Senior Design Final Report

Project #17: Shuttle Valve

Final Deliverable

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Contents

Abstract

Renewable energy, also known as "green" energy, has been the focal point for many present day industries. One push towards renewable energy includes modifying existing technologies in order to improve their efficiency. Verdicorp Inc. is one such company that is at the forefront of developing next generation clean technologies for existing systems [1]. The objective of this project is to increase the efficiency of the Organic Rankine Cycle (ORC) system developed by Verdicorp Inc. This will be achieved by decreasing the parasitic losses within the system by removing the centrifugal pump and replacing it with a shuttle valve system.

Therefore, the purpose of this project is to design a shuttle valve to be used in ORC systems. These systems are used for producing electrical energy from waste and low grade heat. The concept for the shuttle valve is to transfer liquid from the low pressure side of an ORC to the high pressure side without the aid of a centrifugal pump. The end goal will be to design a simple, inexpensive system that can be incorporated into existing ORC's. The benefit of a successful outcome will be to decrease the energy consumption of the existing system and increase the efficiency and overall profit for the consumer.

A final design has been selected that will transfer water from the low pressure side of the system to the high pressure side without the aid of a centrifugal pump. This was accomplished by using the aid of gravity and balancing the pressure on each side of the system with the use of solenoid valves. All major and minor losses were taken into consideration when calculating pipe flows. A prototype of the final design has been constructed. The overall pressure differential was 50 psi and a constant flow rate in and out of the boiler of 1.5 gpm was achieved.

Acknowledgement

The team is very thankful for the assistance of several individuals. Our sponsor, Robert Parsons of Verdicorp Inc., has taken time out of his busy schedule to provide our design team with great advice and guidance every time we have sought information concerning our project. He has also provided his workshop and Verdicorp offices as a sanctuary to gain great knowledge of how engineering is applied in real-world applications. We have also received great advice from Dr. Shih and Dr. Amin during our biweekly staff meetings and midterm presentations.

Project Overview

Project Scope

Verdicorp Inc. has improved a revolutionary power generation system (Figure 1) that converts low grade waste heat into electrical energy. Organic Rankine Cycle systems can best be described as a refrigeration cycle running backwards. Instead of using electrical energy to produce cooling, this system takes heat from a low grade source and turns it into electrical energy. The power is then phase matched to meet the local electrical grids.

Figure 1. Picture of one of Verdicorp's Organic Rankine Cycles.

Verdicorp Inc. uses the environmentally friendly refrigerant 245fa in their ORC systems. The refrigerant is heated from the waste heat of a low grade source in a series of heat exchangers and sent into a turbo generator. The refrigerant spins a turbine blade which turns an electrical generator, producing electrical power. Once the fluid passes through the turbine it then goes through a condenser and back to the pump to be recirculated through the system. The pump is a parasitic loss which consumes electrical energy and lowers the overall efficiency of the ORC. Our sponsor has tasked our design team with the requirement to mitigate this effect with the insertion of the shuttle valve system.

Project Goal

The final prototype of the shuttle valve system must resemble a system which can be incorporated into the existing ORC system in place of the original pump. The ORC is capable of producing ~125 kW of power, but due to parasitic losses in the system that consume ~20 kW of the power produced, it is limited to a surplus of ~105 kW of useful power. The pump accounts for half of these parasitic losses, ~10kW, so replacing the pump with our team's shuttle valve design should basically eliminate half of the parasitic losses, thus increasing the overall efficiency of the system. The prototype must maintain a constant flow rate of 3 gallons per minute through the use of multiple storage tanks. It should sufficiently decrease the amount of electrical waste compared to the original pump. The physical model will use water, but future calculations will be based on refrigerant 245fa since the ORC system will use the refrigerant. The overall expectation of the end product is to increase the efficiency of the existing ORC system by reducing electrical consumption.

Project Objectives

- Design a shuttle valve system to replace the pump within the ORC.
- Maintain the continuous flow of liquid within the ORC (~3 gpm).
- With the use of control valves and the aid of gravity, adjust the pressure inside the tanks up and down by balancing the gas pressure.
- Transfer the liquid from the low pressure side of the system to the high pressure side.
- Minimize parasitic losses in the system, i.e. use a very small pump or no pump at all, effectively minimizing the electrical consumption of the system.
- Construct a prototype of the final design during Spring Semester 2014.

Project Constraints

- The overall design budget is limited to $2000.
- The prototype developed by the senior design team must use water in place of refrigerant 245fa, which is the fluid used in the actual system. Our design team is prohibited to use this product by the FAMU-FSU College of Engineering because of its possible health hazards, which may include irritation and dizziness when exposed.
- The fluid within the system must maintain a constant flow rate, with an approximated flow rate of 3 gallons per minute.
- The design must be as small as possible, with a 2 meter height restriction in place.
- The system must contain numerous tanks which contribute to the constant flow rate. A system containing only one tank would be considered a failed prototype to the sponsor company.
- The modified system must use minimal, to preferably no, electricity.
- The system must be completely closed to prevent any losses in the amount of refrigerant 245fa used in the actual system.
- The system must contain pressure gages to indicate the changes in pressure within the system; when and where the pressure is changing.
- The overall change in pressure within the system is restricted to a total of 50 psi.

Initial Design and Analysis

Initial Function Analysis

The components of the system include the following:

- Pressurized vessels (3 - 4) (boiler and holding tanks)
    - Preferably transparent material (polycarbonate)
    - Must withstand 50 psi internal pressure
- Atmospheric vessel (1) (condenser)
- PVC piping (~20 ft)
- PVC 90° elbows (~6)
- PVC check valves (~6)

- Pneumatic control valves (~6)
- Sensors for fluid level (2)
- Air compressor
  - Must supply a constant pressure of 50 psi (appropriate cfm)
  - Sound must be damped to an acceptable level for indoor use
- Tubing for air pressure lines (~10 ft) (1/4” stainless steel tubing)
- Controller to control all valves throughout the system

The specifications of the system include the following:

- The overall height of system must not exceed 2 meters.
- The length and width of the system are to be reasonable compared to the height but their exact dimensions are not critical.
- All system components must be able to withstand an internal pressure of 75 psi (the required pressure with a safety factor of 1.5).
- Electrical power required for the components should be minimal (control valves, sensors, and air compressor).

Initial Design Concepts

During the fall semester our team focused on generating design concepts individually with the goal of evaluating these designs for final selection as a team during Week 9. The team was able to compose 4 designs, but upon brief analysis, three of the designs were extremely similar, therefore, as a team we combined design concepts 1, 2, and 3 into one concept deemed the title Combined Design Concept. A not-to-scale CAD layout of this design concept can be seen in the following figure (Figure 2).

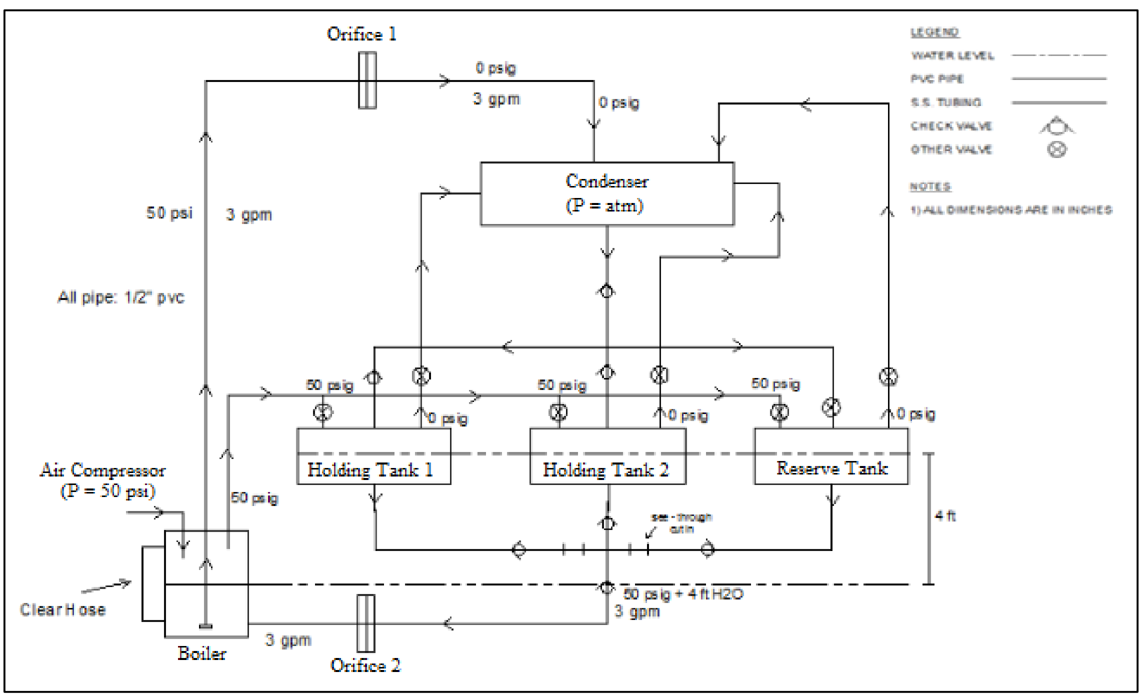


Figure 2. Combined Design Concept: Design concepts 1, 2, and 3.

An in-depth explanation of how the Combined Design Concept (Figure 2) operates has been provided below:

1) To model our boiler a pressure vessel will be filled with water and an air compressor will supply a constant pressure of 50 psi to the vessel. The air pressure in the vessel will push the water up the pipe until it reaches orifice 1.
2) Orifice 1 will represent the turbo expander in our prototype's design. The purpose of this orifice is to resemble the pressure drop from 50 psi to 0 psi (atmospheric pressure) that would occur in the actual system. After the pressure is relieved from the system the water will flow into our condenser which is at atmospheric pressure.
3) Our condenser will be a non-pressurized vessel that is held at atmospheric pressure. The condenser is what supplies water to the holding tanks below it. The condenser also acts as a place for the holding tanks to relieve their pressure back to 0 psi after pressurization.
4) The holding tanks and reserve tank, which will all be pressurized, are the most complex segment in this design due to the fact that they are solely responsible for maintaining the constant flow rate previously supplied by the pump. Analyzing one holding tank allows for an easier explanation. A holding tank, filled with water, is pressurized from opening its control valve to a pressure line from the boiler, which supplies a constant pressure of 50 psi. Once the pressure of the tank is equal to the pressure within the boiler (an instantaneous occurrence) the tank will drain the water by gravitational force due to the pressure balance and elevation difference between the tank and the boiler. When the tank needs to refill the control valve for the pressure line will close and the control valve for the condenser will open thus relieving the pressure inside the tank back to atmospheric pressure. This will result in the flow of water from the condenser into the tank with the aid of gravity and elevation difference.
5) One might have noticed that one vessel is not capable of maintaining a constant flow rate within the system because it needs to refill itself after draining. That is why a second holding tank was added to alternate with the first tank and help establish a constant flow within the system since one tank will always be draining while the other is filling. This sequence of executions can be visualized better with the schematic below (Figure 3).

