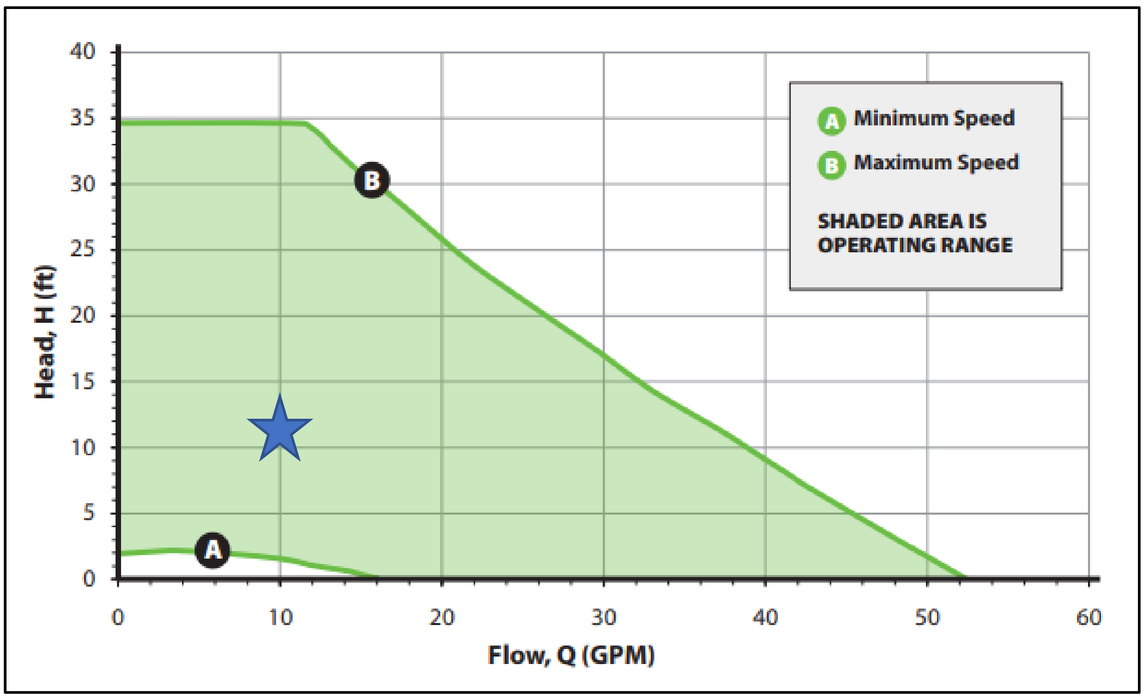


Image 13: Viridian Pump Curve (Star = Design Point)

Table 1: Head Loss Calculations for 3/4-in System at 1 GPM Flow Rate

0.75-in Diameter Pipe @ 1 GPM												
1 GPM Flow =	0.02220	(ft^3/s)	Kinematic Visc @ 50F =	0.000014	(ft^2/s)	Roughness (in) =	0.00006	K-Value =	0.5			
Component	ID (in)	Length (in)	Cross Section Area (in^2)	Flow Velocity (ft/s)	Reynolds Number	Flow	ε/D	Friction Factor	Head Loss (ft)	No. of Components	Total Head Loss (ft)	Pressure Drop (psi)
0.75-in D Elbow	0.804	2.1	0.508	6.297	30134.241	Transition	0.00008	0.042	0.0675388	6	0.405233	0.175871158
0.75-in D Tee - Straight	0.804	1.4	0.508	6.297	30134.241	Transition	0.00008	0.042	0.0450259	0	0.000000	0
0.75-in D Tee - Bend	0.804	4.1	0.508	6.297	30134.241	Transition	0.00008	0.042	0.1318616	4	0.527446	0.228911667
0.75-in D Ball Valve	0.804	1.5	0.508	6.297	30134.241	Transition	0.00008	0.042	0.0482420	9	0.434178	0.188433384
0.75-in D x 3-in L PVC	0.804	3	0.508	6.297	30134.241	Transition	0.00008	0.042	0.0964841	17	1.640229	0.711859451
0.75-in D x 4-in L PVC	0.804	4	0.508	6.297	30134.241	Transition	0.00008	0.042	0.1286454	2	0.257291	0.111664228
0.75-in D x 8-in L PVC	0.804	8	0.508	6.297	30134.241	Transition	0.00008	0.042	0.2572908	2	0.514582	0.223328455
0.75-in D x 18-in L PVC	0.804	18	0.508	6.297	30134.241	Transition	0.00008	0.042	0.5789044	1	0.578904	0.251244512
0.75-in D x 72-in L PVC	0.804	72	0.508	6.297	30134.241	Transition	0.00008	0.042	2.3156176	1	2.315618	1.004978048
0.75-in Socket-to-Thread Fitting	0.804	2	0.508	6.297	30134.241	Transition	0.00008	0.042	0.0643227	9	0.578904	0.251244512
Barbed Hose Fitting for 0.75-in ID Hose	0.804	1.969	0.508	6.297	30134.241	Transition	0.00008	0.042	0.0633257	9	0.569931	0.247350222
1-1/2 in Threaded Female-Female Fitting	1.59	2.0625	1.986	1.610	15237.692	Laminar	0.00008	0.042	0.0021929	1	0.002193	0.000951728
1-1/2 in Threaded Male-Socket Female Fitting	1.59	2	1.986	1.610	15237.692	Laminar	0.00008	0.042	0.0021265	1	0.002126	0.000922887
1-1/2 in D x 3-in L PVC	1.59	3	1.986	1.610	15237.692	Laminar	0.00008	0.042	0.0031897	1	0.003190	0.001384331
1-1/2 in to 0.75-in PVC Reducer	1.59	5.1	1.986	1.610	15237.692	Laminar	0.00008	0.042	0.0054225	1	0.005422	0.002353363
2-in Female Threaded-to-Socket Fitting	2.047	2.41	3.291	0.971	11835.823	Laminar	0.00008	0.054	0.0009315	2	0.001863	0.00080855
2-in D x 5-in L PVC	2.047	5	3.291	0.971	11835.823	Laminar	0.00008	0.054	0.0019326	2	0.003865	0.001677489
2-in to 0.75-in PVC Reducer	2.047	5.1	3.291	0.971	11835.823	Laminar	0.00008	0.054	0.0019712	2	0.003942	0.001711038
0.75-in ID Plastic Tubing	0.75	360	0.442	7.236	32303.906	Transition	0.00008	0.045	17.5620011	1	17.562001	7.621908487
EKM Metering 3/4-in Hot Water Meter	0.804	10	0.508	6.297	30134.241	Transition	0.00008	0.045	0.3445860	1	0.344586	0.149550305
Danfoss Heat Exchanger									1	1	1.000000	0.434
								Totals =	22.7216131	73	26.7515065	11.6101538
										Estimated with 1-in ID Tubing =	9.189	3.988

Table 2: Head Loss Calculations for 3/4-in System at 10 GPM Flow Rate

0.75-in Diameter Pipe @ 10 GPM												
10 GPM Flow =	0.02220	(ft^3/s)	Kinematic Visc @ 50F =	0.000014	(ft^2/s)	Roughness (in) =	0.00006	K-Value =	0.5			
Component	ID (in)	Length (in)	Cross Section Area (in^2)	Flow Velocity (ft/s)	Reynolds Number	Flow	ε/D	Friction Factor	Head Loss (ft)	No. of Components	Total Head Loss (ft)	Pressure Drop (psi)
0.75-in D Elbow	0.804	2.1	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.0385936	6	0.231562	0.100497805
0.75-in D Tee - Straight	0.804	1.4	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.0257291	0	0.000000	0
0.75-in D Tee - Bend	0.804	4.1	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.0753495	4	0.301398	0.130806667
0.75-in D Ball Valve	0.804	1.5	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.0275669	9	0.248102	0.107676219
0.75-in D x 3-in L PVC	0.804	3	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.0551338	17	0.937274	0.406776829
0.75-in D x 4-in L PVC	0.804	4	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.0735117	2	0.147023	0.06380813
0.75-in D x 8-in L PVC	0.804	8	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.1470233	2	0.294047	0.12761626
0.75-in D x 18-in L PVC	0.804	18	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.3308025	1	0.330803	0.143568293
0.75-in D x 72-in L PVC	0.804	72	0.508	6.297	30134.241	Turbulent	0.00008	0.024	1.3232101	1	1.323210	0.57427317
0.75-in Socket-to-Thread Fitting	0.804	2	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.0367558	9	0.330803	0.143568293
Barbed Hose Fitting for 0.75-in ID Hose	0.804	1.969	0.508	6.297	30134.241	Turbulent	0.00008	0.023	0.0346784	9	0.312105	0.135453693
1-1/2 in Threaded Female-Female Fitting	1.59	2.0625	1.986	1.610	15237.692	Turbulent	0.00008	0.029	0.0015142	1	0.001514	0.000657145
1-1/2 in Threaded Male-Socket Female Fitting	1.59	2	1.986	1.610	15237.692	Turbulent	0.00008	0.029	0.0014683	1	0.001468	0.000637232
1-1/2 in D x 3-in L PVC	1.59	3	1.986	1.610	15237.692	Turbulent	0.00008	0.029	0.0022024	1	0.002202	0.000955848
1-1/2 in to 0.75-in PVC Reducer	1.59	5.1	1.986	1.610	15237.692	Turbulent	0.00008	0.029	0.0037441	1	0.003744	0.001624941
2-in Female Threaded-to-Socket Fitting	2.047	2.41	3.291	0.971	11835.823	Turbulent	0.00008	0.03	0.0005175	2	0.001035	0.000449194
2-in D x 5-in L PVC	2.047	5	3.291	0.971	11835.823	Turbulent	0.00008	0.03	0.0010737	2	0.002147	0.000931938
2-in to 0.75-in PVC Reducer	2.047	5	3.291	0.971	11835.823	Turbulent	0.00008	0.03	0.0010737	2	0.002147	0.000931938
0.75-in ID Plastic Tubing	0.75	360	0.442	7.236	32303.906	Turbulent	0.00008	0.023	8.9761339	1	8.976134	3.895642116
EKM Metering 3/4-in Hot Water Meter	0.804	10	0.508	6.297	30134.241	Turbulent	0.00008	0.024	0.1837792	1	0.183779	0.079760163
Danfoss Heat Exchanger									1	1	1.000000	0.434
								Totals =	12.3398615	73	14.6304974	6.3496359
										Estimated with 1-in ID Tubing =	8.054	3.496

Heat Transfer

There are three main avenues for heat transfer in a thermal energy storage tank. The first is head transfer to the outside environment. The second is through the mixing of the fluids within the tank. The third is through axial conduction of the tank walls. It is very difficult to isolate these three avenues of heat transfer, so instead dimensionless numbers are used to measure the efficiency of the tank. A few of these numbers are Richardson's number, Peclet number, and Froude number. This analysis, however, was deemed to be outside the scope of this phase of the project by the teams mentors, but they are something that should probably be considered in the future if heat transfer analysis is undertaken.

Modification Suggestions

As far as modification suggestions are concerned for future project development, the team recommends that the original parameters of the system (i.e. 180-gallon tank & 3' OD x 10' L hole) be taken into consideration. In addition to this, using a tank able to be pressurized may help to mitigate any concerns of over-pressurization. Lastly, it is also recommended that other means of maintaining stratification be explored, such as using packing, commonly used in distillation towers.

Testing and Quality Plan

Given that the objective of this semester was to develop a test bed and not actually conduct testing, the testing plan was simply ensuring the system operated. After the system was assembled, the individual subsystems were tested. The pump operated without fault, achieving a 10 GPM rate as determined using the flow meter. The flow cross functioned perfectly, reversing the flow direction when appropriately configured. Water circulated through the heat exchanger without issue. However, there was a small leak that developed on the outlet side that will need to be remedied. The instrumentation posed some issues that will be addressed later in the report.

For future teams, the current team recommends the following process be used to conduct tests:

1. Fill tank with cold water, allowing air to be purged
2. Connect hot water line to heat exchanger
3. Take temperature measurement of hot & cold water
4. Arrange valves for cold water discharge
5. Begin data collection
6. Turn on pump and set to desired flow rate
7. Monitor system throughout test
8. Conclude test and archive the data

Costs & Bill of Materials

Total costs and the bill of materials for the project are provided in Table 3. Most of the expensive equipment was already on-hand, which allowed for significant cost savings.

Table 3: Project Costs

COSTS & BILL OF MATERIALS								
MATERIALS & PARTS TO BE PURCHASED								
Supplier Name	**Part #**	**Description**	**Notes**	**Quantity**	**Cost/Unit**	**Total Cost**	**Shipping**	**ETA**
Lowe's	1	3/4-in PVC Ball Valve		9	$ 3.48	$ 31.32	$ -	0 Days
Lowe's	2	3/4-in D 10-ft L PVC Pipe		3	$ 5.96	$ 17.88	$ -	0 Days
Lowe's	3	3/4-in D 5-ft L PVC Pipe		1	$ 5.07	$ 5.07	$ -	0 Days
Lowe's	4	2-in D 2-ft L PVC Pipe		1	$ 11.38	$ 11.38	$ -	0 Days
Lowe's	5	1.5-in D 2-ft L PVC Pipe		1	$ 8.08	$ 8.08	$ -	0 Days
Lowe's	6	3/4-in PVC Elbow		6	$ 0.90	$ 5.40	$ -	0 Days
Lowe's	7	3/4-in PVC Tee		4	$ 0.86	$ 3.44	$ -	0 Days
Lowe's	8	Oatey Fusion Primer + Cement		1	$ 14.98	$ 14.98	$ -	0 Days
Lowe's	9	Hose Clamp for 1" Tubing		14	$ 2.68	$ 37.52	$ -	0 Days
Lowe's	10	3/4-in x 3/4-in Socket-to-Threaded	For connecting hose fitting	16	$ 1.02	$ 16.32	$ -	0 Days
Lowe's	11	2-in Thread to Socket Adapter		4	$ 3.68	$ 14.72	$ -	0 Days
Lowe's	12	Foil Insulation	To be wrapped around tank	2	$ 24.28	$ 48.56	$ -	0 Days
McMaster-Carr	13	Hose Fitting for 1-in Tubing to 3/4-in Fitting		14	$ 1.00	$ 14.00	$ -	2 Days
McMaster-Carr	14	2-in D to 3/4-in D Reducer		4	$ 11.48	$ 45.92	$ -	2 Days
McMaster-Carr	15	1.5-in D to 3/4-in D Reducer		1	$ 5.28	$ 5.28	$ -	2 Days
Amazon	16	1-in Clamps	For baffles	4	$ 7.96	$ 31.84	$ -	1 Day
Amazon	17	160-Gal Containment Pool		1	$ 36.99	$ 36.99	$ -	3 Days
Lowe's	18	1-in x 25-ft Plastic Tubing		1	$ 68.50	$ 68.50	$ 19.43	2 Days
Lowe's	19	1-1/2 in D x 1-ft L Plastic Tubing		1	$ 5.98	$ 5.98	$ -	0 Days
McMaster-Carr	20	1-1/2 in Threaded Female Connector		1	$ 10.82	$ 10.82	$ -	2 Days
McMaster-Carr	21	1-1/2 in Hose Fitting		1	$ 3.49	$ 3.49	$ -	2 Days
McMaster-Carr	22	1-1/2 in Male x 3/4-in Female Fitting		1	$ 4.09	$ 4.09	$ -	2 Days
McMaster-Carr	23	Sheets for Baffles		5	$ 75.97	$ 379.85	$ -	4 Days
Amazon	24	DAE AS200U Hot Water Flow Meter		1	$ 78.00	$ 78.00	$ 13.22	4 Days
Lowe's	25	3/4-in PVC Plug	For bottom of tank	1	$ 2.37	$ 2.37	$ -	0 Days
Lowe's	26	3/4-in D 10-ft L PVC Pipe	Extra material	1	$ 5.96	$ 5.96	$ -	0 Days
Lowe's	27	Latch	To secure top to tank	2	$ 3.48	$ 6.96	$ -	0 Days
AdaFruit	28	Temperature Sensors	Additional Temp Sensors	5	$ 9.95	$ 49.75	$ 14.08	7 Days
Lowe's	28	3/8"x1" Hex Bolt		4	$ 0.97	$ 3.88		0 Days
Lowe's	29	3/8-in Nut		4	$ 0.15	$ 0.60		1 Days
Lowe's	30	3/8-in Lock Washer		4	$ 0.25	$ 1.00		2 Days
Lowe's	31	3/8-in Washer		8	$ 0.15	$ 1.20		3 Days
AdaFruit	32	Breadboard		1	$ 4.95	$ 4.95		7 Days
All Electronics	33	3-Conductor Calbe		1	$ 20.00	$ 20.00	$ 9.50	7 Days
AdaFruit	34	Break-Away Pins		1	$ 3.00	$ 3.00		7 Days
AdaFruit	35	Breadboard		1	$ 4.95	$ 4.95	$ -	7 Days
Amazon	36	Sealant for Electronics		1	$ 11.98	$ 11.98	$ -	5 Days
Lowe's	37	Sealant		1	$ 4.98	$ 4.98	$ -	0 Days
Lowe's	38	2x4 Wood		2	$ 8.88	$ 17.76	$ -	0 Days
Lowe's	39	Hose Clamp for 1" Tubing		4	$ 2.68	$ 10.72	$ -	0 Days
Lowe's	40	1-in Reinforced Vinyl Tubing		10	$ 3.98	$ 39.80	$ -	0 Days
Lowe's	41	U-Bolt to fasten pump		2	$ 2.28	$ 4.56	$ -	0 Days
Lowe's	42	10 pk Hose Clamps for Temp Sensors		1	$ 18.28	$ 18.28	$ -	0 Days
Lowe's	43	PVC Cap for instrument tube		1	$ 0.82	$ 0.82	$ -	0 Days
Amazon	44	Electrical Box for Instrumentation		1	$ 27.99	$ 27.99	$ -	2 Days
Lowe's	45	Paint		3	$ 9.98	$ 29.94	$ -	0 Days
						TOTAL COST =	$ 1,227.11	
						TOTAL COST + 10% CONTINGENCY =	$ 1,349.82	
MATERIALS & PARTS ALREADY ON-HAND								
Supplier Name	**Part #**	**Description**	**Notes**	**Quantity**	**Cost/Unit**	**Total Value**		
OSU	46	300-Gallon HDPE Tank		1	$ 570.00	$ 570.00		
OSU	47	Jebao DCP 20,000 Pump	Backup Pump	1	$ 250.00	$ 250.00		
OSU	48	Viridian VR 3452 Pump		1	$ 1,075.00	$ 1,075.00		
OSU	49	Danfoss Micro Plate Heat Exchanger		1	$ 400.00	$ 400.00		
OSU	50	Arduino Uno		2	$ 30.00	$ 60.00		
OSU	51	10-ft Unistrut		1	$ 50.00	$ 50.00		
OSU	52	Pallet		1	$ 60.00	$ 60.00		
						TOTAL VALUE =	$ 2,465.00	
						TOTAL PROJECT VALUE =	$ 3,814.82	

Project Plan

To ensure that the team completed project goals on time, a detailed plan was created. Image 14 & Image 15 show the plan that was developed at the start of the semester. Image 16 & Image 17 show how the semester actually unfolded.