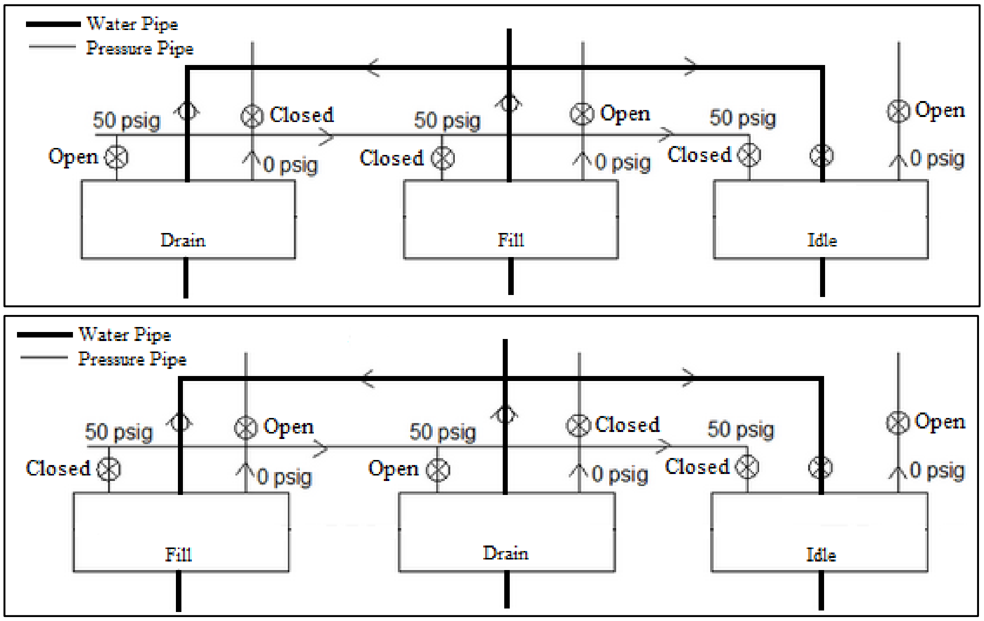


Figure 3. Combined Design Concept: A schematic showing the execution of holding tank 1 (top) and execution of holding tank 2 (bottom) seen in the system in Figure 2.

In the figure above (Figure 3) the execution of holding tank 1 and execution of holding tank 2 is shown. In the execution of holding tank 1, the first tank is draining because it is being pressurized by the pressure line from the boiler while the second tank is filling because it is open to atmospheric pressure from the condenser. The execution of holding tank 2 shows a switch in these roles between tanks 1 and 2. A third tank is seen above, labeled "Idle" during both phases. This is a reserve tank in case the system faces any problems which might arise from sensor or control valve malfunctions. This tank, being twice in volume as the others, would drain and allow tanks 1 and 2 to refill completely. Then the execution of holding tank 1 can restart for tanks 1 and 2 and the reserve tank will refill itself from the condenser. This process is visually demonstrated in the schematic below (Figure 4).

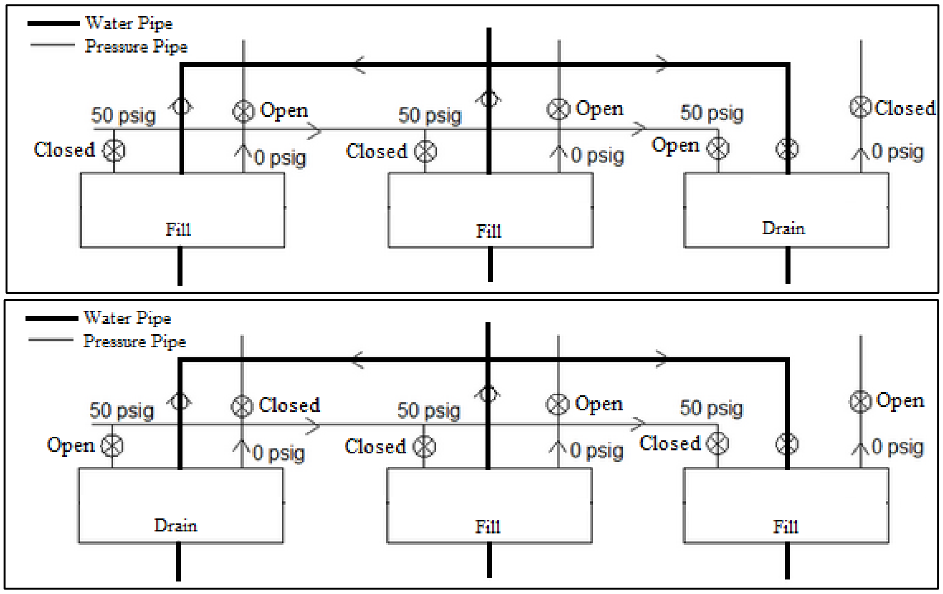


Figure 4. Combined Design Concept: A schematic showing the execution of the reserve vessel (top) and reserve vessel recovery (bottom) seen in the system in Figures 2 and 3.

6) After the water is drained from a pressure tank it goes through orifice 2 before reconnecting with the boiler and completing the entirely closed system. The second orifice is considered at this point to possibly minimize the flow rate back into the boiler if it is not at a constant 3 gpm, the desired flow rate in our system.

The fourth design concept, Design Concept 4 (Figure 5), was the only design that showed significant difference in the components required for the design. These significant differences included the use of 4 holding tanks in constant operation and the collection of the liquid from these 4 tanks by a pressurized storage tank below them. Otherwise, the entire system operates in the same exact manner as the Combined Design Concept (Figure 2), explained previously. Holding tanks 1 and 2, and holding tanks 3 and 4, undergo the same execution of holding tanks 1 and 2, demonstrated (Figure 3) and explained previously. This design also used a pressurized storage tank below the holding tanks, collecting the water from the tanks which drained two at a time. This storage tank was constantly pressurized at 50 psi due to the pressure being supplied by the holding tanks above which drain into it. This constant pressure is equal to the pressure of the boiler, allowing for continuous drainage of the storage tank at the appropriate flow rate (3 gpm) back to the boiler.

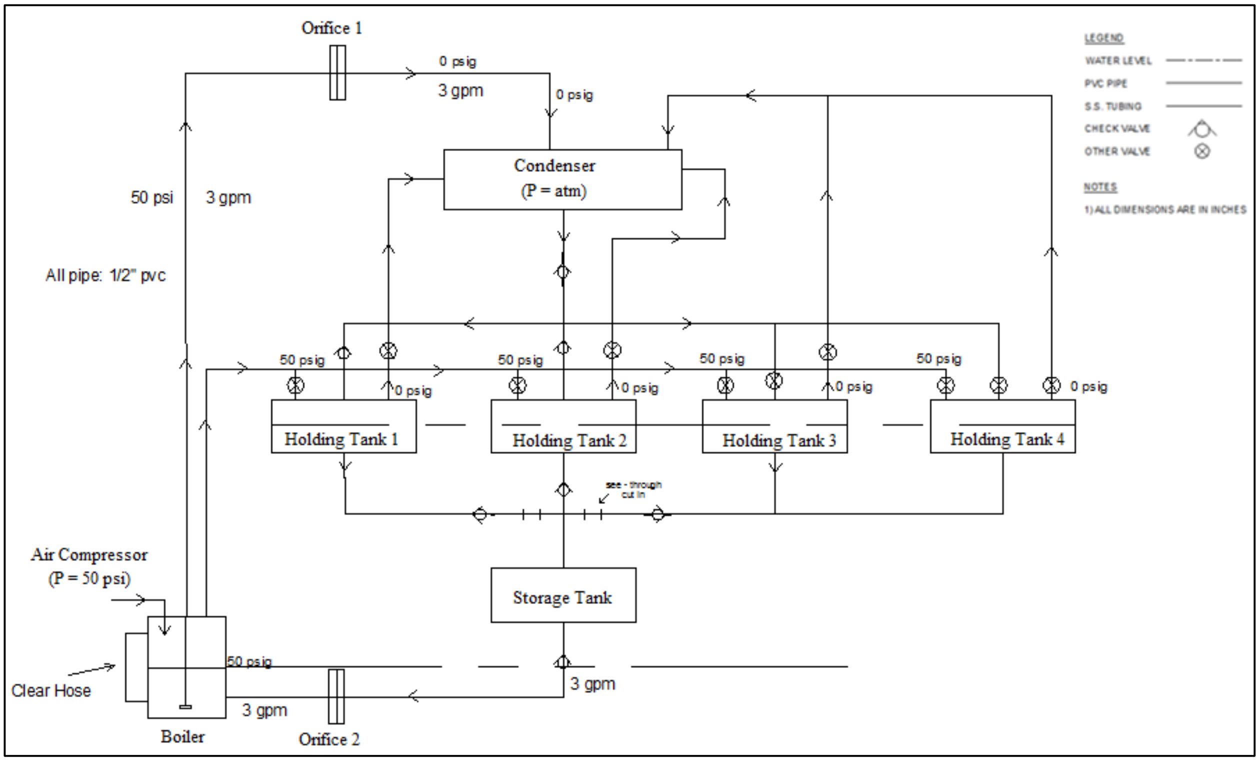


Figure 5. Design Concept 4.

Evaluation of Design Concepts

During Week 9 of the fall semester the design team had produced 4 individual designs needed to be evaluated for the selection of a final design. Of the four designs, three of the designs were extremely similar; therefore, the team combined these designs into the Combined Design Concept. The design team and our sponsor both agreed upon this Combined Design Concept and decided it would be pursued as the final design selection, with possible modifications, for our prototype. The fourth design was the only design that showed significant differences from the others. This design used a storage tank to collect water from 4 vessels that were all in continuous usage. This design was still evaluated but because of its extra materials and components to accomplish the same goal as the other concept it was discarded. During Week 10 the design team, in close collaboration with our sponsor, selected the Combined Design Concept as the final design for the prototype.