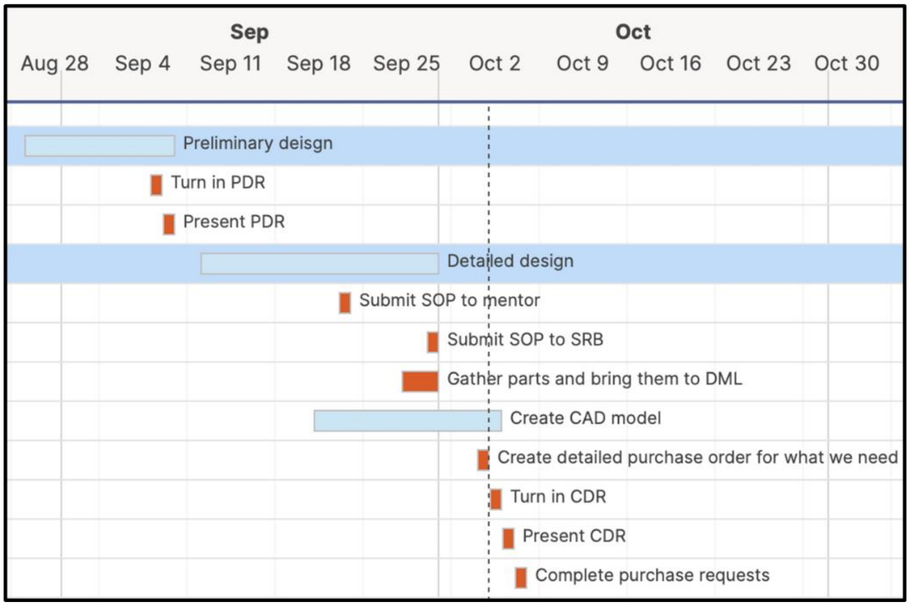


Image 14: Planned Schedule (Part I)

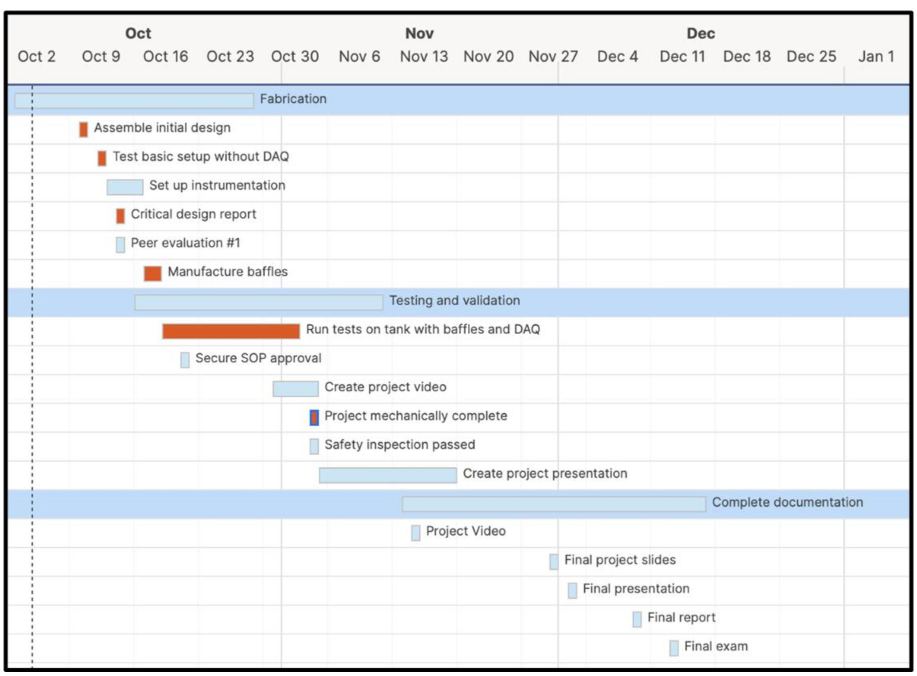


Image 15:Planned Schedule (Part II)

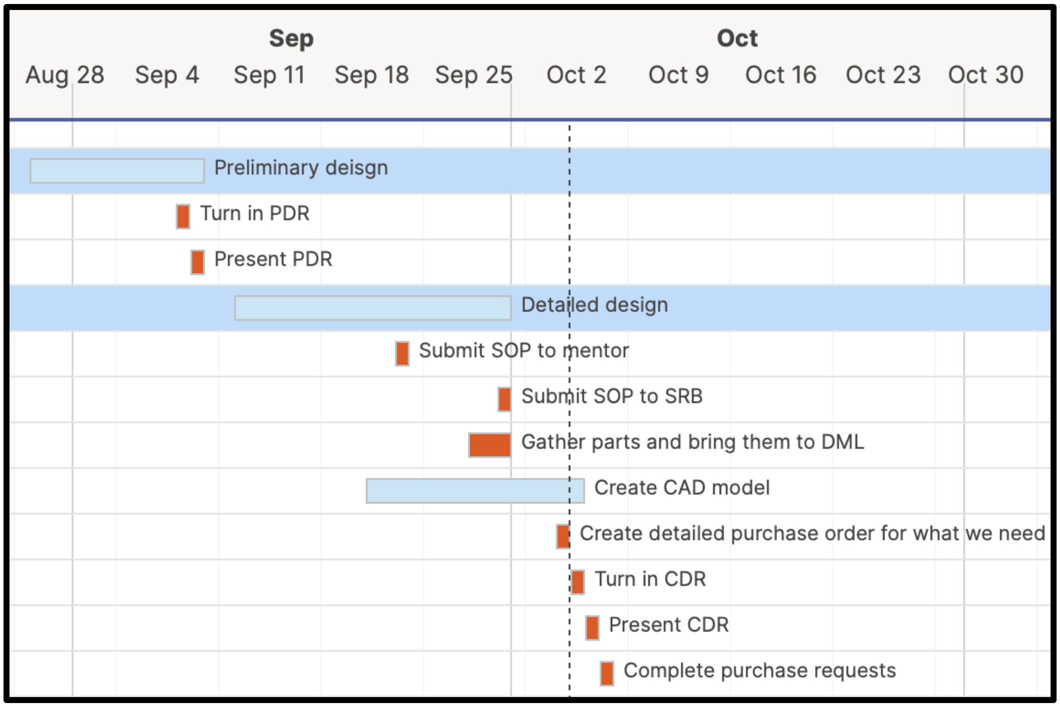


Image 16: Actual Schedule (Part I)

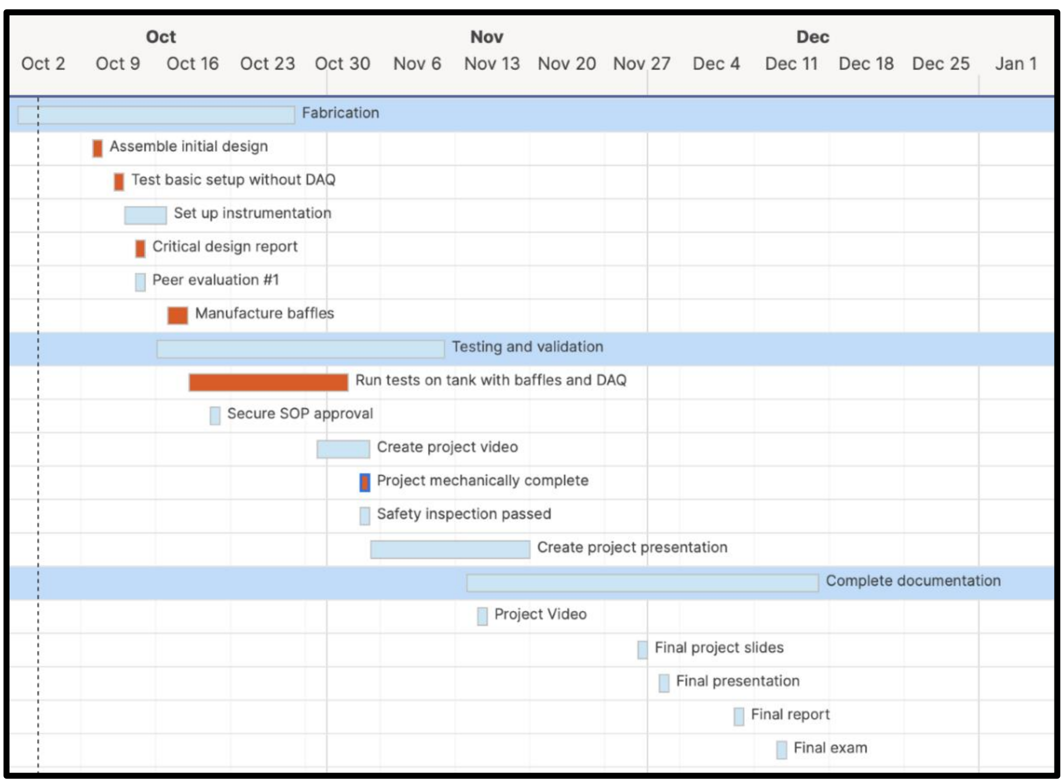


Image 17: Actual Schedule (Part II)

Risk Management

There were two types of risks present with the project: hazards and delays. Within hazardous risks, precautions were laid out to minimize the risks, namely precautions for electrocution, tank failure, ladder falling, tripping hazards, slipping, and pipe bursts. The team also made sure to have contingencies for delay failures including tank, baffle, pump, and equipment failures. Image 18 and Image 19 show the likelihood and severity of the identified.

To prevent electrocution, wires were checked for damaged connections and kept away from water. In the event of a tank failure, containment (kiddie pool) was implemented so the effect of water seepage/spillage could be minimized. To prevent ladder hazards, the team completed ladder safety training and kept three points of contact and had a partner hold the ladder. In order to prevent tripping hazards, the team maintained an organized workspace to keep walking spaces open. To prevent slipping hazards, the team made sure to clean up all water spills regardless of the magnitude of the spill. Finally, to prevent any pipes from bursting or leaks developing, the team ensured strong cementation of all PVC connections and used silicon to seal any leaks that developed anyway.

In the event that components were damaged and could not be fixed, the team checked the price and lead time of replacing the individual components of the system, including the tank, pump, baffle, and supporting equipment. The tank had a 48-hour lead time and could be purchased in Oklahoma. In the event that the baffles may be ineffective, the team considered fabricating alternative designs as well as installing packing. The original pump, the Jebao DCP-20000, was kept on standby in case the Viridian pump failed. All supporting equipment could be bought locally at Lowes at minimal costs.

A summary of risks and mitigative measures are provided below:

Hazardous Risks

1. Electrocution - To prevent electrocution, the team checked wires and connections for damage and made sure to keep electronics from water
2. Tank failure - In the case of a tank failure, the team designed the system so that the tank sits in a containment (kiddie pool)
3. Ladder - To prevent ladder hazards, the team made sure to keep the three points of contact as well as have a partner hold the ladder
4. Tripping - In order to prevent tripping hazards, the team maintained an organized workspace to keep walking spaces open
5. Slipping - To prevent slipping hazards, the team made sure to clean up all water spills regardless of the magnitude of the spill

6. Pipe bursts/Leaks - To prevent any pipes from bursting or leaking, the team ensured strong cementation of all PVC connections and checked them before begin operating the system

Delays

1. Tank failure - The replacement tank had a 48-hour lead time and could be purchased in Oklahoma
2. Baffle failure - In the case of ineffective baffles, the team considered fabricating alternative designs as well as installing packing
3. Pump failure – The backup Jebao DCP-20000 pump could be used
4. Supporting equipment failure - All supporting equipment could be bought locally at Lowes for minimal expense

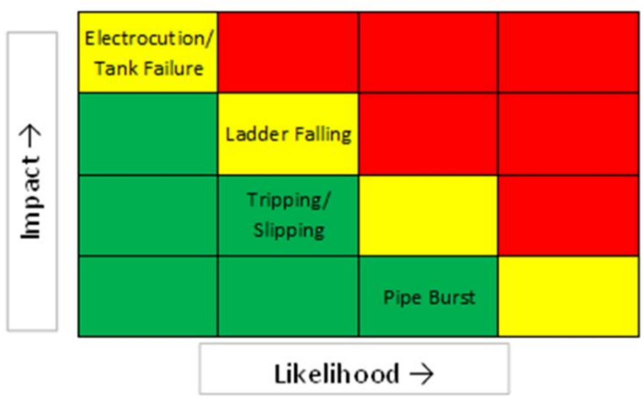


Image 18: Hazard Risks - Severity Analysis

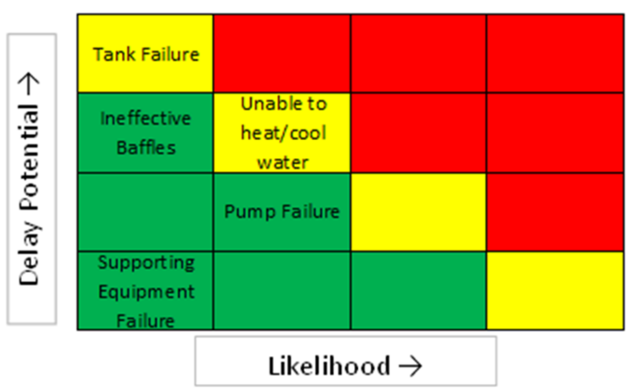


Image 19: Delay Risks - Severity Analysis

Work Breakdown Overview

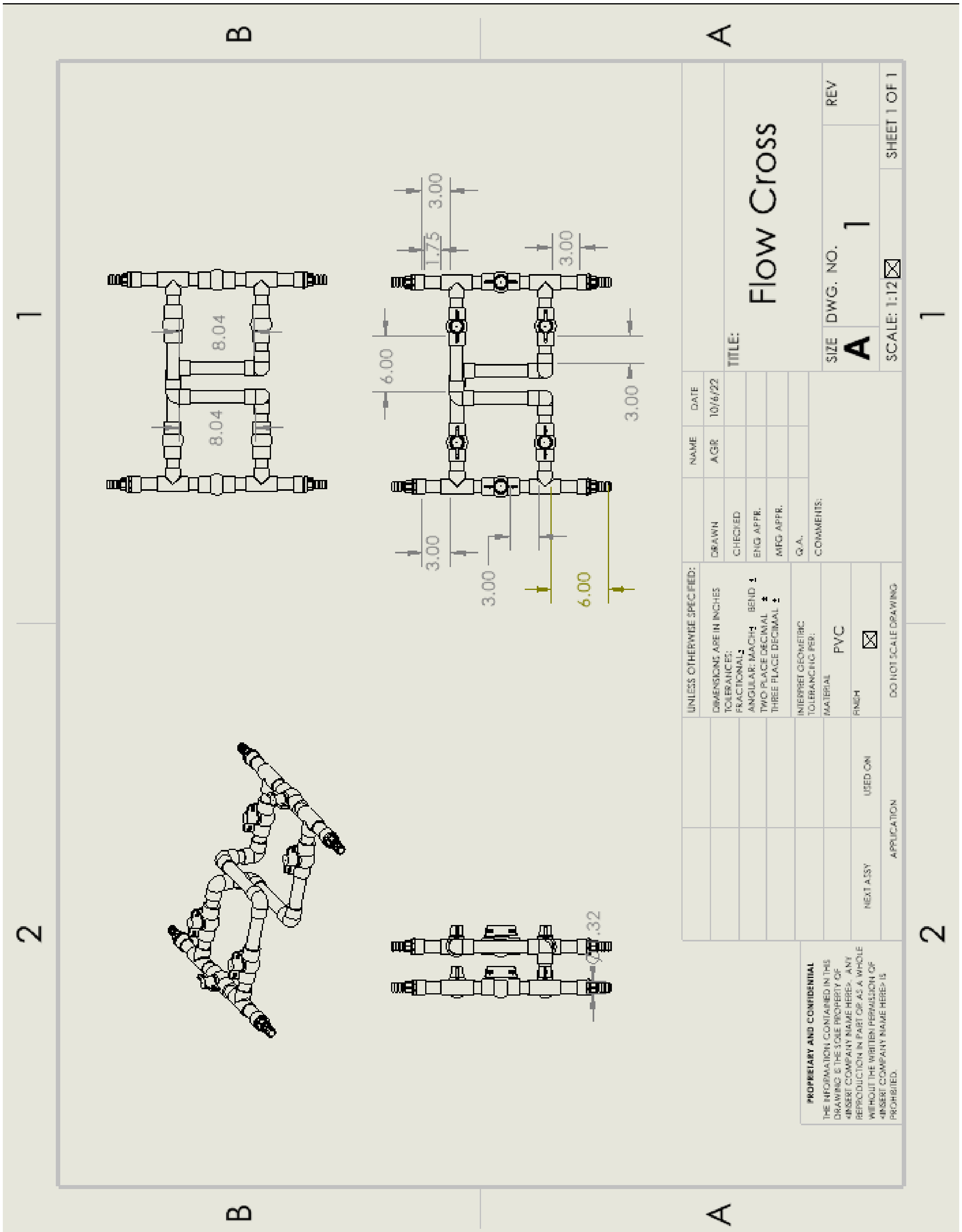
Alexander Roubik

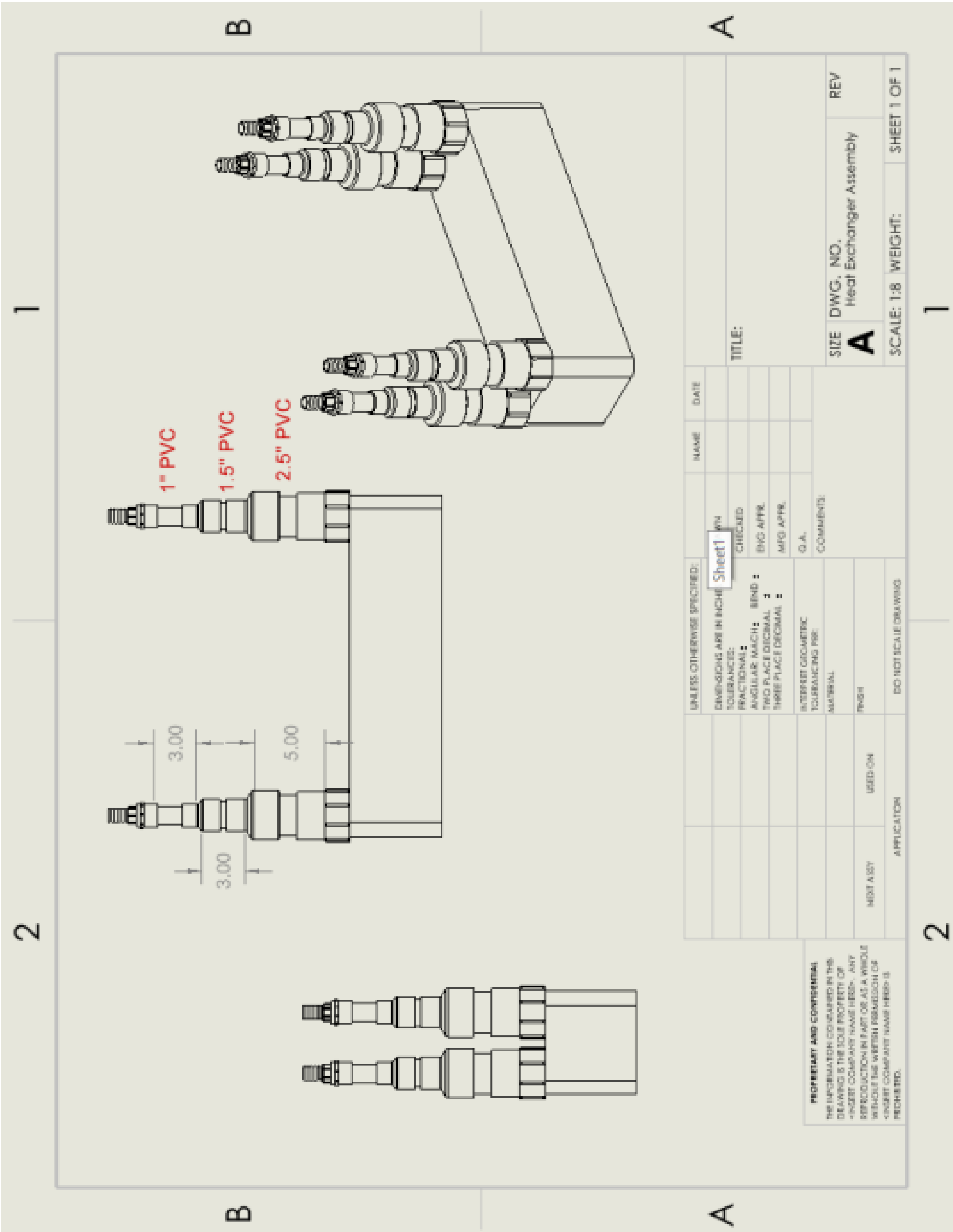
- Introduction & Problem Statement
- Engineering Principles
- EHS & Other Considerations
- Detailed Design
- Engineering Analysis
- Costs & Bill of Materials
- Risk Management
- Engineering Drawings
- Fabrication
- User Manual
- Maintenance Manual
- Decommissioning Plan