Much of the spring semester was dedicated to the actual fabrication and building of the prototype. Since the design team started working on the final design, there were a few minor changes that had to be made along the way. Many different materials were chosen for the magnet floats. Foam was used, which was crushed under the 50 psi pressure and due to its decrease in volume it also lost its buoyancy. The first alternative material to be used was cork. The cork seemed to absorb water while being submerged. This caused an increase in density until the cork would barely stay afloat. The second alternative was wood. Wood is practically incompressible; therefore it will not change volume under the pressure conditions. The wood was also sealed with Thompson’s water sealer to prevent the wood from absorbing water and becoming more dense and/or expanding in volume. The wood floats did exceptionally well during testing and will be used in the final design.

Final Design and Analysis

Final Function Analysis

The components of the system, which can also be found in the bill of materials provided in Appendix 1, include the following:

- Pressurized Vessels (3) (boiler and holding tanks)
  - Transparent material (polycarbonate)
  - Must withstand 50 psi internal pressure
- Atmospheric Vessel (1) (condenser)
- Mechanical Valves
  - 1/2” Throttling Valves (2)
  - 1/2” Check Valves (2)
  - 3/4” Check Valves (2)
  - 1/2” Ball Valve
- Air Control Valves
  - 1/8” NPT Single Solenoid 3-Way Control Valves (2)
    - Parker B3G0BB549C
- Sensors and Relay
  - Float Switch Sensor (2)
  - Relays
    - Potter & Brumfield KHAU-17012L-24 (2)
    - Magnecraft 785XBXCD-24D (1)
  - 14 Standard Wire Gauge electrical wires (~20 ft)
- Pressure Line
  - 3/16” copper tubing (~8 ft)
  - 1/4" hose (~8 ft)
- Water Piping
  - 1/2” PVC Schedule 40 (~16 ft)
  - 3/4” PVC Schedule 40 (~6 ft)
  - Pipe Fittings:
    - 1/2” PVC Pipe 90° Elbow (5)
    - 3/4” PVC Pipe 90° Elbow (2)
    - 1/2” PVC Pipe Tee (5)
    - 1/2” Galvanized Pipe Tee (1)
    - 3/4” Galvanized Pipe Tee (1)
    - 1/2" PVC pipe nipples (2)
- Analytical Components
  - Orange Research liquid variable flow meter, 0-5 gpm
  - 0-100 psi pressure gauges (4)
- Power Supply (1)
  - Siemens 6EP1332-15H31

- Breaker (1)
    - Eaton WMZT2C08
- Air Compressor (1)
    - Must supply a constant pressure of 50 psi (appropriate cfm)

The specifications of the system include the following:

- The overall height of system must not exceed 2 meters.
- The length and width of the system are to be reasonable compared to the height but their exact dimensions are not critical.
- All system components must be able to withstand an internal pressure of 75 psi (the design pressure with a safety factor of 1.5).
- Electrical power required for the components should be minimal (control valves, sensors, and air compressor).

Final Design Concept

The final design concept with all major modifications has been selected and approved by the design team in collaboration with our sponsor. A dimensioned CAD drawing of this design concept can be seen in the following figure (Figure 6).

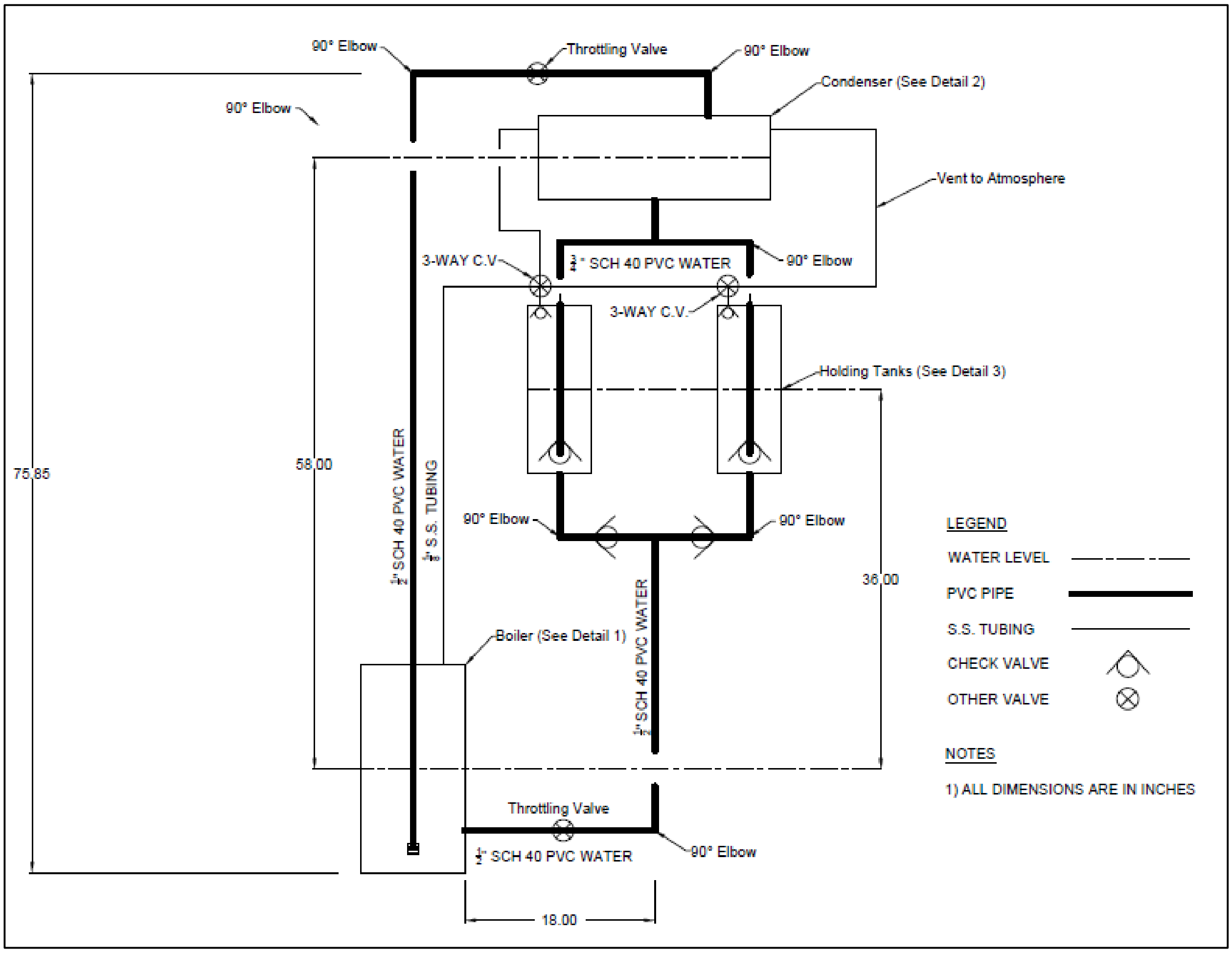


Figure 6. The final selected and approved design concept for the prototype.

Overall this design concept is very similar to the Combined Design Concept discussed in the previous section of this report. The major modifications made to that design include:

- Instead of orifices, throttling valves are used to regulate the flow rate at the beginning and end of the shuttle valve system.
- The piping from the condenser to the holding tanks was upgraded from 1/2" PVC to 3/4" PVC to solve a problem pertaining to unwanted flow rate restrictions.
- Only two holding tanks are used in alteration to maintain a continuous flow rate in the system. The reserve tank was discarded due to the fact that it would require extra materials and machining for a component that would have limited use.
- The pressure lines from the boiler and condenser to the holding tanks are operated by one single solenoid 3-way control valve for each holding tank. This reduces the number of components needed for the prototype.

The operation of the entire system is basically the same as the Combined Design Concept and to avoid redundancy one may refer back to the in-depth explanation of how that system operates in the previous section. What may require explanation is the modification and improvements to the execution of the holding tanks. Helpful schematics (Figures 7 and 8) and an in-depth explanation of these schematics have been provided.

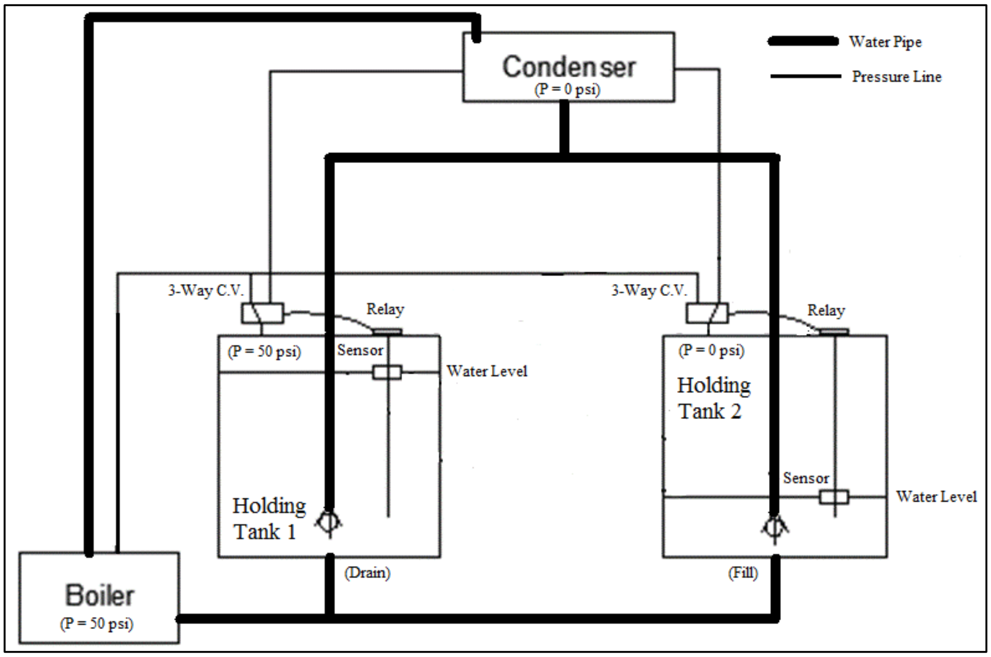


Figure 7. The execution of holding tank 1 in the final design concept.