Drew White

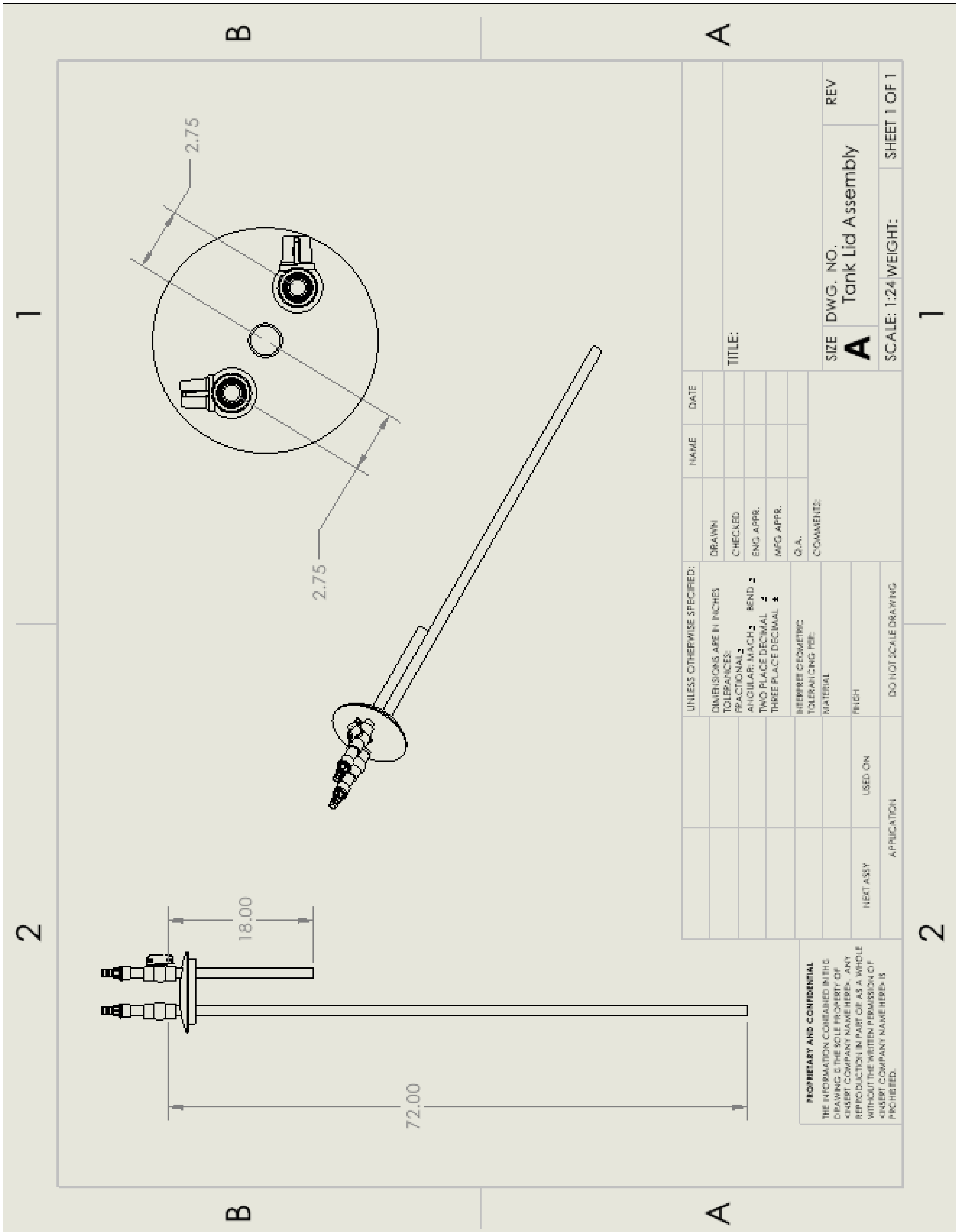
- Introduction & Problem Statement
- Engineering Codes & Standards
- Knowledge Acquisition
- Detailed Design
- Testing & Quality Plan
- Risk Management
- Instrumentation
- Fabrication
- User Manual
- Maintenance Manual
- Decommissioning Plan

Engineering Drawings




1" PVC
1.5" PVC
2.5" PVC
3.00
3.00
5.00
TITLE:
SIZE
A
DWG. NO.
Heat Exchanger Assembly
REV
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1

11


Tank Lid Assembly
SCALE: 1:24
SHEET 1 OF 1
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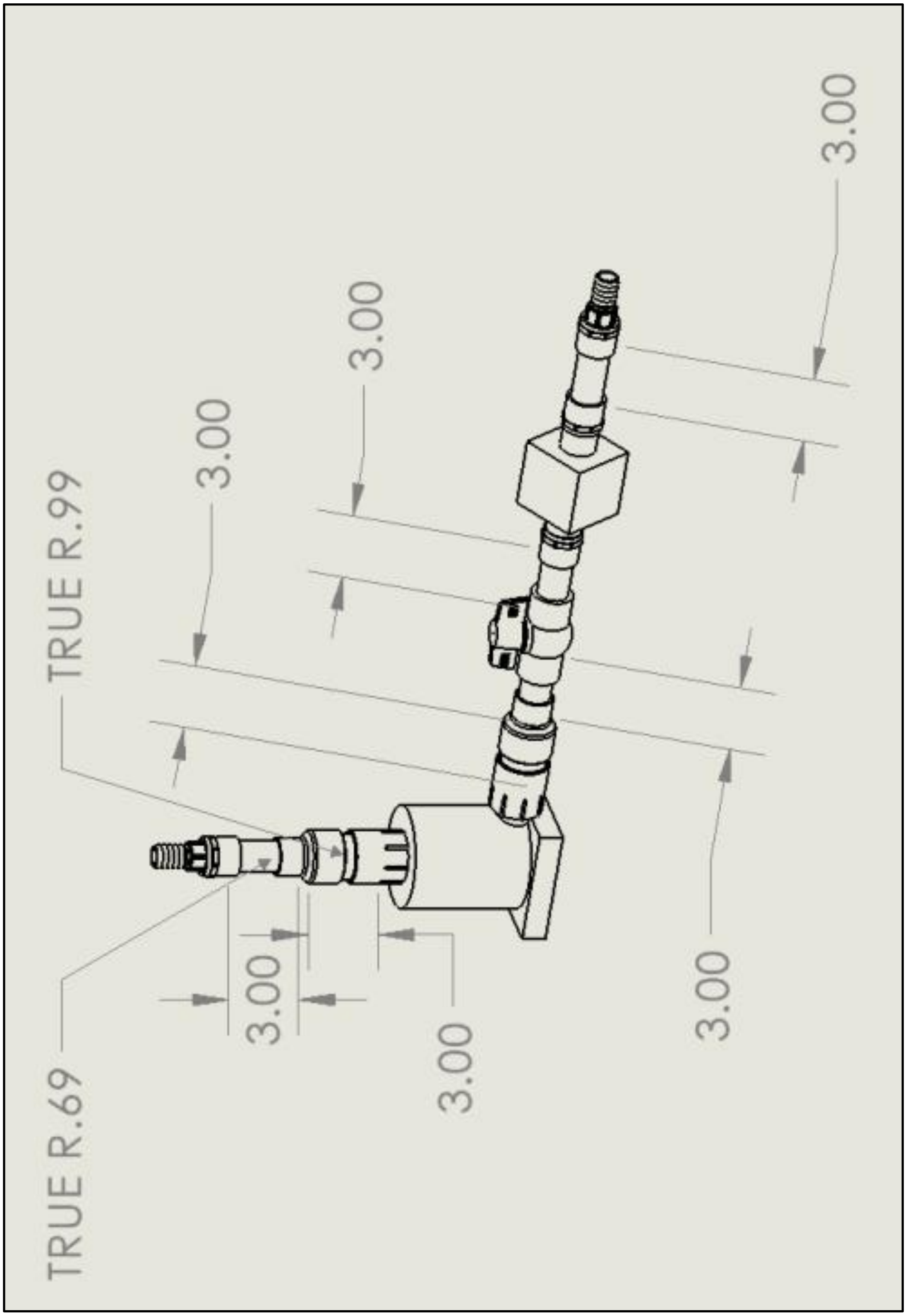
18.00
2.75
2.75
UNLESS OTHERWISE SPECIFIED:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL


TRUE R.69
TRUE R.99
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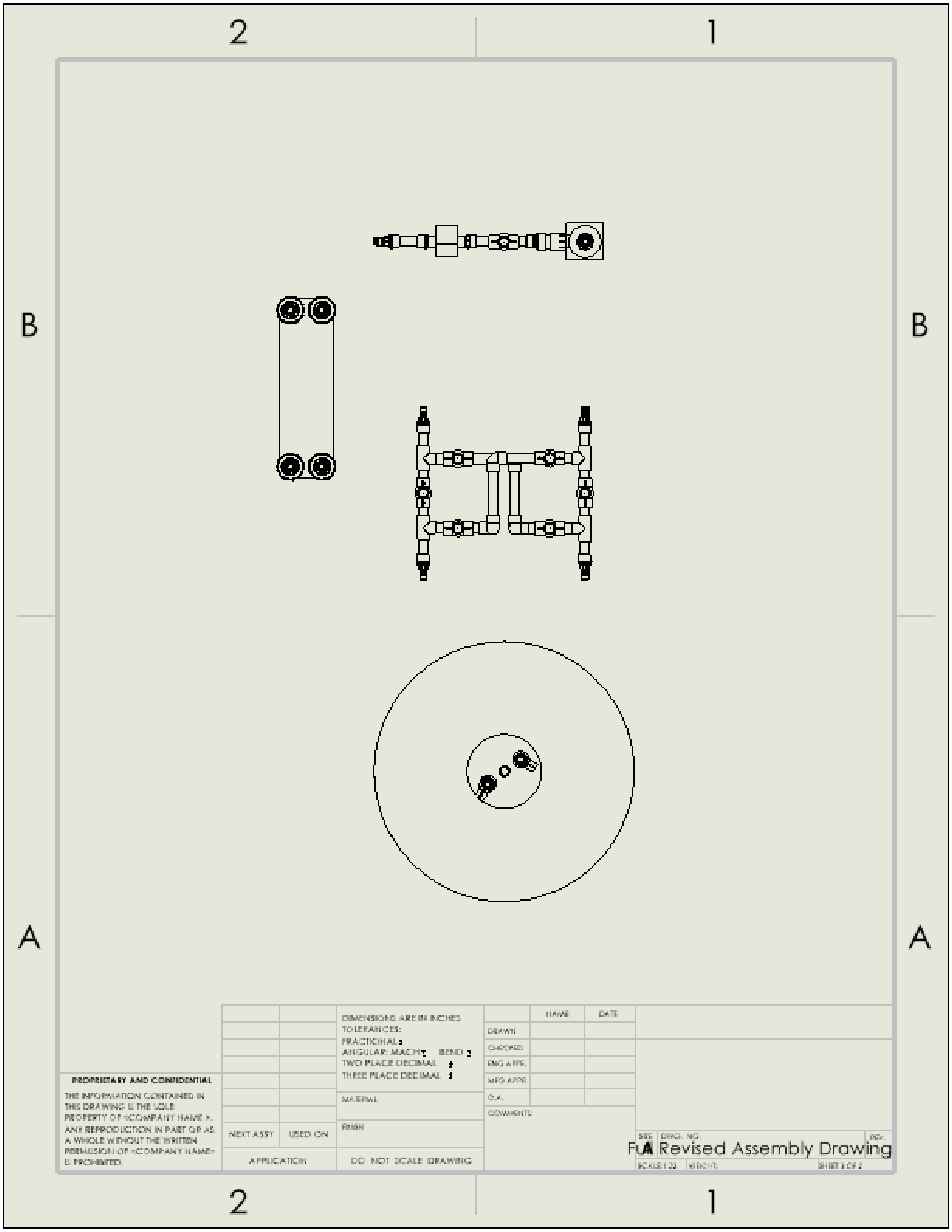
2
1
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2
1
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <COMPANY NAME>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <COMPANY NAME> IS PROHIBITED.
SIZE
DWG. NO.
REV.
A
Revised Assembly Drawing
SHEET 2 OF 2

User Manual

Instrumentation

A visual of the breadboard set up can be found below. However, instead of just one sensor, there are 5 sensors on each breadboard (only room for about 5) and there are two breadboards. All data output wire were connected in the breadboard and sent to one of the numbered terminals. The code then was able to read out all 10 temperature sensor readings.

Occasionally, the labelled sensor reading did not match the actual sensor, so the team would hold onto one of the sensors to increase the temperature. Once one of the temperatures increases, the sensor accordingly could be labeled accordingly.

While the team chose to use breadboards for the design, it is highly recommend to use a PCB for further testing to prevent loose wires from coming out of their terminals. The setup similar to the one employed by the team is visible in Image 20.

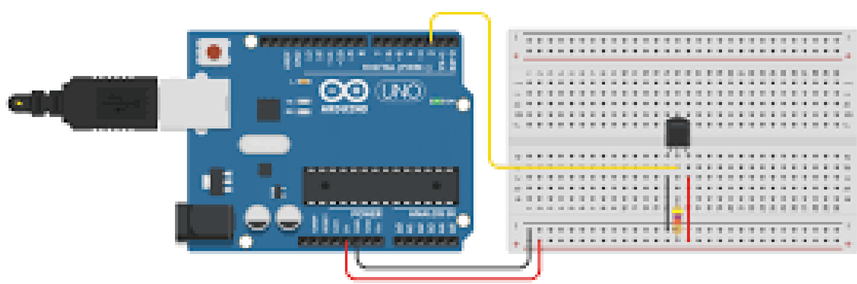


Image 20: Arduino & Breadboard Configuration

System Operation

At the time of this report, the tank is completely empty and stored in the high bay area of the DML. The following will outline the steps necessary to fill the tank, prime the system, and operate it properly to conduct tests.

Note: The tank has a bulkhead near the bottom with a PVC plug in it. This plug should NOT be removed as it has proven to be a very effective seal and no leakage was experienced over the course of the semester while the plug was in place. The plug should not be removed to drain the tank. An effective method for draining the tank will be outlined later in this manual.

Filling the Tank

Use a garden hose and fill the tank to the desired level by running the hose up to the top of the tank. It is recommended that the water be turned off a few minutes before reaching the desired volume to account for some additional water that will enter the system during the priming process.

Inserting Baffle System

First, note the method by which the temperature sensors have been secured in place along the baffle shaft as this configuration will have to be replicated once the baffles have been threaded onto the baffle shaft. Now that the tank has been filled, thread the baffles onto the baffle shaft in the desired configuration. To do this, it is recommended that all of the hose clamps holding the temperature sensors in place be removed – make sure the temperature sensors do not get pushed inside the shaft as it will be very difficult to get them out. When threading the baffles onto the shaft, first put a baffle clamp on followed by the baffle and then followed by another baffle clamp. Wedge the baffle between the two clamps so it maintains flat and perpendicular with the length of the shaft. Slits have been cut in the baffles so it can pass over the temperature sensors without moving them.

After this, reattach the hose clamps onto the shaft. To secure the temperature sensors back into place, hold them perpendicular to the baffle shaft and wedge them upward into the slits that have been cut for them. While wedging them in place, use the hose clamps to keep pressure on the sensors and tighten them so they remain in place and hold the sensors in place.

Now that the baffles have been configured, insert the large dip tube into the holes cut off-center in the baffles. Raise the baffle shaft with the large dip tube now inserted above the tank and lower it into the tank. The weight of the baffle system will not be enough to sink down into the tank, so a team member will need to stand on a ladder and force the baffle system down into the tank. Make sure the bottom of the baffle shaft makes contact with the bottom of the tank and the baffles are perpendicular inside the tank. At this point, the baffles are considered to be installed.

Priming the Tank

After the baffle system has been installed, disconnect the smaller dip tube from its tubing by loosening the hose clamp. Now, insert the male end of the garden hose into the tubing and secure the two together with the hose clamp that was loosened. The connection will likely leak since the male end of the garden hose is threaded, so place a bucket or some kind of containment underneath the connection to collect the leaking water.

From here, open the valve on the long dip tube, close valves 1, 3, 4, & 6 on the flow cross (preferably two people will perform this procedure), and open valves 2 & 5 on the flow cross. Turn the water to the garden hose on and allow for the water to purge the air from the system. Let it run for a few minutes to ensure most of the air has been purged.

After this, close valves 2 & 5 on the flow cross and open valves 1, 3, 4, & 6 so the water can purge the air trapped inside the flow cross. Once the air has been purged from the flow cross, close valves 1, 3, 4, & 6 and open valves 2 & 5. Then, have one team member turn off the water to the garden hose while another teammate simultaneously closes the valve on the large dip tube and then valves 2 & 5 – this will ensure that the large dip tube and the flow cross remains primed with water.

Disconnect the tubing from the garden hose and reconnect it to the smaller dip tube. Make sure the tubing is held up while disconnecting it from the garden hose so as much water as possible remains in it. Also, make sure that the valve on the small dip tube is closed so the water does not come out of the tubing once it is reconnected to the small dip tube. Insert the small dip tube into the tank and make sure that the open end is submerged.

At this point, all of the valves should be closed. Turn on the pump and set the desired flow rate – don't open any valves yet. Once the desired flow rate is set, open valves 2 & 5 – there will be no flow through the system yet since the valves on the tip tubes are closed – this is by design. Open the valve on the large dip tube first – this is the suction side. The pump is now pulling water from the bottom of the tank and through the system, but it is not flowing out yet. Open the valve on the small dip tube and the water will begin flowing. Allow the system to circulate for a few minutes to purge any air that may still be in it.

After some time has passed, reverse the flow by first closing valves 2 & 5 and then opening valves 1, 3, 4 & 6. Allow some time for any remaining air to be purged. After the air has been purged, close the valve on the large dip tube and then the valve on the small dip tube. Then, close all of the valves on the flow cross. At this point, the system should be adequately primed and ready for operation.

Operating the System

Now that the tank is primed and all valves are closed, test the instrumentation and ensure it is working. To begin, all of the temperature sensors should read similar values since the water in the tank is isothermal.

Connect a garden hose of hot or cold water (depending on the test being run) to the heat exchanger and another hose to the outlet. The outlet hose should be run to a drain or some kind of water disposal area. Turn on the water and let it run for a while to ensure that the heat exchanger has been purged of air and that the water is at the desired temperature.

Configure the valves on the flow cross for the desired inlet/discharge and then turn on the pump. Begin data collection and then open up the suction side dip tube valve followed by the outlet side dip tube valve. Record the data and analyze.

Draining the Tank

To drain the tank, DO NOT remove the plug at the bottom of the tank. Ensure the system is primed and all valves are closed. Connect the tubing from the small dip tube to a garden hose using a hose clamp. Run the garden hose to a drain or some other water disposal area. After this, turn on the pump and set it to a high flow rate. Open valves 2 & 5 on the flow cross and then open the valve on the large dip tube. The water will be suctioned out of the tank by the large dip tube and discharged out through the garden hose. Allow this process to occur until the tank is entirely drained. There will be some residual water left in the piping system, which can be purged by simply disconnecting the tubing and allowing the water to drain.

Maintenance Manual

Given the simplicity of the system, some minor maintenance is required to prolong the lifespan of the design. The instrumentation should not require maintenance. However, after every few tests, sealant should be reapplied to the temperature sensors so that they maintain their integrity. The primary maintenance areas identified are:

1. <u>Leaks</u>: apply silicon to leaks and wrap with duct tape to maintain pressure on leak until silicon solidifies (<u>note</u>: silicon should be applied to a dry surface and when water is not in the component with the leak). Leaks will likely occur at the heat exchanger connections and possibly at hose fittings where tubing is consistently connected and disconnected.

2. <u>Tubing</u>: kinks in the tubing a persistent issue and over time they will get worse, so the tubing will likely need to be replaced over time unless a new means of conveying the water is adopted

3. <u>Water</u>: if tests are conducted over long periods of time, the water in the tank may turn foul. Should this be the case, a fungicide should be used in the tank. It is recommended to avoid any kind of chlorine-based fungicide as the chlorine may interact negatively with some of the system components

4. <u>Wood Rot</u>: paint should be reapplied to areas of the pallet that are consistently exposed to water

When maintenance should occur is largely dependent on the condition of the system and the discretion of the operating team. Therefore, a specified maintenance interval is not provided.

Decommissioning Plan

When the time comes to decommission the project, the following steps should be followed:

1. Viridian pump to be returned to Dr. Bach
2. Danfoss heat exchanger to be returned to Dr. Bach
3. Uni-strut to be recycled to DML supply area for possible use in future
4. Flow meter to be given to Dr. Bach and his research team
5. Flow cross to be stored for possible use in future
6. Hose clamps can be collected and stored for future use
7. Tubing can be collected and stored for future use
8. Heat exchanger PVC fittings to be removed from heat exchanger and stored for future use
9. Tank lid and cap to be reattached to tank and whole assembly set aside for future use
10. Containment (“Kiddie Pool”) to be stored for future use
11. Dip tubes to be stored for future use or can be
12. Foil insulation to be kept or removed from tank and stored for future use
13. Pallet assembly to be kept or disassembled for future use or proper disposal according to City of Stillwater and Oklahoma State University guidelines
14. Baffle shaft to be kept for future use
15. Temperature sensors to be returned to Dr. Bach
16. Arduino to be returned to Dr. Bach
17. Breadboards to be returned to Dr. Bach
18. Jumper cables to be returned to Endeavor computer lab
19. Temperature sensor extension cables to be removed from temperature sensors and stored in DML wiring & soldering room for future use
20. Electrical box to be stored for future use
21. Baffles to be stored for future use along with leftover baffle material originally ordered from Home Depot

Oklahoma State University Standard Operating Procedure (SOP)

OKLAHOMA STATE UNIVERSITY
CEAT UNDERGRADUATE PROJECT
STANDARD OPERATING PROCEDURE
Revision: 0621

This document is for use by the Project Team to develop a Standard Operating Procedure (SOP) and sent to the NCL Safety Review Board. **The completed SOP should be shared with all the members of the team.** The SOP should be revised whenever a significant change to the location or scope of work occurs. The NCL and ENDEAVOR Safety Review Board (SRB) are available to assist in completion or review of the SOP. For questions, please email ceatsop@okstate.edu. Submit the completed SOP by emailing an electronic copy to ceatsop@okstate.edu with the subject heading: SOP_<Team/Group name>. The SOP should be submitted as a single document, using the following file name format (<team/group name>_<date-of-submission> Ex: ***ImpactTester_2018-01-31***). Please allow at least two business days for approval or requested revisions.

The following SOP generally follows under:

☐	SOP is for a general lab operation/process that could apply to several chemicals
☒	SOP is for a specific protocol/experiment/procedure
☐	SOP is for a specific chemical or class of chemicals with similar hazards

Section I.

Project Title:	THERMAL ENERGY STORAGE TANK		
Principal Investigator/Project Manager:	CHRISTIAN BACH	Department:	MAE
Email:	CBACH@OKSTATE.EDU	Phone:	4057445916
Project Duration:	12 MONTHS		

Location of Fabrication/Testing Include room number(s) as appropriate

NCL	126G	ENDEAVOR	
ATRC		UAFS	

Other	

OSU Contact Person:	JOHN GAGE	Phone:	4057445915
Local (Field) Contact Person:	ALEXANDER ROUBIK	Phone:	4054163325

Group/Project Members (Attach an addendum as needed)

Name	Email	Team Leader	Team Member
ALEXANDER ROUBIK	ALEXANDER.ROUBIK@OKSTATE.EDU	☐	☒
DREW WHITE	AWHIT23@OKSTATE.EDU	☐	☒

Section II.

Procedure Overview: Provide a brief description of the project and/or procedure. (Addendum document as needed)
The purpose of this project is to develop and optimize a baffle system for a thermal energy storage (TES) tank. The baffle system will be adjustable and able to be raised and lowered into a tank that serves as a test bed for trialing different baffle configurations and flow rates. The tank is open top and not pressured. A flow cross will be rigged up outside the tank to regulate the direction of flow. A varying rate pump will be tied into the flow cross and will serve as the primary means of pumping water throughout the system. To account for thermal expansion of the water, the level of the water column in the tank will be maintained at a height above the inlet line at the top of the tank. The tank will be wrapped in insulating material to minimize loss of heat/cold in the system.

Section III.

Hazards Inherent to the Project (Check all that Apply)

☐ Extreme Temperature (outside range of -20°F to 120°F)	☐ Trenching/Excavating
☒ Electrical Hazard > 50 volts or high current	☐ Explosion
☐ Noise Generated > 85 dBA	☐ Potential for Oxygen Deficiency or Other Atmospheric Hazard (i.e. gas, vapor)
☐ Exposed Sharp Edges	☐ Storage of Hazardous Materials on site
☐ Pinch points	☐ Lithium Batteries
☐ Flying Debris or Impact	☐ Transportation of Hazardous Materials
☐ Pressure Vessel/Compressed Gas	☐ Other:_____
☐ Bungee Cables/Elastic Energy Storage	**Equipment Used**
☐ Fire Hazards (open flame, welding, cutting)	☐ Golf Cart/ATV/Go-Kart
☐ Handling Hazardous Materials	☐ Forklift
☐ Dusts/Other Particulate Hazards	☐ Tractor
☐ Work in Confined Space (natural or man-made)	☐ Airborne Drone
☒ Overhead Falling Objects	☐ Other _____
☒ Heights (roofs, lifts, towers, catwalks, etc.)	

Health and Safety Information: Briefly describe the hazards associated with the materials or equipment used during the procedure. (Addendum document as needed)

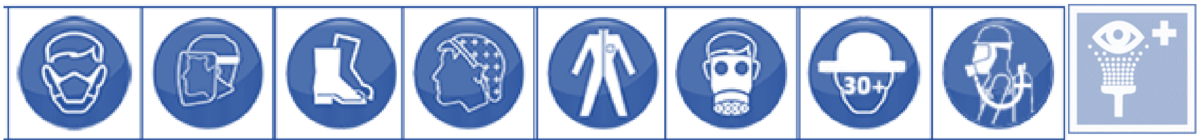
Electrical Hazard – There will be an electrical hazard due to the combination of the pump and water. Electrical hazards will be mitigated by implementing a ground fault circuit interrupter (GFCI) to supply power to our system.

Ladder Hazard – We will be using a ladder to work through the open top of our tank. Ladder trainings will be taken and appropriate precautions taken such as having team member hold ladder steady while another team member is on the ladder.

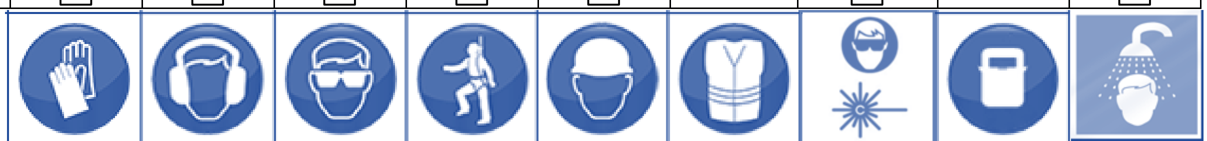
Overhead Falling Objects Hazard – We will be lifting the baffle system in and out of the tank creating a falling objects hazard. This hazard will be mitigated by ensuring the area below the baffle is clear of any persons.

Section IV.

Personal Protective Equipment or Clothing Required: All activities require basic protection including appropriate clothing, hand protection, safety shoes/boots, and eye protection. Any additional PPE requirements based on the hazards identified as part of minimizing risk of exposure, injury or illness. (Check all that Apply)
Required checked if the SDS or safety procedures calls it out directly.
As Needed checked if the user elects to use but it not required.