The holding tanks operate on sensors that inform the control valves to change positions once the water level in the holding tank has been drained to its lowest allowable height. In the figure above (Figure 7), the holding tanks are at the instantaneous moment when the sensor in holding tank 2 has been triggered. This sensor relays a message back to the control valves for it to change its position to the atmospheric pressure line, for holding tank 2, and to the boiler pressure line, for holding tank 1. The balancing in pressure between holding tank 1 and the boiler allows this tank to drain. The pressure relief back to atmospheric pressure in holding tank 2 allows this tank to refill with water from the condenser. These holding tanks alternate draining and filling with one tank always draining and one tank always filling. This is how a constant flow rate in the system is maintained. The alternate situation of the instantaneous moment when holding tank 1 has drained to its minimum allowable water level and the sensor has triggered the change in position of the control valves can be seen in the following figure (Figure 8).

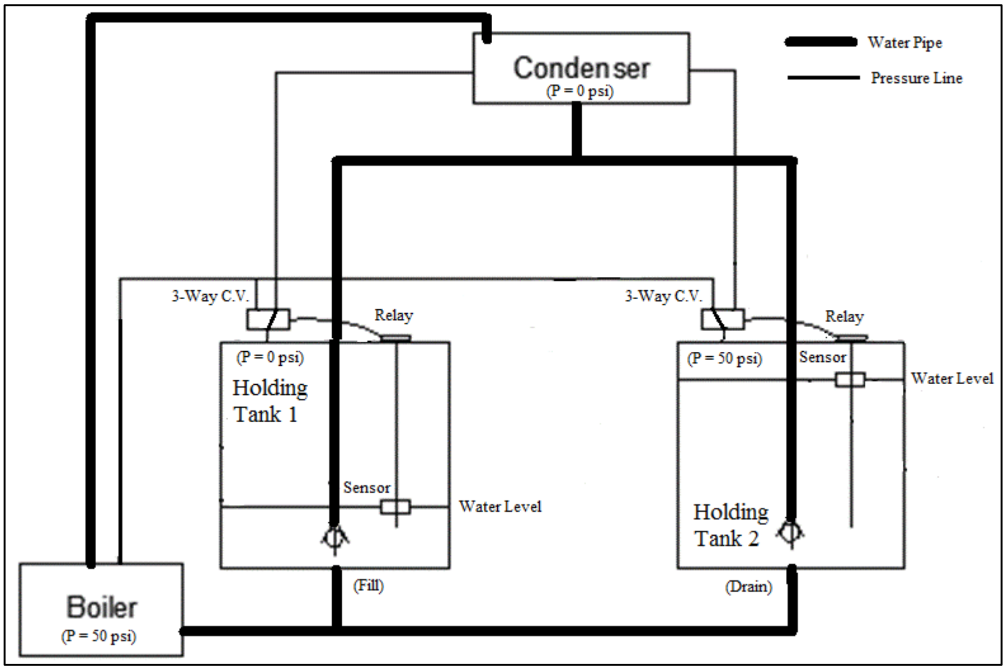


Figure 8. The execution of holding tank 2 in the final design concept.

Pipe-Flo Analysis

PIPE-FLO Professional is fluid flow analytical software that is widely used in industry [2]. This program simulates the operation of piping systems transporting liquids and industrial gases under a variety of expected operating conditions. The professional version of the program has no limits as to the number of pipelines that can be analyzed at once. The version that was used for calculating the flow rates in the group's prototype is a demo version that can only analyze a maximum of five pipe segments at a time. Therefore, the group had to analyze each portion of the design separately to get the flow rate information desired. The program can also size pumps and compressors given any certain criteria that the user inputs. For this design, the group was most concerned with choosing appropriate pipe diameters and orifice sizes to get the desired flow rate throughout the system.

The desired flow rate for the prototype is 3 gallons per minute (gpm). It is also known that the pressure vessel (boiler) remains at an almost constant pressure of 50 psi. These parameters, including the desired length of the pipes, the height of the condenser, and the height of the boiler at the reference height of 0 ft, were inputted into the PIPE-FLO software. An orifice was implemented and a suitable diameter was selected to drop the pressure from 50 psig to a pressure very close to atmospheric pressure. The schematic below (Figure 9) shows this calculation performed in PIPE-FLO.

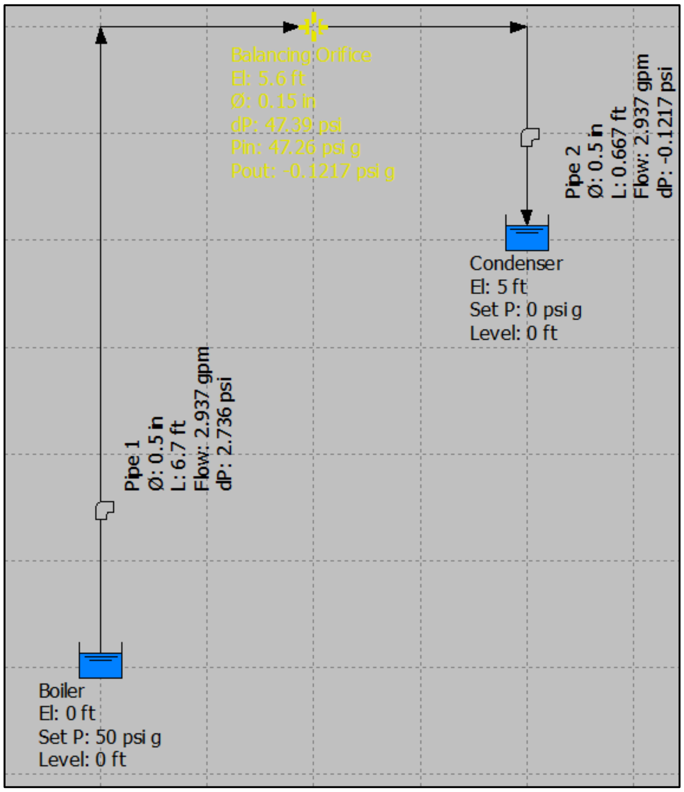


Figure 9. PIPE-FLO calculation from the boiler to the condenser.

From the figure, it can be seen that by using 1/2 inch PVC pipe and the proper balancing orifice that the flow rate has been regulated very close to 3 gpm. In the actual prototype, instead of using an orifice, a throttling valve will be used to drop the pressure and control the flow rate. As mentioned before this mimics the pressure drop that occurs across the turbo expander in the ORC system built by Verdicorp. It is important to note that the driving force for the flow of liquid in this segment of the system is the 50 psi pressure that is being induced by an air compressor to the boiler. In the actual system, the high pressure is generated by superheating the refrigerant 245fa.

In the next portion of the system, the condenser to the holding tanks, a very similar analysis was done and the flow rate was again calculated. The major difference in this portion is that the driving force for the flow of liquid is gravity. Since the pressure has been reduced and the condenser is relieved to atmospheric pressure, only gravity can be relied on to transport the liquid from the condenser to the holding tank. The schematic below (Figure 10) shows this calculation performed in the PIPE-FLO software. The height difference between the condenser and the holding tank(s) is 1 ft. The calculation was ran using 1/2 inch PVC piping and, considering all major and minor losses (pipe friction and pipe fittings), the calculated flow rate was 4.2 gpm. Increasing the pipe diameter to 3/4 inch PVC piping resulted in a flow rate of 7.4 gpm. This flow rate is a little higher than the desired flow rate of 3 gpm but this will actually work to the design’s advantage. This will allow the holding tanks to refill faster than they will empty, ensuring that there will always be a constant flow out of the bottom of the holding tanks. At the instant that holding tank 1 stops draining it will start to refill and holding tank 2 will start to drain. Therefore, tank 1 will be patiently waiting for tank 2 to finish draining so that the cycle can be reversed and tank 1 can begin draining again.

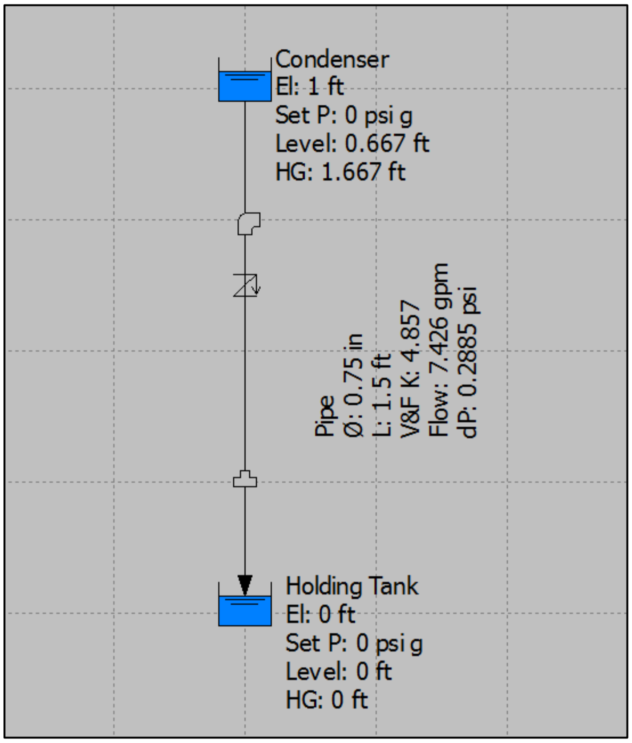


Figure 10. PIPE-FLO calculation from the condenser to a holding tank.

The calculation for the flow rate from the holding tank(s) to the boiler, shown in the schematic below (Figure 11), is very similar to the one for the flow rate from the condenser to the holding tank(s). This flow will be gravity driven at a height difference of 3 ft.

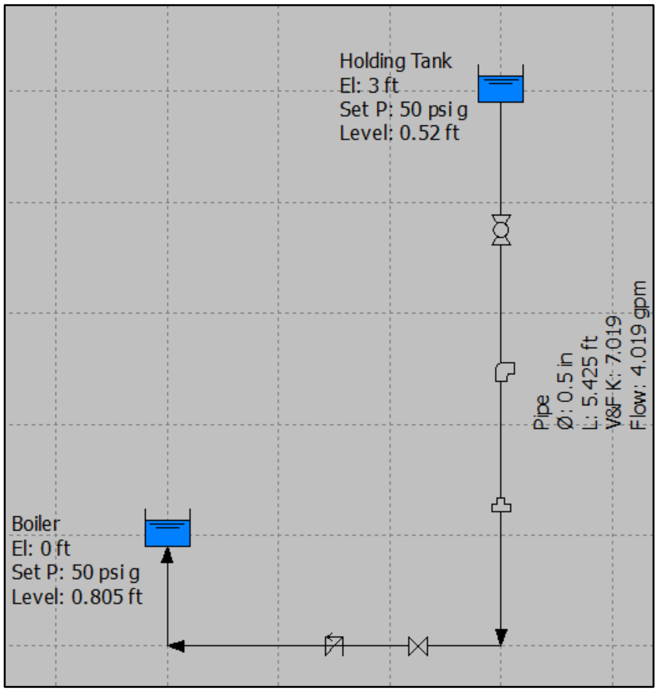


Figure 11. PIPE-FLO calculation from a holding tank to the boiler.

The flow rate was calculated using 1/2 inch PVC piping and with the pipe fittings and throttling valve included the flow rate was found to be 4 gpm. This flow rate is slightly higher than the desired 3 gpm but so that is why a throttling valve will be used to regulate it. In the actual ORC system there will likely be a small circulation pump in the place of this throttling valve that will be powered by a variable frequency drive motor. A sensor will sense the flow demand of the superheated vapor to the turbo-expander and will control how fast the motor must rotate the pump in order to maintain the constant flow rate in the system. The small circulation pump will require a small fraction of the energy that is consumed by the current high pressure pump that is used on the current system. For the prototype, due to design and budget constraints, a simple throttling valve will be used here to manually regulate the flow rate to match the flow rate that is observed coming out of the boiler.

Detailed Design and Manufacturing

The bill of materials containing all of the components in the design can be found in Appendix 1. A detailed engineering drawing correlating the part numbers of the components in Appendix 1 to their location in the prototype can be found in Appendix 2. Of these components, the only one the design team physically constructed and machined from scratch were the holding tanks. Engineering drawings for the Verdicorp machine shop have been provided in Appendix 3. Other components in the system were also modified in the Verdicorp machine shop. These components included the boiler and the condenser. Engineering drawings have not been provided for these components they were purchased.

Programming Needs/Controls

Our system did not require any programming and our controls were a simple sensor and switch. Our sensor was a simple float switch that moved up and down with the water level inside the holding tanks. Once the water has drained to the specified level, the sensor uses a relay to send a signal to the control valve, informing it to change positions between the pressure line from the boiler (at 50 psi) and the pressure line from the condenser (at atmospheric pressure). This allows the tanks to either drain or fill, respectively, and maintain the appropriate flow rate of 3 gpm desired in the prototype.

ABET Quality Engineering

Environmental and Safety Issues

The ORC system uses refrigerant 245fa. There are environmental benefits to using this refrigerant because it is a long-lasting and non-flammable substance [3]. The ORC system itself is also very environmentally beneficial. Since it generates electrical power from strictly low grade renewable heat sources, it is a prime example of renewable energy option that generates power without CO_2 emissions.

However, even though refrigerant 245fa is environmentally beneficial, it has several safety risks. This refrigerant has several negative health effects associated with it. The refrigerant will cause irritation if it comes in contact with the eyes. At low oxygen levels inhaling the refrigerant would cause an increased pulse rate and loss of coordination. At high levels of exposure, inhaling could cause cardiac arrhythmia. Due to the possible harmful effects of refrigerant 245fa, tests and calculations for our prototype were instead done using water and air pressure. However, future calculations will be made with the properties of refrigerant 245fa.

There is also a risk that the holding tanks would not withstand the pressure of 50 psi. Before the prototype was completely built, both of the holding tanks were pressure tested to make sure that they wouldn't explode due to over pressurization. Extreme caution was used by the team, with each member standing a safe distance away from the holding tanks as they were being tested. The catastrophic event that the prototype system will fail and explode due to over pressurizing while it is running was also taken into consideration. In order to protect the system from over pressurizing, a pressure relief valve was added to the air pressure line just outside the boiler. This will allow the system to safely relieve of pressures that reach 65 psi.

Ethics

The design team has operated morally and professionally throughout the course of the semester. All members have contributed their fair share of work to the requirements of the class and have been prompt in being on time for all team meetings, staff meetings, and meetings with the sponsor. A position of camaraderie has been developed between the group members since the beginning of the semester. Each member has encouraged each other while working on deliverables and preparing for group presentations. There have been no ethical issues amongst the design team members. The team members respect each other's differences and beliefs. No member has insulted another based on their race, religion, or political ideology.

Risk and Reliability Assessment

Our prototype was designed with the idea for implementation into the Organic Rankine Cycle that uses refrigerant 245fa. However, due to safety issues, our prototype was tested with water and compressed air. The calculations we have completed for our test model, with water and air, have been close to the project constraints of having a constant mass flow of 3 gpm and a differential pressure of 50 psi. Calculations for the refrigerant have not yet been completed. However, based on our calculations with water and compressed air, we believe that our test model is a reliable prototype to be improved and implemented into the ORC.

Because the ORC runs on renewable energy, our project has no environmental risks. However, there are some risks involving safety. It is possible for the components of the system to wear over time and become unable to withstand the pressure of 50 psi. If this happens, the components could break or explode and anyone standing near the equipment could be injured.

Procurement and Budgeting

A bill of materials containing each component of the prototype has been provided in Appendix 1. This bill of materials also lists the description of each component, quantity, vendor, and total cost. All components purchased and ordered online were done through our sponsor. Ordering forms were provided to us and an example of a completed form for the purchase and order of our condenser can be found in Appendix 4. A majority of the components were purchased by the team at local stores in Tallahassee. The receipt were then provided to Verdicorp for reimbursement of the purchases. All machining needed was performed in the machine shop at Verdicorp. The engineering drawings developed by the team were submitted to the machine shop and the components were then constructed and modified there.

The budget allocated to us by our sponsor was $2000. All of the components used in the completion of the prototype resulted in a total expenditure of $1106.32. The breakdown of this expenditure is provided below:

- Air and Liquid Control Valves: $116.86 ($99)
- Heat Exchanger: $145.11
- Condenser: $54.15
- Holding Tanks (Walls): $61.52 ($88.20)
- Holding Tanks (End Caps): $114.52
- Relays: $43.17
- PVC Piping, PVC Fittings, Standard Valves: $47.23
- Air Compressor, Sensors, Outer Frame, Pressure Line Piping: $0
- Flow Meter: $106.00
- Pressure Gauges, PVC and Copper Components: $130.56
- Additional PVC and Copper components: $100

This was well under our allocated budget, saving $893.68, which was a desired characteristic for our team. Our team was able to accomplish this by selecting a majority of components for our design that were widely available and require little to no modifications. By applying our personal ingenuities and thinking outside the box as a design team, we were able save huge savings by creating our own float sensors and prototype frame. The values corresponding to only these two accounts of savings was approximated to be $300 and $400, respectively.

Prototype Details, Testing, and Analysis

There were only a few parts that needed to be machined for the prototype. The design team had to machine caps for the boiler that would allow for connections of the water and pressure piping. These pieces were machined on the lathe in the Verdicorp machine shop and then the proper threads were tapped into the cap. The caps for the holding tanks were also machined. They were constructed from 3/4 in. aluminum stock and cut into 6 in. by 6 in. squares. Then the 1/2 in. and 1/8 in. NPT threads were tapped into them for the liquid inlet and outlet as well as the inlet for the three-way control valve. The 6 in. diameter polycarbonate tubes were also machined on the lathe to make the ends even and rounded to prevent stress cracks.

Once all parts were machined and/or purchased the design team began the assembly process. All piping had to be either cemented together or threaded. For all cemented fittings it was paramount that all surfaces were clean of any debris and that a liberal amount of PVC cement was applied to both connections. Then both connections were mated and allowed at least 30 minutes before any further assembly of that piece. All male threads for each threaded joint had to be wrapped with Teflon thread tape in a very cautious manner to prevent leaks. Each threaded join was then carefully threaded together while being cautious not to over tighten and possibly bust any of the fittings.

The holding tanks were very carefully put together. Each cap for each of the holding tanks has an O-ring that must be seated properly into the O-ring slot in order to prevent leaking from the tank. The tank caps were fitted with the O-rings and then, slowly and evenly as possible, they were bound together using the threaded rods by tightening in a crisscross pattern. All fittings leading into the caps, including the control valves, were connected to the caps before the holding tanks were assembled.

Once all piping and sub-assemblies were fully assembled everything was lifted into place and bolted to the support frame which was constructed from 80/20 aluminum. After everything was fully assembled the prototype was filled with water and leak tested. There were no leaks at atmospheric pressure so the team then attached the hose from the compressor and pressurized the system to 20 psi; still there were no leaks. The system was then slowly pressurized to 65 psi when the pressure relief valve started to open. This proved that our system was safe and would not be allowed to operate over 65 psi.

The system was then backed down to the operating pressure of 50 psi. The throttling valve was opened until the flow meter read 3 gpm. At the rate of the gpm the boiler was running out of water. This meant that the flow into the boiler was less than the flow out of the boiler. This could be for a few different reasons. Since the team had last calculated the flows using PIPE-FLO, there were a few minor changes to the piping from the holding tanks to the boiler, including another tee and another gate valve. These minor losses were not considered in the initial calculations. Also, there is a small pressure drop from the boiler to the holding tanks due to the small copper tubing and the inlets and outlets of the control valves. Therefore the pressure in the holding tanks was actually a little bit lower than that of the boiler, almost 1 psi different. This could definitely be the cause for this anomaly. To fix this problem one could either place a small circulation pump in place of the gate valve leading into the boiler or simply increase the diameter of the piping.

Communications

As a team we met with our sponsor, Robert Parsons, regularly in order to update him on the design’s progress and to address any questions we might have. Construction of the prototype was also done at the Verdicorp machine shop, where Mr. Parsons was available to give us advice and supervision. Mr. Parsons has also machined several of the components for the prototype system and had them ready for us as soon as possible. When not in a meeting, the team communicated with Mr. Parsons via email. Responses to the emails were usually within the day they were sent. Unfortunately, we didn’t have any communication with our proposed staff advisor Dr. A. Krothapalli, and so our sponsor, Mr. Parsons, did most of the advising for our design team. We also had several meetings with our senior design instructor, Dr. Kamal Amin, throughout the term in order to update him on the progress of the prototype. The team communicated with each other via text messaging. The team usually met several times a week in order to work on the project. When working individually, the team uploaded any appropriate documents and files onto a file share on Dropbox.

Conclusions

The team was able to construct the prototype using only half of the allocated budget. The constructed prototype went through several modifications during the testing phase. After the modifications were made, the prototype performed as expected by the team. As shown by the pressure gauges, the system was able to achieve a pressure differential of 50 psi. The system was also able to maintain a continuous flow rate. The prototype ran with a continuous flow rate for about 30 minutes. However, the achieved flow rate was 1.5 gpm instead of the calculated 3 gpm. To achieve the required flow rate, the size of PVC piping segment that runs from the holding tanks to the boiler should be increased to a 3/4 in. diameter. Overall, the team was able to prove the theory that by using solenoid valves and the aid of gravity, fluid can be transferred from the low pressure side of the system to the high pressure side without the use of a centrifugal pump.

Future Plans

Even though the theory of the design has been proven by the prototype, calculations still must be made for the actual ORC system. The calculations that were made for the water and compressed air should also be made for the refrigerant 245fa. Calculations will be made using the operating temperatures and pressures within the actual ORC. The change in performance efficiency and cost effectiveness of the new system also have to be calculated for the large scale version of the prototype replacing the pump in the ORC system.

References

[1] "Verdicorp Environmental Technologies," Verdicorp INC., [Online]. Available: http://verdicorp.com/. [Accessed 18 September 2013].

[2] "eng-software.com," [Online]. Available: http://eng-software.com/products/pipeflo/professional/. [Accessed 6 December 2013].

[3] "Material Safety Data Sheet," [Online]. Available: http://www.honeywell.com/sites/servlet/com.merx.npoint.servlets.DocumentServlet?docid=DFEB0B15A-EAEA-99FF-C834-AF04936DFF16. [Accessed 25 November 2013].

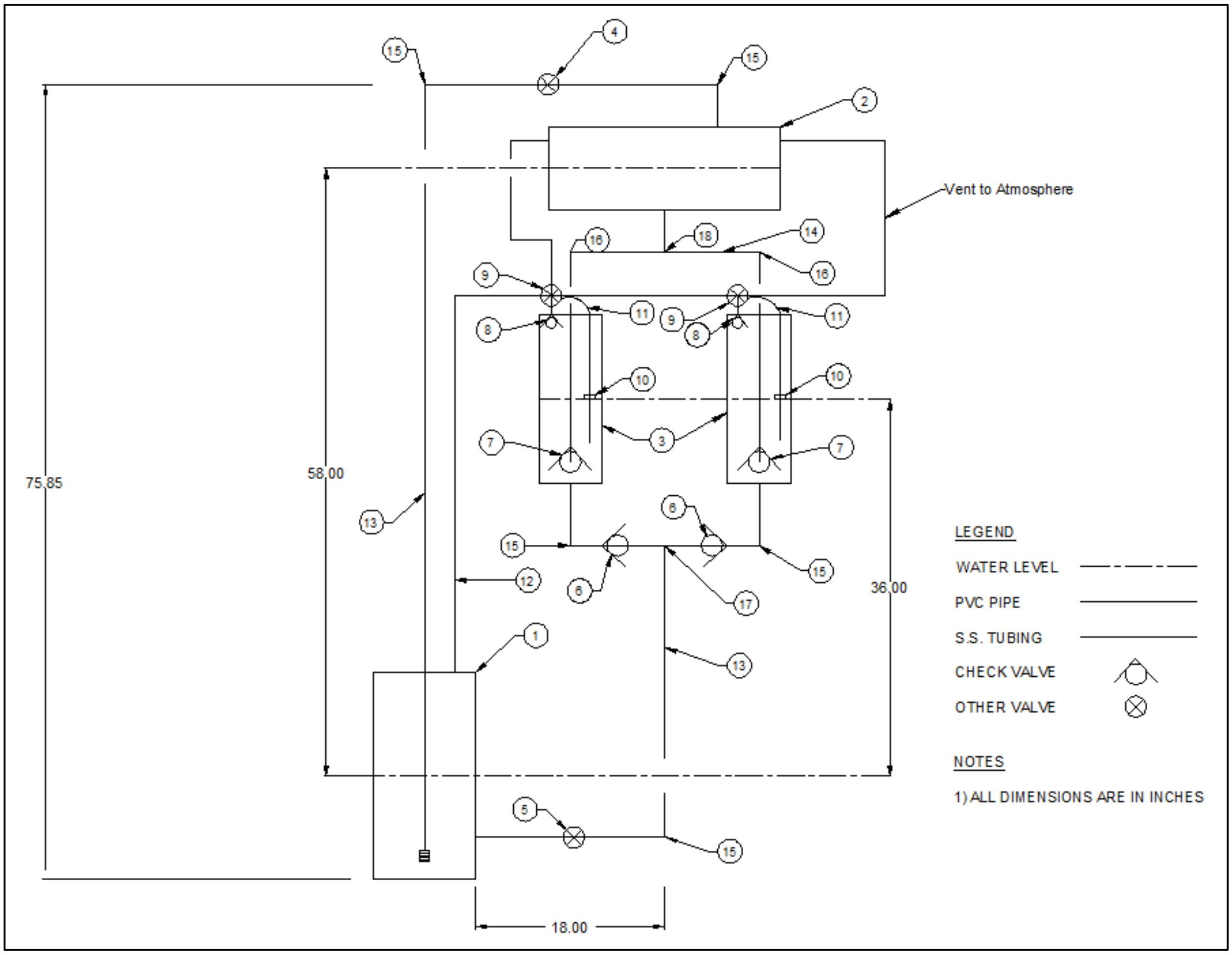
Appendices

Appendix 1: Bill of Materials

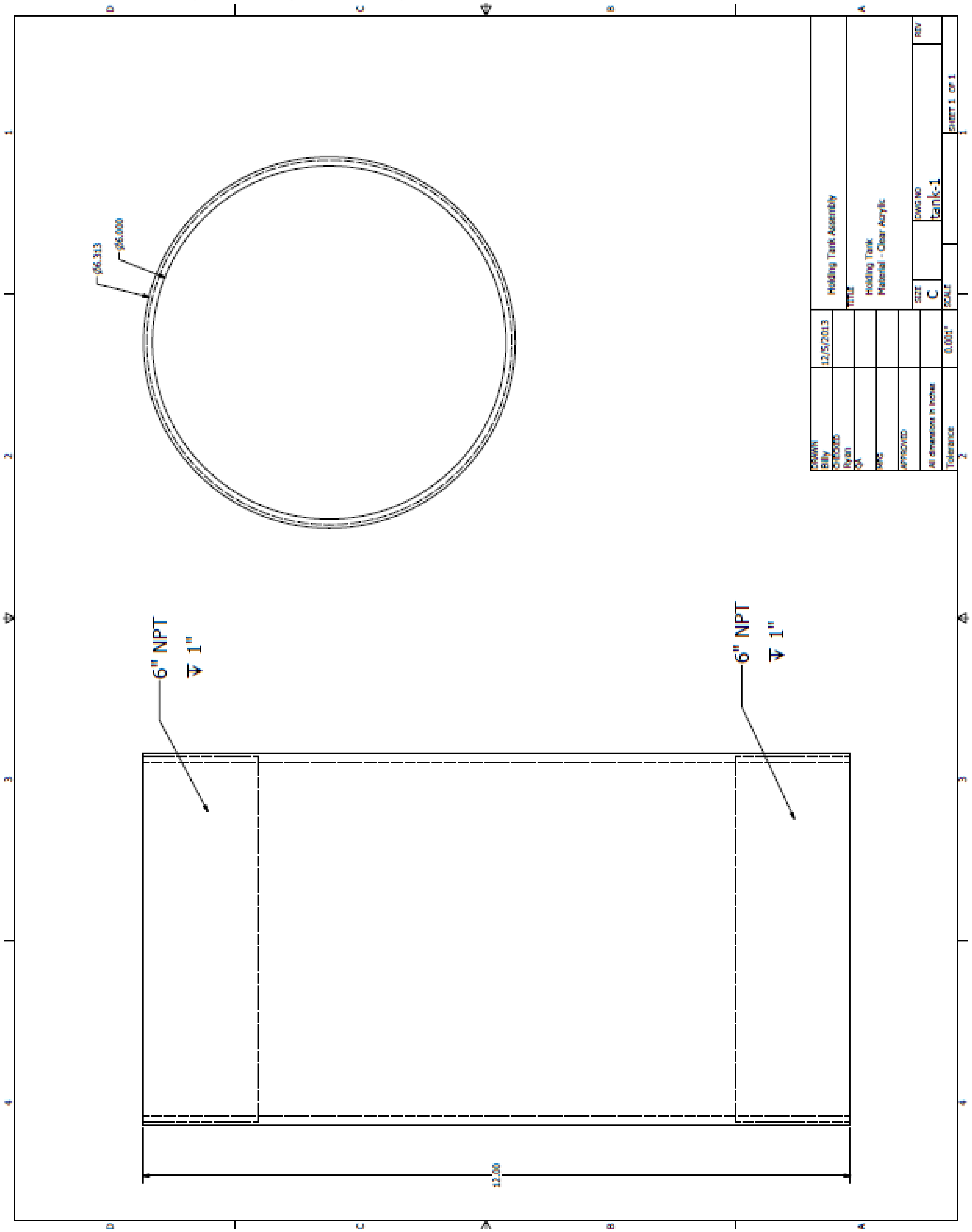
Part #	Component	Product Description	Quantity	Vendor	Total Price (Each)
1	Heat Exchanger	6.25 Gallon Oil Extractor	1	Harbor Freight Tools	$145.11
2	Condenser	Ace / DenHartog 3 Gallon Rectangular Specialty Rinse Tank	1	The Tank Depot (Online)	$54.15
3	Holding Tanks (Walls)	6” Polycarbonate Tubing Sold in 4 ft. segments	1	Purchased through Verdicorp	$61.52
3	Holding Tanks (End Caps)	Aluminum Stock (6” x 3/4” x 2’), O-rings, 3/8” tie rods	1, 4, 8	Purchased through Verdicorp	114.52
4	Throttle Valve 1	1/2” Brass FBTxFBT Gate Valve	2	The Home Depot	$6.35
5	Throttle Valve 2 (REMOVED)	3/4" Brass FBTxFBT Gate Valve	0	The Home Depot	REMOVED
6	Check Valve 1	1/2" Lead Free Brass FPTxFPT Swing Check Valve	2	The Home Depot	$15
7	Check Valve 2	3/4" Lead Free Brass FPTxFPT Swing Check Valve	2	The Home Depot	$18
8	Check Valve 3 (REMOVED)	1/8 in. Brass NPT x NPT Service Check Valve	2	The Home Depot	REMOVED
9	Control Valve	Parker Air Control Valve Single Solenoid, 3-way, 2-pos, 1/8” NPT	2	Global Industrial (Online)	$116.86
10	Sensor	Float Switch Sensor	2	Built at Verdicorp	$0
11	Relay	Potter & Brumfield KHAU-17012L-24; Magnecraft 785XBXCD-24D	2,1	Purchased through Verdicorp	$43.17
12	Pressure Line	1/8” x 6’ Stainless Steel Tubing	~8 ft.	Supplied by Verdicorp	$0
13	Water Pipe 1	1/2" x 10’ PVC Schedule 40	~16 ft.	The Home Depot	$1.81
14	Water Pipe 2	3/4" x 10’ PVC Schedule 40	~6 ft.	The Home Depot	$2.28
15	Water Pipe Elbow 1	1/2” PVC Pipe 90° Elbow	5	The Home Depot	$0.46
16	Water Pipe Elbow 2	3/4” PVC Pipe 90° Elbow	2	The Home Depot	$0.46
17	Water Pipe Tee 1	1/2" PVC Pipe Tee	1	The Home Depot	$0.47

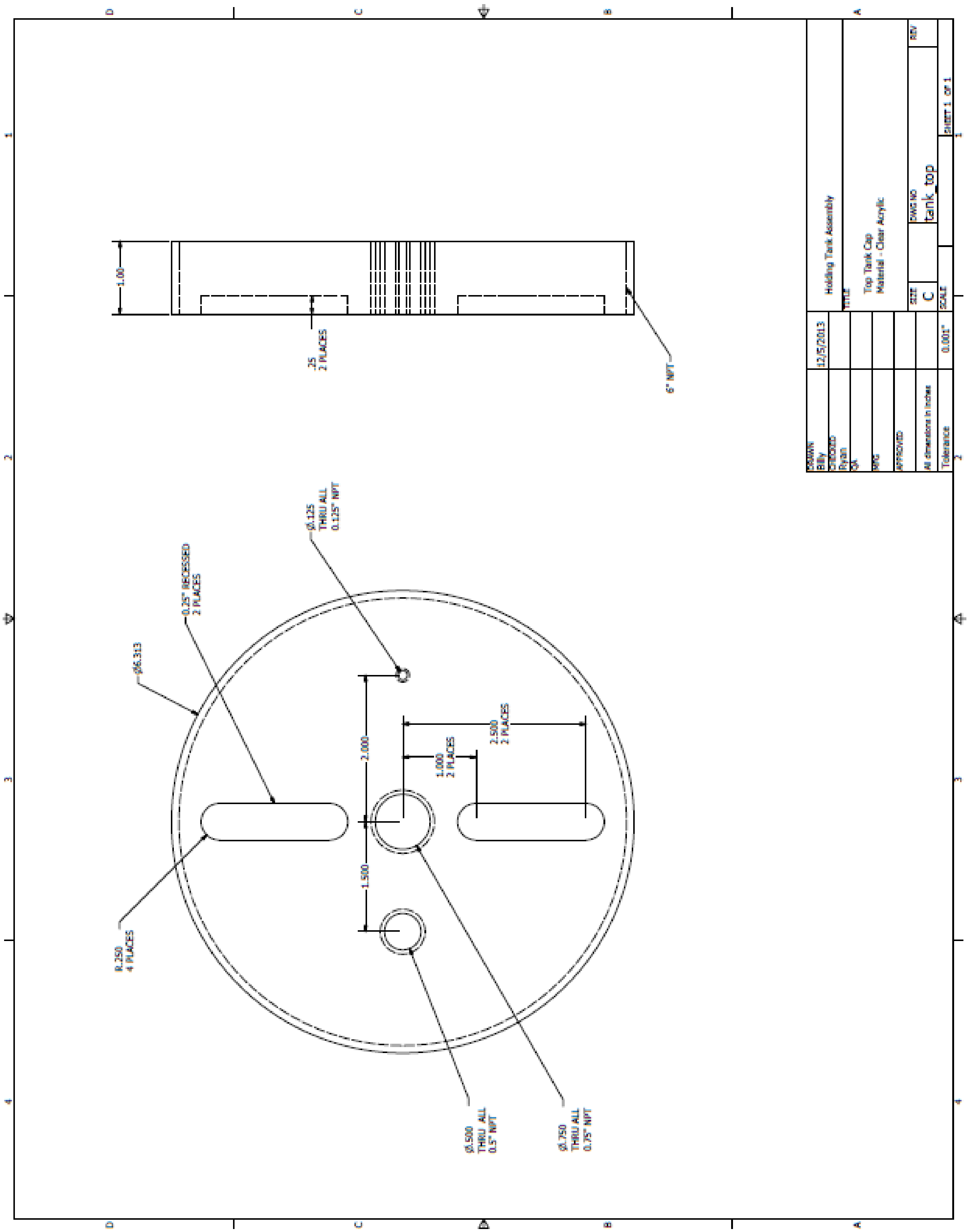
18	Water Pipe Tee 2	3/4" PVC Pipe Tee	1	The Home Depot	$0.47
19	Air Compressor	Porter-Cable 3.5 Gallon 135 psi Pancake Compressor	1	Provided by Verdicorp	$0

Appendix 2: Detailed Design Drawing

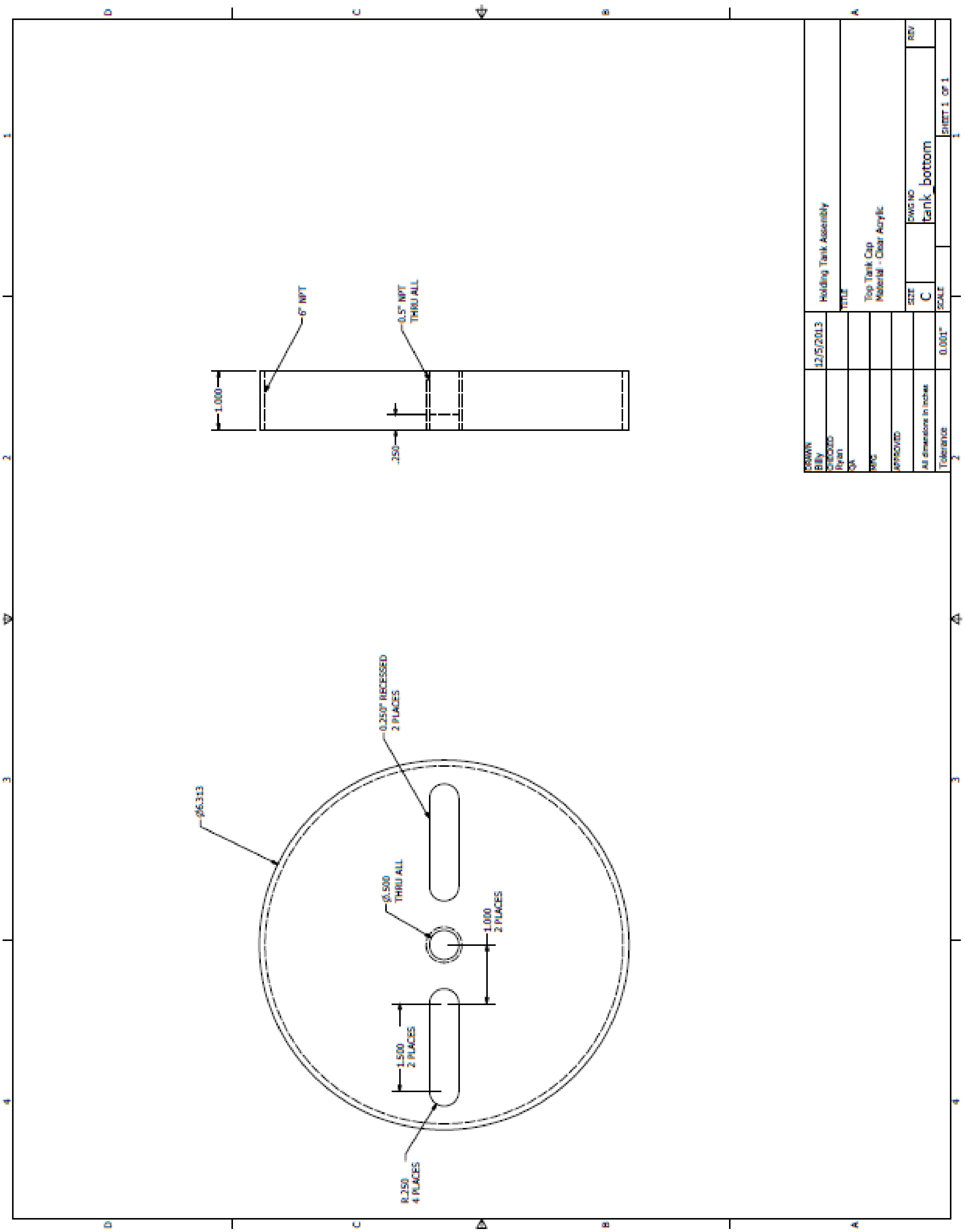


Appendix 3: Engineering Drawings





Holding Tank Assembly
TITLE
Top Tank Cap
Material - Clear Acrylic
DRAWN
Billy
CHECKED
Ryan
QA
MFG
APPROVED
12/5/2013
All dimensions in inches
Tolerance
0.001"
SIZE
C
DWG NO
tank_top
REV
SCALE
SHEET 1 OF 1
1.00
.25
2 PLACES
6" NPT
Ø.125
THRU ALL
0.125" NPT
0.25" RECESSED
2 PLACES
Ø6.313
2.000
2.500
2 PLACES
1.000
2 PLACES
1.500
R.250
4 PLACES
Ø.500
THRU ALL
0.5" NPT
Ø.750
THRU ALL
0.75" NPT


Holding Tank Assembly
TITLE
Top Tank Cap
Material - Clear Acrylic
DWG NO
tank_bottom
SIZE
C
SCALE
SHEET 1 OF 1
REV
DRAWN
Billy
12/5/2013
CHECKED
Ryan
QA
MFG
APPROVED
All dimensions in inches
Tolerance
0.001"
6" NPT
0.5" NPT
THRU ALL
1.000
.250
0.250" RECESSED
2 PLACES
Ø6.313
Ø.500
THRU ALL
1.000
2 PLACES
1.500
2 PLACES
R.250
4 PLACES

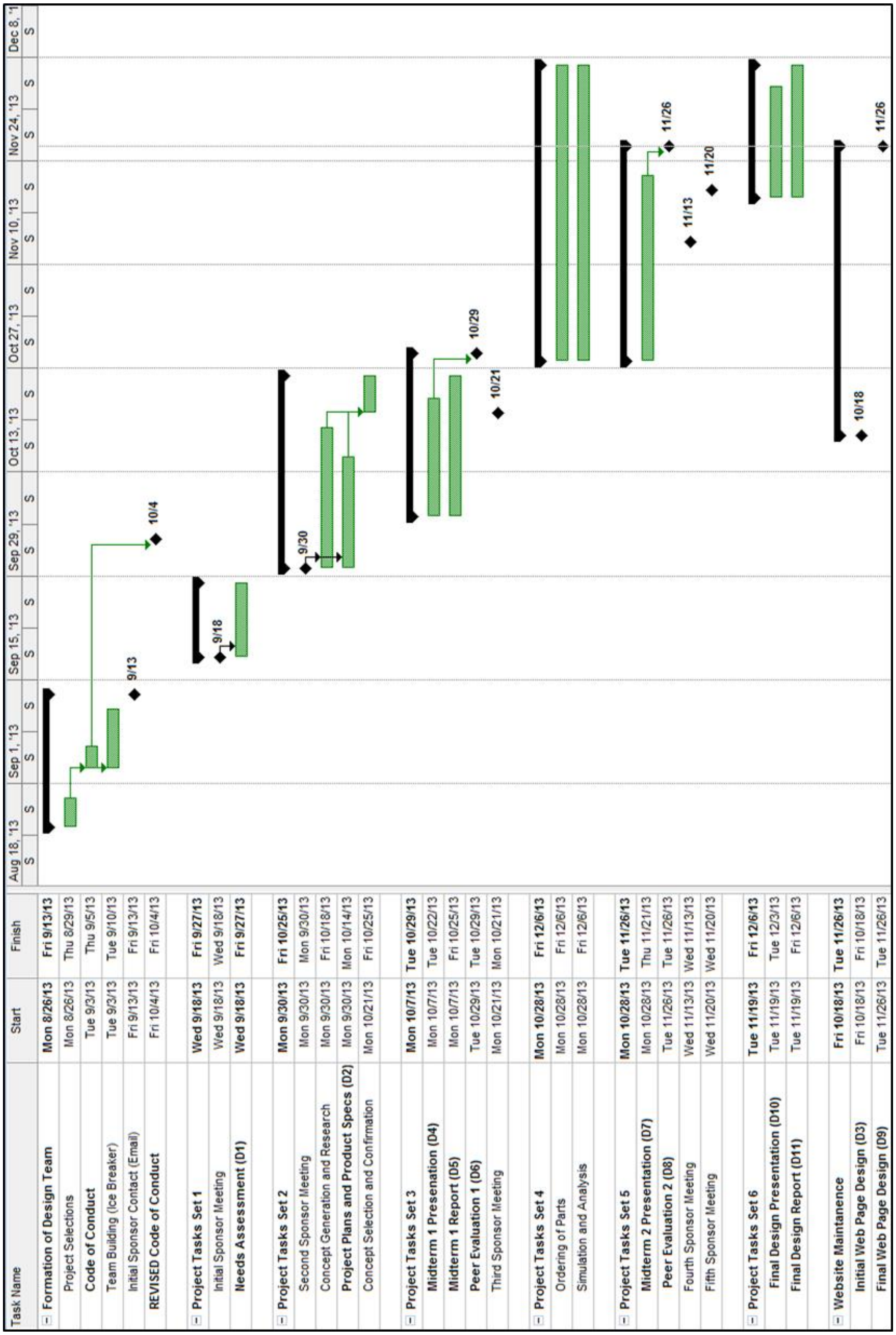
Appendix 4: Example Ordering Form

Verdicorp
Environmental Technologies

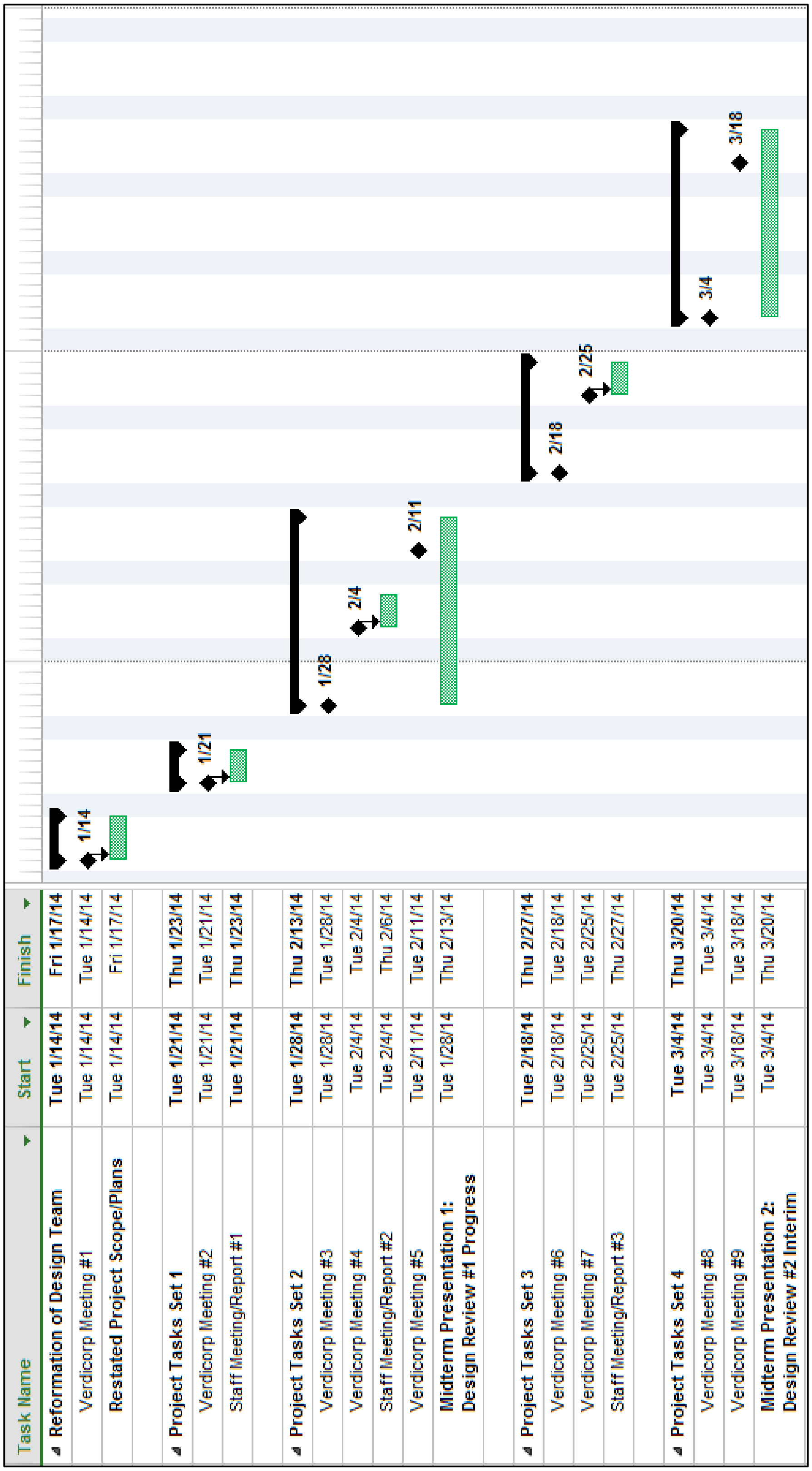
Purchase Order Requisition

Date: 11/26/13	**Vendor: The Tank Depot**	**Requested by: Ryan Laney**			
Ship Via: Shipped from Retail Store (Contact: Zach - zsutphin@tank-depot.com)		**Delivery Due Date: 2 Business Days**			
Item/Product Number	**Description**	**COA Code**	**Quantity**	**Rate**	**Amount**
A-SP0003-RT	Ace / DenHartog 3 Gallon Rectangular Specialty Rinse Tank	12511	1	$33.99	$33.99
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
Freight estimate:	Standard S&H from Retail Store		1	$15.00	$15.00
					$48.99

Appendix 5: Fall Gantt Chart



Appendix 6: Early Spring Semester Gantt Chart



Appendix 7: Late Spring Semester Gantt Chart

Project Tasks Set 5	Thu 3/20/14	Fri 3/28/14
Verdicorp Meeting #10	Tue 3/25/14	Tue 3/25/14
Staff Meeting/Report #4	Tue 3/25/14	Thu 3/27/14
Operational Manual	Thu 3/20/14	Fri 3/28/14
Project Tasks Set 6	Fri 3/28/14	Fri 4/4/14
Verdicorp Meeting #11	Tue 4/1/14	Tue 4/1/14
Design for Manufacturing, Reliability, and Economics	Fri 3/28/14	Fri 4/4/14
Project Tasks Set 7	Fri 4/4/14	Thu 4/10/14
Verdicorp Meeting #12	Tue 4/8/14	Tue 4/8/14
Design Review #2: Walk Through Presentation	Fri 4/4/14	Thu 4/10/14
Final Project Tasks	Thu 3/20/14	Thu 4/17/14
Verdicorp Meeting #13 (Final)	Tue 4/15/14	Tue 4/15/14
OPEN HOUSE Final Presentations	Thu 3/20/14	Thu 4/17/14
Final Project Report	Thu 3/20/14	Thu 4/17/14
Post-Project Tasks	Tue 4/22/14	Thu 4/24/14
Staff Meeting/Report #5 (Final)	Tue 4/22/14	Thu 4/24/14
Peer Evaluations	Thu 4/24/14	Thu 4/24/14
Website Maintenence	Fri 1/31/14	Thu 4/17/14
Design Web Page Update	Fri 1/31/14	Fri 1/31/14
Completed Web Page	Thu 4/17/14	Thu 4/17/14