	Dust Mask	Face Shield	Foot Protection	Hair Net	Protective Clothing	Respirator	Sun Protection	Breathing Apparatus	Eye Wash Station
Required	☐	☐	☒	☐	☒	☐	☐	☐	☐
As needed	☐	☐	☐	☐	☐		☐		☐



	Hand Protection	Hearing Protection	Safety Glasses	Safety Harness	Safety Helmet	Safety Vest	Laser Safety Glasses	Welding Mask	Safety Shower
Required	☐	☐	☒	☐	☐	☐	☐	☐	☐
As needed	☐	☐	☐	☐	☐	☐			☐

☐ Other(s): Closed-toe shoes, long pants, & safety glasses

Respirator	Laser Safety	Fire Extinguisher	Welding
Type:_____	Class: _____	Class:_____	Type:______
Cartridge/Filter Type: _____	Frequency _____		Lens Shade: _____

Safety Training Required

☐ Advanced First Aid	☐ Confined Space
☐ CPR	☐ Laser Safety
☐ Emergency Action and Preparedness	☐ Forklift/Other Heavy Equipment
☐ Project Specific Hazard Communication	☐ N95 Particulate Mask Disclaimer
☐ Compressed Gasses	☐ Respiratory Protections
☐ HotWorks (Welding, Torch/Plasma Cutting)	☐ Fire Extinguisher
☒ Ladder	☐ Other:_____

Section V.

Method Procedures: Give a step-by-step instruction for the procedure. (Addendum document as needed)

<u>Testing</u>

1. Fill tank with desired fluid
2. <u>Reference diagram from Section XIII</u>: open all valves and turn on pump to purge air from flow cross
3. Set up heat exchanger for desired temperature effect
4. Assemble baffle system in desired configuration
5. Connect the dip tube hoses to the flow cross
6. Using a ladder, insert the baffle system into the top of the tank by hand
7. Set baffle system in fluid and secure to tank
8. Prime system with water
9. Test thermocouples and data acquisition system
10. <u>Reference diagram from Section XIII</u>: To discharge cold water from the tank, open valves 2 & 5 on the flow cross and close valves 1, 3, 4, & 6 on the flow cross. To discharge hot water from the tank, close valves 2 & 5 on the flow cross and open valves 1, 3, 4, & 6 on the flow cross. Ensure that the valves on the dip tubes are open before turning on pump.
11. Begin data collection
12. Begin pumping fluid at desired rate and monitor temperatures
13. Allow for one whole cycle to occur and observe data
14. Record data
15. Disconnect the dip tube hoses from the flow cross and remove the baffle system in the same manner it was installed and reconfigure baffle system and repeat process

When testing is complete, close the valves on the dip tubes to prevent any kind of siphon from developing

Section VI.

Waste Disposal: Give a step-by-step instruction for the procedure (if applicable). (Addendum document as needed)
Our only waste material for this project will be water. There are floor drains in our test section of the DML which will be the way that we dispose of this water.

Section VII.

End of Project/ Decommissioning Procedure: Directions for end of project disposition. • Is it to be moved to a specific location for immediate student or research use? If so, specify the location and any precautions to be taken before transport. • Is it to be stored in a specific place for use later? If so, what needs to be done prior to long term storage? Fluids drained? Lines purged? Partially disassembled? • Will it be dismantled? If so, are there any precautions that should be observed? Hazardous materials to be disposed of? Is there a certain order in which it should be taken apart? If this project carries over then indicate end target date. (Addendum document as needed)
This project is the beginning of a multi-semester project so there will be things that need to be stored. Our tank design will most likely be dismantled because our primary objective is to create and optimize a baffle system for the tank. Whether or not the tank is repurposed or used again for the project is unknown. However, there will be no concern of hazardous materials, flushing, or purging. The baffle system will simply need to be stored for future project members to use and utilize in their project.

Section VIII.

First Aid Procedures: Give a step-by-step instruction for the procedure. (Addendum document as needed) This section should also contain the address and location(s) that the SOP will be used.

All incidents require that as soon as possible the Instructor of Record and Professional Staff over lab be notified.

Location: **DML (1724 W. Tyler, Stillwater, OK 74078)**

Location of Nearest Hard Phone Line or Emergency Callbox: **DML 126G (on south side of cage)**

Nearest Location of a solid Cell phone signal: **DML**

Emergencies:

- One person is assigned to stay with the injured personal
- One person should be assigned to call 911, this person will stay on the phone and state the following
  - Location of the accident (This should include building and room)
  - Type of injury
- One person should be assigned to escort the emergency response crew to the location

Specialized First Aid Procedures as related to this project:

In event of electrocution:

1. **Turn off power source – breaker box location on south well of DML 126 (Box P-1, Breaker 23)**
2. **Call 911 if necessary**
3. **Perform CPR if necessary**
4. **Apply bandages if necessary**

Section IX.

Spill/Release Containment, Decontamination, and Clean-up Procedures: Give a step-by-step instruction for the procedure (if applicable). (Addendum document as needed)
For minor spill, put up "Wet Floor" sign and squeegee water to drain. For major spill, notify the lab manager. Ensure the spill area is sanctioned off and electrical breakers to the area are turned off so as to minimize any chance of electrocution. Identify any equipment that needs to be moved from the spill area and move it. Begin to squeegee water to drain. Coordinate any additional cleanup measure with lab manager and other staff.

Section XI.

Approvals Required: Describe any special approvals required before conducting this work such as approval by Principal Investigator or lab supervisor before beginning work (if applicable). (Addendum document as needed)
Approval to perform work needed from John Gage, Dr. Christian Bach, and Professor Southard.

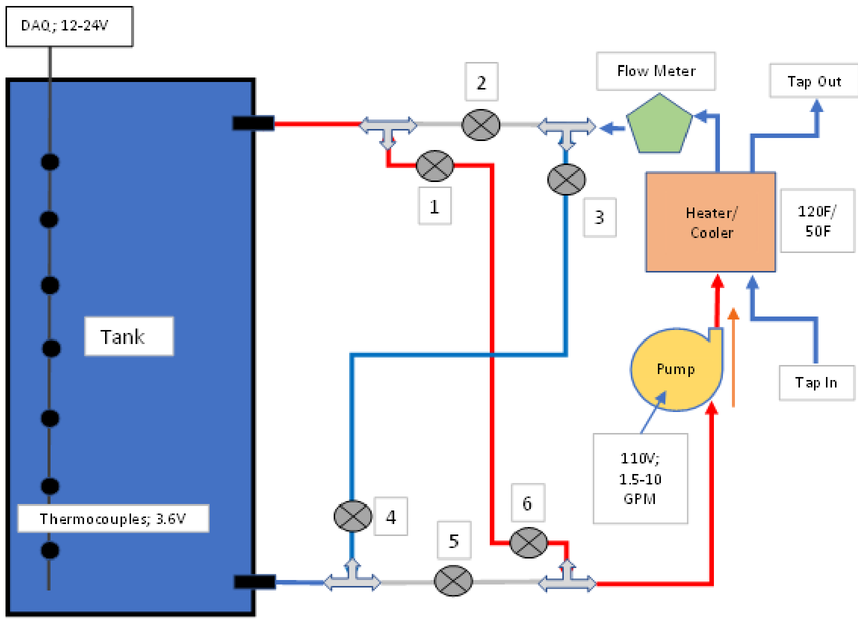
Section X.

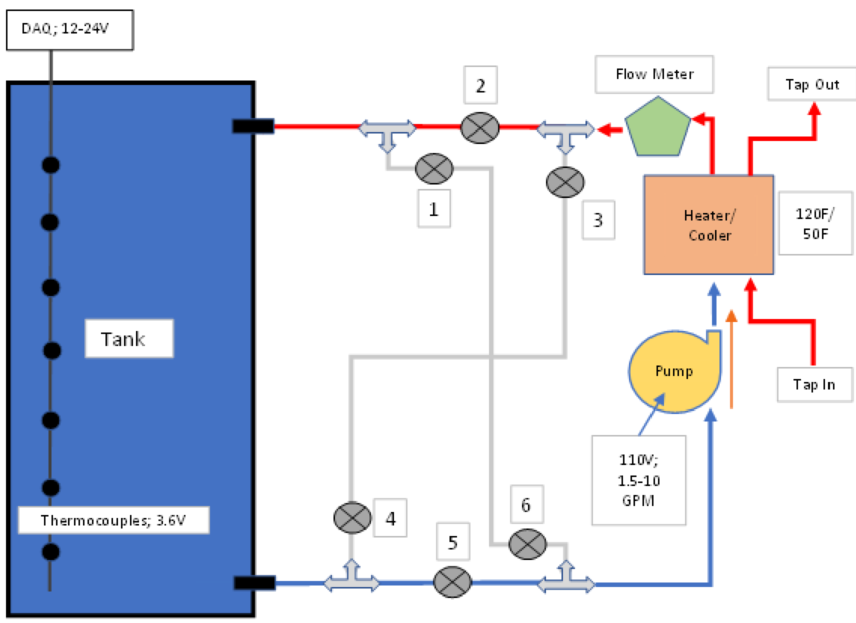
Designated Area/Communications: (For work involving particularly hazardous dangers, identify the area where the work will be conducted and to where it will be confined; identify any communication that will be done to assure others know the hazards and location of this work.) (if applicable). (Addendum document as needed)
Our project does not entail anything deemed particularly hazardous outside of what is outlined in Section IV.

Section XII.

Piping, Wiring, and Instrumentation diagram: (This should include a detailed schematic illustration of the functional relationship of piping, instrumentation, and system equipment components. Should include expected loads (Voltage, Current, Flow Rate, Pressure, etc.)

(Attach separate page(s) with document if necessary)





The section below will be filled out using Adobe E-Sign Do Not Fill out.
Once the SRB has approved the document, all team members will be required to electronically sign the document below.

By signing below, I certify that I have read the Standard Operating Plan (SOP) and agree that all listed participants and I will abide by the SOP and adhere to all OSU policies and procedures as well as any local policies, procedures or guidelines.

PI Signature: ______________________

Participants: ALEXANDER ROUBIK

DREW WHITE

Course Instructor(s): ______________________

SRB: ______________________

Section XIII.

Attachment Section: