Human Powered Potable Water Still

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Mechanical Engineering 450
Winter 2007
Final Report
Prepared for Kazuhiro Saitou
April 17, 2007

ABSTRACT

Each year the American Society of Mechanical Engineers sponsors a student design competition. This year's designs were presented at the ASME District conference, hosted by the University of Michigan. The competition objective was to design, construct and operate a human-powered water still.

All significant energy input needed to come from a linkage or mechanism driven by human effort. It needed to be small enough to be easily stored or transported for emergency use. It needed to be easily assembled from its stored configuration. Over 65 schools were invited and 18 teams submitted designs to the competition which was held on March 31, 2007.

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INTRODUCTION

During the aftermath of Hurricane Katrina, survivors were surrounded by polluted water and had limited access to purified water. A device to treat water so that it is drinkable would be valuable for this and other emergency situations. During distillation, water temperature is raised so that steam forms. This steam can condense on a surface and be recollected. Only pure potable water remains because containment particles will not evaporate. The ASME Student Competition requires us to develop a human powered still that will vaporize water to remove contaminants. The time limit is one hour. No energy may be put into the system before beginning the timing, (charged batteries, etc).

The competition requires the device to:

1. Use only human-generated energy from one team member at a time
2. Remove a simulated contaminant (food coloring)
3. Be of minimal size and weight
4. Disallow leaking

These criteria will allow the device to be used in extreme conditions such as environmental disasters. [1]

INFORMATION SEARCH

We began researching existing water stills and found that the majority of the stills online were solar powered. These stills used the sun to heat a large surface area, which in turn, slowly evaporated the water. The evaporated water condensed on an inclined plane and dripped into a collecting basin. In order to utilize this method, we would want to replace the sunlight with human power. [2,3]

We also found that electrical stills could use up to 5000 Watts of power, producing approximately 6 liters of water per hour. Often, these units operated in a low-pressure chamber which lowers the boiling temperature. We compared this to that of a human pedaling full speed on an exercise bicycle and found it could only produce a maximum of 110 Watts. This discovery gives us a processing expectation of significantly lower than 6 liters of water per hour. [4,5]

To better understand how we could use human power to transfer heat, we consulted both the Fundamentals of Thermodynamics [6] and the Principles of Heat Transfers [7] books. It was important to revisit the refrigeration cycle and the possible ways to transfer heat from one surface to the next. After reviewing these books, we needed a more detailed understanding of the distillation process, so we met with the author of the thermodynamics book, Professor Claus Borgnakke [8]. He filled in the final gaps in our knowledge, including major energy assumptions and construction limitations.

Initially, we sought test material from Chemical Engineering Senior Engineer, Pablo LaValle, who was kind enough to show us an industrial still and lend us a Bunsen burner and a condensing tube. Later, we sought production advice from laboratory facilitators and research specialists Bob Coury, Marv Cressey, Steve Emanuel, and Mark. They provided invaluable insight into material weld and adhesion compatibility and behavior.

Finally, we visited and consulted with many stores and websites, such as Home Depot, Bed Bath and Beyond, and McMaster-Carr, to explore other heating products and purchasing commercial products.

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

Since our engineering specifications were directly related to the competition details (Appendix A) and scoring formula (Eq. 1), we did not need to run any consumer feedback reports to determine customer requirements.

$$\begin{aligned}\text{SCORE} = &\ (\text{Weight of distilled water, gm}) * 10{,}000*(1-.05*\#\ \text{leaks}) \\ &+ (\text{Weight of test water in device, gm, at end}) * (T_{end} - T_{start},\ ^{\circ}\text{C}) \\ &- (\text{Dry weight of the device, gm}) / 100 \\ &- (\text{Volume of box in which device can be packed, cm}^3) / 1000\end{aligned} \qquad \text{(Eq. 1)}$$

When creating a Quality Function Diagram (QFD) (Appendix B), we first placed the competition's requirements in the desired components. Then we added a few additional requirements to operate a still including ergonomics. Next, using our researched information, we began to brainstorm physical aspects that would meet our requirements and placed them on the engineering specifications. Major factors for our thermal project include thermal conductivity of components and surface areas of components. However, we included some manufacturing requirements as well for packaging and assembly purposes.

We then compared the interactions of the physical features, finding complimentary and detrimental relationships, and rated the relationships of the characteristic features to meeting the desired requirements. We also examined other forms of water stills, to compare the effectiveness of water stills. Figures 1 and 2 shows a Merit water still and an El Paso Solar Energy Association (EPSEA) solar still. The Merit water still is an electrical still that produces up to 4 liters of water per hour using AC power and a heating element. The EPSEA solar still uses the sun to produce over 3 gallons of water a day by collection on a dark plate. [10,11]

Figure 1: Merit Water Still

Figure 2: EPSEA Solar Still

Once the QFD was completed we were able to use the importance rating to determine which engineering specifications would be most influential in the design of our water still. Table 1 shows the rank of the specifications in descending order. In developing our still, we focused on optimizing the components in the same order.

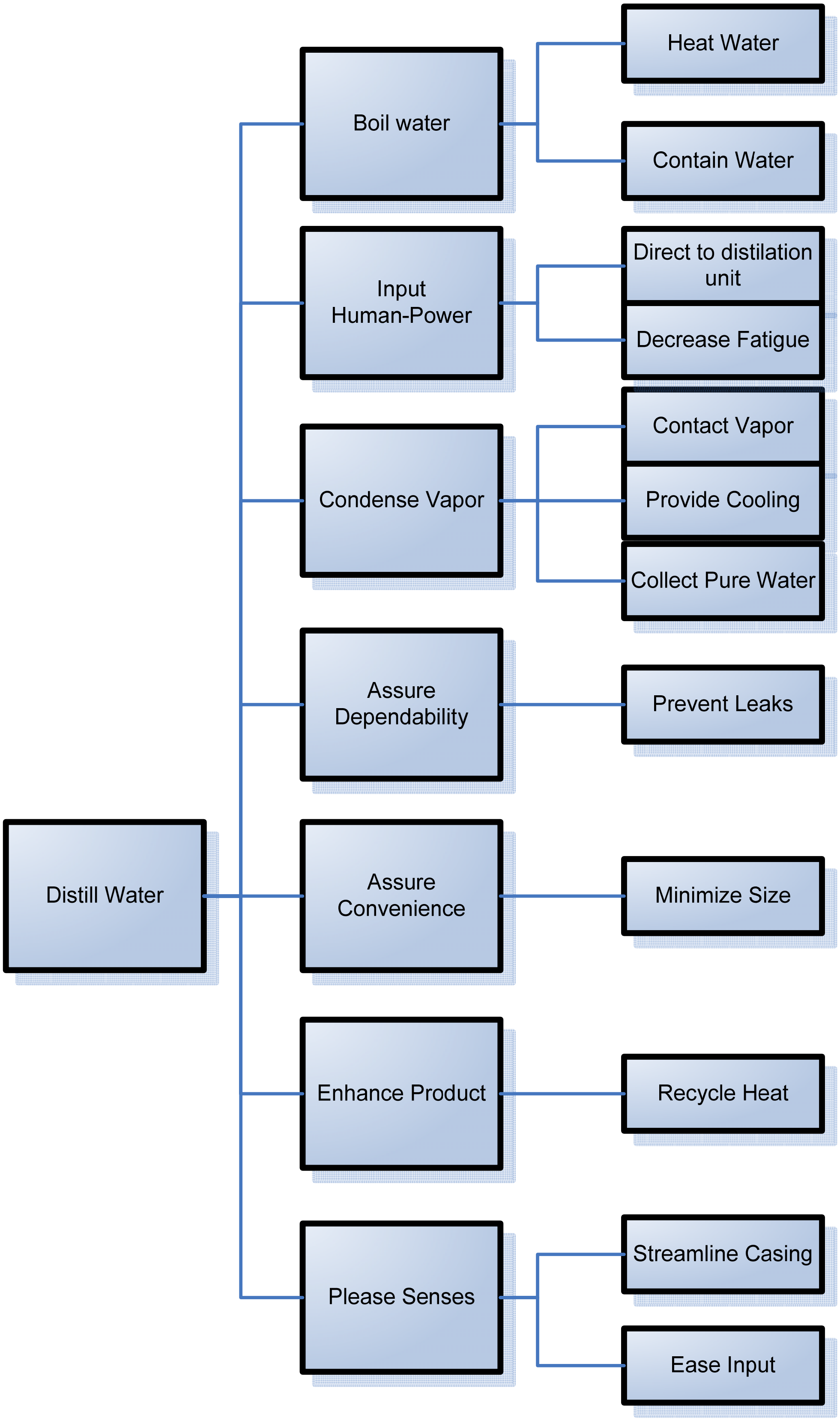
Table 1 – ASME Defined Engineering Specifications (descending rank)

Thermal properties of materials must maximize heat transfer
Surface of condensing plate must maximize condensate
Volume of water heating reservoir must hold all titrated dirty water
Angle of condensing surface must provide maximum condensate runoff
Surface area of heating element must be efficient for boiling water
Dirty water reservoir must retain 1.2 liters of water
Surface area of cooling element should be efficient for condensation
Water still will require insulation
Still should require nominal components to reduce assembly time and sources for failure
Water still needs to be as light as possible
Water Still must be assembled in 30 minutes
Length plus girth of shipping box must be less than or equal to 4.2 m

CONCEPT GENERATION

The TASK function of the still is to distill water. The primary functions are to translate human power into heat, boil water, and condense water vapor. Other functions included in scoring were also incorporated into the FAST chart below (Fig. 3, p.6). Though preventing leaks and minimizing size are scored, they are supporting functions because their value coefficients are weighted very low compared to the amount of water distilled. Other functions that are not directly scored were deemed supporting and categorized under assuring dependability, assuring convenience, enhancing the product or pleasing the senses.

Figure 3: FAST Diagram



After having created the FAST chart, we could begin to brainstorm on different designs for each basic function. First, we individually produced a few designs, often mimicking traditional water still used in a high school chemistry course. Then, we reconvened and discussed the designs we created. For the most part, they were similar; each having a different orientation, or source, of the same function. Recognizing we needed a more compact and therefore less traditional design, we executed a brainstorming session.

There were multiple methods considered to heat the water, including purchasing a small heating element and depressurizing the tank to lower the boiling temperature of the water. We also thought of how to create human energy using only our bodies. We generated a list of any possible motions created with either our legs or arms. Our ideas ranged from shaking a magnet through an inductor, to dancing, to pedaling in order to produce energy. Another function to consider was the ability to condense water. Initially, we thought of purchasing a basic water still condenser, but we decided a custom condenser with an optimized surface area, higher conductive properties, and reduced weight would be desirable.

A morphological chart, (Table 2), shows all of the concepts that we considered for each function of the still.

Concept 1, in Appendix D, shows an industrial water still where polluted water starts in a reservoir chamber and then flows into a depressurized chamber with a heating element. Finally, the steam travels up to a condenser before it exists as condensate. Water travels from component to component through tubes, and therefore has high potential for heat losses.

Concept 2, in Appendix E, shows a welded vertical still with no insulation. This still uses gravity to move the water from the reservoir chamber to the heating chamber and reuses the reservoir as an insulator. The heating element is powered through a treadmill.

Concept 3, in Appendix F, shows a stacked, vertical still with internal insulation to prevent heat losses. It utilizes gravity to move the water, but it also reuses heat energy from the polluted water by using a finned condenser.

Table 2: Morphological Chart

Function	Concept 1	Concept 2	Concept 3
Boil Water	Small hot plate	Heating element	Nichrome wire
Input Human Power	Induce charge with magnet and coil of wire	Run on treadmill	Pedal on a bicycle
Condense vapor	Chemistry condenser	Blown glass	Spun or drawn metal
Assure Dependability	Extrude to avoid seams/leaks	Weld together for durability	Direct connection between power input and heat source minimizes failures
Assure Convenience	Keep small and compact	Quick to disassemble	Input power with minimal fatigue
Easy Assembly	Standardized connections	Pre-assembled	Pre-assembled

CONCEPT EVALUATION AND SELECTION

With all these concepts, we created a Pugh chart to see what best met our customer requirements. With this we were able to see what ideas worked and what did not. The Pugh Chart (Fig 4) compared all three concepts to an industrial water still.

Customer requirements and weight were taken from the QFD diagram and weighted against each sketch. Positive and negative signs show what concept had better or substandard functions compared to the reference still. “S” signs show that it would have the same function. The weights of each function were summed for each sketch and we were able to narrow it down to two designs. From the Pugh chart, we saw that concept 1 would be an inferior design to the reference still. Concept 3 prevented less heat loss than concept 2 and was more compact. The ideal design should be small since this would contribute more points to our scoring rubric.

Figure 4: Pugh Chart

		SKETCH VARIANTS			
SELECTION CRITERIA	**WEIGHT**	**1**	**2**	**3**	**REF**
Vaporize Water	10	s	s	s	0
Condense Water	10	s	s	s	0
Contain Dirty Water	10	s	s	s	0
Contain Purified Water	10	s	s	s	0
Produce Energy with Human	7	+	+	+	
Maximize Ease of Human Input	5	-	+	+	
Minimize Size Parameters	3	-	s	+	
Maximize Ease of Assembly	2	-	s	+	
Durabilility	5	-	+	+	
Stability	5	-	+	+	
Visibility	3	s	s	+	
Low Weight	8	-	s	+	
	PLUSES	1	4	8	
	SAMES	5	8	4	
	MINUSES	6	0	0	
	NET	-5	4	8	
	WEIGHTED TOTAL	-21	22	38	
	RANK	3	2	1	
	CONTINUE?	NO	YES	YES	

We decided against the idea of creating a vacuum since it would be extremely difficult to produce a perfect vacuum, and detract energy from boiling the water. Pressurizing the tank with a hand held pump would also complicate the system since it would push the incoming water and heat out of the still. As stated earlier, we had originally thought of finding a heating element small enough to evaporate the small amount of water but the smallest size found was still too large. Too much heat would be lost to the ambient and not enough heat would remain to boil the water with the energy created, so we decided to construct the heating element out of a heating wire.

After going through the list of human generated motions, we decided that pedaling or stepping with our legs were ideal choices. Inducing a current with a magnet would be time consuming, strenuous, and not produce enough energy. With pedaling, we could connect gears to the device to produce a higher rpm with less rotational velocity on the customer's end.

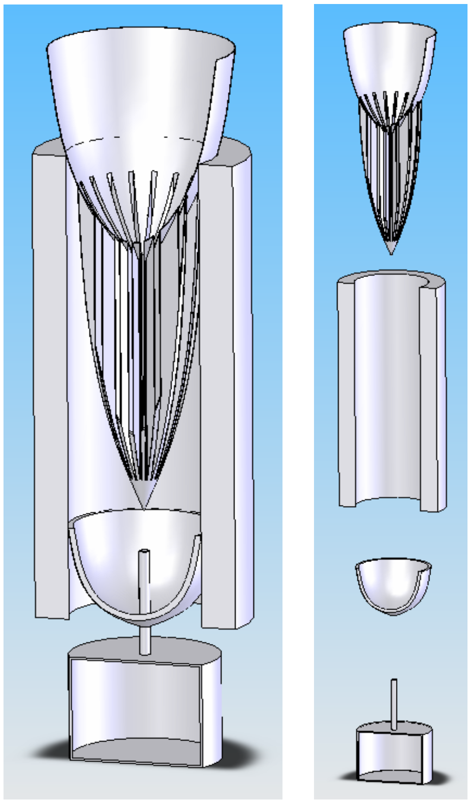
In the end, concept 3 was chosen since it best fit the selection criteria.

SELECTED CONCEPT

With the initial concept selected, we were able to create a model in SolidWorks. The dimensions were developed considering the amount of water expected to be distilled, the amount of water necessary to condense the water vapor, and the size constraints of the competition. The sole power of the water still will be generated through a bike crank and translated to a DC motor through a series of gears and cylinders. A short electric cable will run from the DC motor to the heating water still so as to limit resistivity losses.

The still (Fig. 5) consists of 6 major components: the waste water reservoir, the inlet tube, the heating element container, the outlet tube, clean water reservoir, and the insulation tube. The water will initially be poured into the waste water reservoir, an elongated copper container. It also serves as the condenser, and therefore is shaped like an elongated juicer to optimize surface area for heat transfer and water beading. The water rests in the condenser (Fig. 6) until it is fed through a valve in the inlet tube into the heating element container.

Figure 5: Initial Water Still – Assembled & Exploded



The heating element container (Fig. 7) is a 1mm thick drawn sheet metal that is highly reflective and is backed by a 10mm thick foam with low thermal conductivity properties. It has a cupping shape so that the water rests closest to the heating element regardless of varying water levels. The water is vaporized in the heating element and is drifted up the insulation tube (Fig. 8, p. 11), where it contacts with the waste water reservoir, which also serves as the condenser.

Figure 6: Initial Waste Water Reservoir

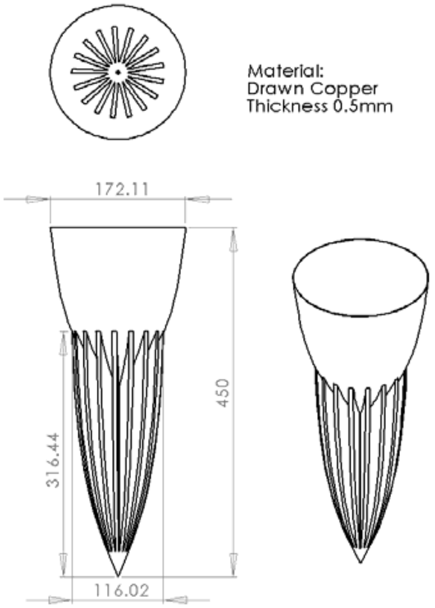
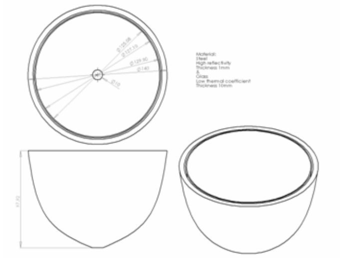


Figure 7: Initial Heating Element Container



As the water condenses on the metal, gravity pulls the droplets along the swept surface of the condenser until it reaches the tip. Upon reaching the tip, the water will fall down the outlet tube and into the clean water reservoir. The clean water reservoir (Fig. 9, p. 11) is made of a relatively thin plastic or glass container. The competition requires the spout to be constructed of clear material so that the collection of distilled water is observed during the trial.

Production of the waste water reservoir is complicated and will be created either through drawing or welding copper sheet metal. This process will be outsourced to a prototyping company, due to the difficulty of creating the part and the critical value the condenser adds to the water still. The heating element container will be crafted using stamping methods, since we are able to press metal at a cheaper value than outsourcing for production.

Figure 8: Initial Insulation Tube

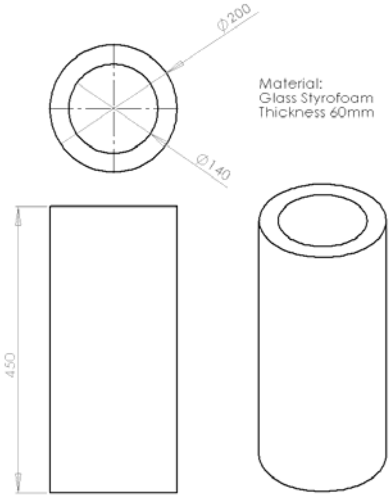
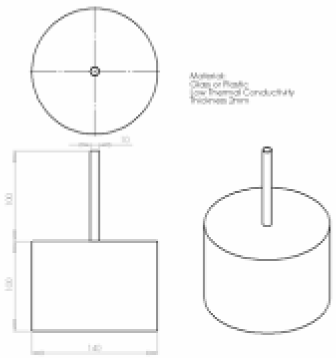


Figure 9: Initial Clean Water Reservoir



Insulation for the heating element container and body, and the inlet and outlet tubes, will be purchased from a general hardware shop and cut to fit the container. The external insulation tube will be purchased from a hardware shop and modified to fit our water still. The heating element will be created by the team, after analyzing the most efficient element, shape, and configuration. The clean water reservoir will be a purchased container, since any clear container is sufficient.

Finally, the source of energy will come from a biker, but the electrical power will be generated by an electric scooter motor (Fig.10). The most critical factor to energizing the still is an efficient generator. Thus, a bike will be purchased and the drive crank will be removed to be attached to a purchased generator for our water still. The generator is also critical to the water still, so a professionally produced product will be used to guarantee optimal power available during utilization.

Figure 10: Electric scooter motor

ENGINEERING ANALYSIS

After selecting our concept design, we performed several tests that would enable us to improve upon and tweak our ideas. The first concern we had was the shape of our condenser. In theory, we thought that the elongated juicer shape would maximize surface area and therefore condense more water. To test this theory, we sculpted several shapes out of Play-Doh (Fig. 11) These shapes ranged from smooth semi-spheres to extruded juicers. Once the Play-Doh dried, we vacuum formed sheets of 1/16" PETG over the molds. We then conducted a series of spray tests to compare the way in which the water dripped off of the formed surfaces. The results and pictures can be found in the Appendix H. After this test, we concluded that the juicer shape would make it more difficult for the condensed water to fall. Our optimal shape was a smooth surface funnel.

Figure 11: Play-Doh molds and vacuum forms

Energy Conversion

The still begins with human input, transfers power through pedals and gears, then transfers power to electrical energy with a generator, then transfers power to the fluid heating and evaporation. Through each step there were losses, mostly heat losses to the atmosphere.

Mechanical The energy in the mechanical system (pedals and gears) is the same at each component. We measured the power at the first stage—pedal input:

$$Horsepower = \frac{Torque*RPM}{5252} = \frac{Force*Radius*RPM}{5252} = \frac{10lb*.7ft*125RPM}{5252} = .167hp = 124.5W$$

Force on pedal = 10lb, measured with fish scales
Radius of pedal = 0.7ft, measured with ruler
RPM = 125, measured with tachometer

$$5252 = \frac{lb*ft*rot}{\min utes*hp}$$

Electrical System We measured the generator output to determine its power output. An operator pedaled with our ideal speed, 125rpm, while the output was measured from the motor leads. Resistance was taken from the heating element.

$$Power = \frac{Voltage^2}{\mathrm{Re}\,sis\,\tan ce} = \frac{(70Volts)^2}{53Ohms} = 92.4Watts$$

Voltage = 70 Volts, measured with voltmeter
Resistance = 53 Ohms, measured with ohmmeter

Heating System The resistance rope needs 41.5 W/ft to heat the rope to 900 F. We tested the rope with our mechanical input and found the rope quickly heated at 1.5 feet. The heater required an element as long as possible to increase the area of heat transfer, while still being short enough to heat above boiling. We scorched the insulation in the rope, so we know the wire reached at least the rated 120°C.

*Power = Power rating * length*

$$Power = 41.5Watts * 1.5 = 83Watts$$

Distillation System Determining the heat transfer to boil the water is complex. The heat rope outputs at least 150°C. The heating chamber conducts heat through a .017” thick 304 stainless steel bowl. However, the water flows in at a consistent rate from the water reservoir, so as time passes, the heat is transferred throughout a continuously cooled larger body of water. Analysis would be better replicated with a dynamic measurement system such as Fluent; however, no team members knew the program to complete performance analysis.

Manufacturing Analysis

After verifying power transfer, we incorporated assembly needs into our design. Our goals were to simplify manufacturing, use stock parts, and break down assembly into subassemblies.

Overall simplicity

1. Minimize the number of parts we used.
2. Part symmetry: nearly all parts are symmetrical, allowing for easy placement.
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4. The assembly is oriented in the Z axis and can be built from the bottom, with no turning.
5. There are few fasteners and many of the joints—especially welds--can be made by automated robots, though the prototype will not have this capability.

Stock Parts

1. Our cups are stock subassemblies.
2. The wire of our heating element is already coated, eliminating the need for a separate coating assembly.

3. Frame used stock metal components and fasteners.
4. Seat was stock.

Subassemblies

1. The exterior insulation tubing can be assembled before stacking into the main assembly.
2. Internal insulation can be attached to the lower bowl before final assembly.
3. The water input mechanism can be assembled and then attached to the still.

Environmental Impact The environmental impact of the still is important. The principle function of the design is to create potable water, especially during environmental disasters, so environmental benefit is a main goal. Human input powers the device, using no fossil fuels and minimizing environmental disturbances. The purification process is accomplished by distillation, as opposed to chemical treatment requiring hazardous materials or filtration requiring continuous material replacement. Metals in the still can be recycled and insulating material will be reused.

Failure Mode Analysis Our design has minimal opportunity for catastrophic failure. The hot water assembly is welded tight, so any tipping or collapse would contain water and prevent burns. Electrical components are insulated, so shorts would be contained and minimized, preventing fire. The pedaling components are set away from the still, so that a fall will not injure the operator or destroy the still. The pedaling mechanism is angled forward so that the operator can catch himself or herself if they fall off of the seat. The hottest parts of the still are deepest within it, minimizing the chance for burns.

Generally, minimizing the complexity of the design improves its manufacturability, reduces the environmental detriment and minimizes catastrophic failure. Our design iterations have moved towards this simplicity and improved the product function.

FINAL DESIGN

For our final design, we made a few modifications to our previously selected design. After having completed the drip tests we changed the shape of the condenser by eliminating the fins. Additionally, after considering the possibility of an electrical short wrapping a bare wire around a metal bowl, we chose a high resistance wire wrapped in fiberglass instead of Nichrome wire as our heating element. The final view of the still can be seen in Figure 12 (page 15) and the completed product can be seen in Figure 13 (page 15). More detailed dimensions of the still can be seen in Appendix J and the entire water distillation process can be seen in Appendix K.

Due to time constraints and limited metal spinning professionals still in the trade, we were forced to modify industrial spun products or weld our own rudimentary parts. With our limited budget, we decided to go with a condenser that was within our price range, has high thermal conductivity, and is readily available in spun production. The most common and available spun products are made of stainless steel. Thus, we hammered a tip on the end of an IKEA serving bowl to serve the purpose of our condenser (Figure 14, page 15).

We purchased sheets of stainless steel to be rolled and made into the cylinders that would encase the still and would hold the excess dirty water. For the boiling chamber, the outer surface that would hold the high resistance wire in place, and ultimately for the condensing surface, we purchased stainless steel bowls from IKEA.

Figure 12: Final Sectional View and Actual View

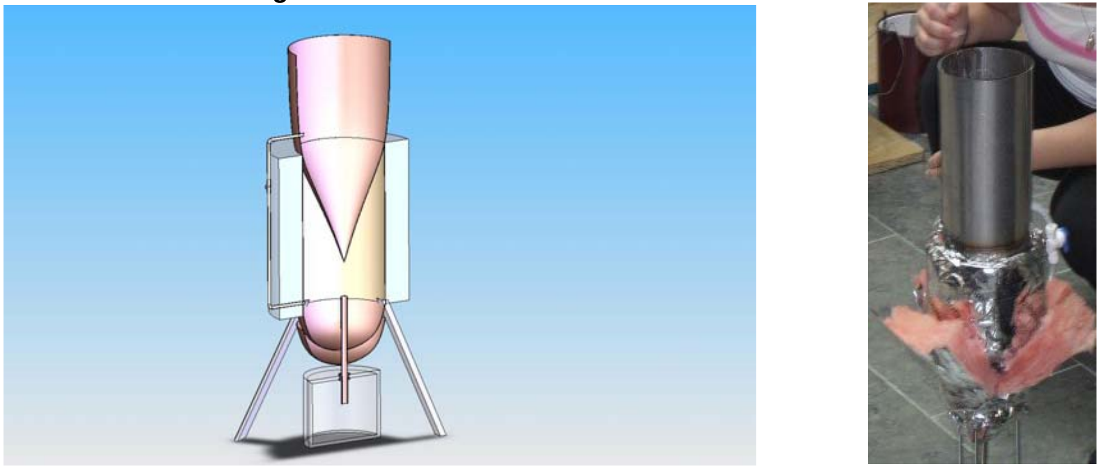


Figure 13: Final Full View

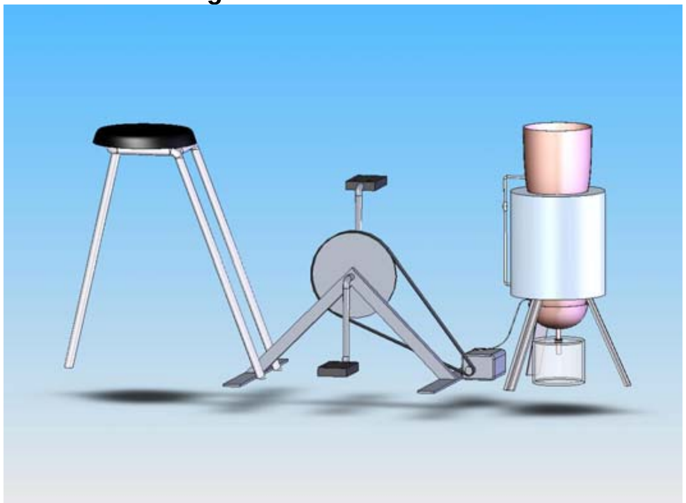


Figure 14: Condenser

In order to insulate the still to limit the heat loss through the sides, we decided on fiberglass insulation. We wrapped this insulation around the boiling chamber and secured it with an aluminum foil tape.

The completed still was attached with epoxy to a tripod to make sure that the still did not tip over or tilt during distillation.

We also added a small stainless steel funnel to the top of the outflow pipe to increase the area over which the condensed water could be collected. This funnel was attached with a JB weld.

As previously mentioned the Nichrome wire that we had initially chosen as our heating element had some logistical errors, such as a possibility of a short circuit so we had to research an alternative. We disassembled a coffee maker to see how the heating element inside of it worked and to perhaps use that heating element for our own design (Appendix I). We tested the coffee maker's heating element and it sufficiently evaporated the water, but it seemed to turn itself on and off, we assume so that that surface did not get too hot. This was probably put into effect so the coffee sitting on the heating element did not boil or evaporate. After more research, we found heating ropes that were high resistance wires, covered in fiber glass.

Further analysis through McMaster Carr led to some possibilities including rubber heaters and heating tape. Talking to the technical specialist, we determined that with our 50 Watts produced we could generate theoretically 700° F with a super heating rope of 36". These ropes would eliminate the short circuiting problem and could reach temperatures of 900˚F which is more than enough to boil water (212˚F).

The BOM (Appendix H) shows all the parts and components that were purchased to construct the prototype. We were within our suggested of budget of $700. The final prototype will be constructed and completed over the next two weeks in time for the District design competition.

MANUFACTURING PLAN

Due to time constraints, our prototype was constructed from mainly purchased components. After extensive online research, we came across a man who had created a human powered generator to run two chain saws. This human powered generator was something we might want to know more about for our own design, so we purchased the plans as a resource. Beginning with the power input section of our design; we obtained a used bicycle on February 9, in order to dismantle it to use the pedals and gears. Instead of creating a seat that was a part of the pedal/gear configuration, we purchased a folding chair that was extremely light weight and inexpensive. We also, on February 16, purchased the motor that was recommended in the plans: 24V 250 Watt 2650 RPM Electric Scooter Motor. This motor was to be attached to the super-high-temperature heat rope, purchased on March 8th. This rope will be wrapped around the heating reservoir. Following Fig. 12 on pg. 13 the condenser, initially was going to be hand made by our team, but after researching the methods necessary to mold the metal into a funnel shape, we decided to just purchase a bowl to save time on the prototype. The outer insulation was bought from a local hardware store and was cut to fit the container. The insulation was wrapped in place with aluminum duct flashing tape. The clean water reservoir was a graduated beaker in order to be clear and be able to read the water measurements. To stabilize the weight of the large amount of water that will be in the dirty water chamber, we purchased a chemistry beaker tripod and mounted it to the water still with epoxy.

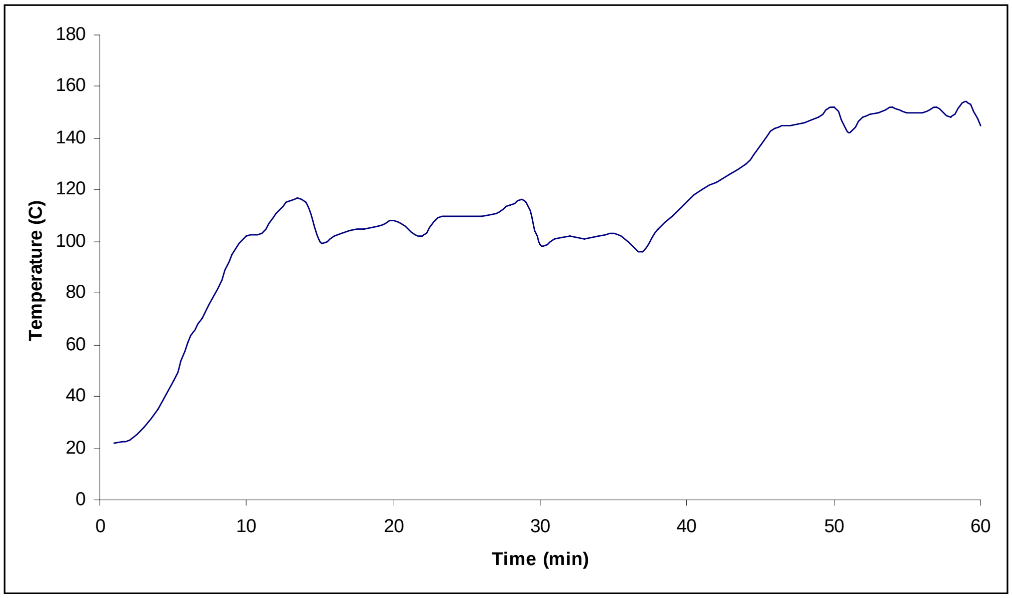
The still itself was assembled in a mainly z-axis configuration where each piece fits into or on top of one another. The clean water reservoir is placed on a flat surface while the clean water outlet pipe is inserted into the top of it. The clean water outlet pipe is threaded through the center of the boiling chamber and the contact seam is welded to prevent leakage. This was then inserted into the bottom of the insulation tube. The funnel was welded shut at the rim to prevent leakage and a hole was drilled in the side of the water reservoir to create a water outlet to the boiling chamber. A valve was attached to monitor the flow rate of the water coming into the chamber. The funnel was then welded to the top of the heating chamber. The power input was a little more complicated to assemble. The crank drives the rear wheel which in turn contacts a cylinder attached to the motor's drive shaft. The motor will generate energy that will be input into the heat rope.

TESTING

The debut performance of HydroBlue was during the ASME district conference design competition (Appendix L). The competition began with a weigh in of our entire prototype. HydroBlue weighed 18.5 lbs, which was one of the lightest designs out of the 18 competitors. Additionally, stills were disassembled and placed in packaging boxes to measure volume. HydroBlue’s box was measured to be 23529in^2, which fit the competition’s required dimensions.

During the competition 1.7L of water with food coloring was poured into the dirty water reservoir. Temperatures of the heating chamber were recorded, seen in Figure 15, to monitor if the water was being heated. Unfortunately, after 59 minutes HydroBlue did not produce any water, distilled or otherwise. This was attributed to the lack of an internal funnel that had broken off when HydroBlue was dropped a day prior to the competition. Although HydroBlue did not produce distilled water, it had boiled water in the heat chamber during the competition. At the end of the competition all water in the HydroBlue was collected and measured. A total of 1.7L of water was collected at an overall temperature of 32° C, which was 8° C higher than room temperature.

Figure 15: Heating Chamber Temperature during ASME Student Competition



After the competition, HydroBlue's heating chamber was cut open (Appendix M) and the internal funnel was reattached using J.B. Weld epoxy. The chamber was once again welded and prepared for the Engineering Design Exposition.

During the 4 hour exposition, members took turns pedaling HydroBlue. Pedaling speed was moderate with intermittent breaks. However, this time with an intact internal funnel, distilled water exited from HydroBlue. In the end 3mL of water was distilled. Considering that the power input was inconsistent and mild, distilled water output would have been significantly higher if we had replicated competition pedaling.

DISCUSSION FOR FUTURE IMPROVEMENTS

After reattaching the small funnel at the tip of the outflow pipe, the still successfully produced a measurable amount of "clean" water. HydroBlue is easy to assemble, highly compact, and gets hot enough to boil water and cool enough to condense the water. Although fully functioning, there are many changes that could be made to improve the efficiency of the prototype. The inability to access the heating chamber was one of our largest problems. After breaking off the funnel on the outflow pipe, there was no way to fix the problem other than cutting open the still, reattaching the funnel, and rewelding the still shut. To avoid this problem in the future, the still should be able to slide together and seal with an o-ring in order to gain access to the heating chamber. The heating chamber may also be made of Styrofoam instead of stainless steel to avoid condensation along the sides. To increase the power output from the motor, we could use a motor with stronger magnets and more coiling. While pedaling, we were reaching our maximum RPM output, but were not actually fatiguing our muscles. With a little more resistance in the motor, we could pedal harder and a little slower to get a greater power output to heat the high resistance wire.

CONCLUSIONS

The ASME student design competition required us to design and manufacture a human-powered potable water still. Our sleek and compact design was a success at the competition, with our still weighing in at just 18.1 lbs which was the lightest of the stills. HydroBlue also had the fastest assembly time at the conference. After some minor adjustments, we successfully produced distilled water at the design expo. The output was low, which we had anticipated. Although we successfully distilled water and met all of the design requirements, we don't feel that human input is a reasonable source of energy for distillation units. Biking on the machine dehydrated the user more than output water could replenish. Perhaps a battery or solar powered still would be more effective and efficient.

ACKNOWLEDGEMENTS

We would like to thank our sponsor ASME for sponsoring our project. We would like also like to thank Bob Coury, Marv Cressey, Steven Emanual, and John Mears from the machine shop and Mark Krecic, Zack Weaver, and Chris Whaley from the Art School with their experience and knowledge of manufacturing. We would like to thank Pablo LaValle from the Chemical Engineering department and Claus Borgnakke from the Mechanical Engineering department for giving advice regarding the functions of a still and answering heat transfer questions. We would like to thank Kazuhiro Saitou for encouraging and giving input in our weekly progress reports and for understanding with the uniqueness of our project.

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APPENDIX A – RULES AND PROCEDURES

Human-Powered Potable Water Still

SYSTEM DESIGN REQUIREMENTS

For this contest, the specific device requirements and procedures will be as follows:

1. Each team must arrive with their device and its support equipment, if any, packed into the smallest rectangular parallelepiped box it can fit into. Immediately after check-in each team must report to the judging team to have the outside dimensions of their storage box determined. This volume will be used in the scoring of this contest. (Smaller is better!)
2. In any event, the storage box must be small enough to meet shipping requirements, which are determined as follows:
    a. Measure the longest dimension of the storage box. That is the “Length”.
    b. Measure the circumference around the box in the plane normal to the length measurement. This is the “Girth”.
    c. When added, Length plus Girth must be less than or equal to 4.2 m
3. Once the storage dimensions have been determined the teams must assemble their devices and take them to the judges for weighing in the “dry” state. All system components must be included in the weight. This includes auxiliary equipment needed to operate the still. For example, any separate charging aids such as funnels must be included. This weight will also be used in the scoring. (Light is better!)
4. Energy input can be by any convenient mechanical means driven by human effort. Examples would be pedal systems, linkages, lever systems, cranks, etc.
5. The human mechanical energy input can be changed to any other kind of energy and as many different kinds of energy as desired in the process of heating the water.
6. The use of a vacuum in any part of the system is permitted, but the vacuum must be generated and maintained by the human operator.
7. Two bottles of “polluted” water will be given to each team prior to the start of the timed period. One of these bottles will contain 200 ml of “polluted” water. The second bottle will contain a weighed and recorded quantity (approximately one liter) of “polluted” water. All of the water will be at room temperature, as verified by measuring with a thermometer.
8. An amount of food coloring sufficient to visibly alter the color of the water will be added to the water given to contestants.. This will simulate the salinity and other pollutants for the purposes of this contest. Due to the nature of the distilling process, this will not carry through into the condensate. Each team will be required to charge their still with a minimum of 200 ml of “polluted” water from the first bottle they are given. Teams wishing to charge greater amounts of water will need to make arrangements with the judging team for proper measurement of the quantity prior to the start of the testing period.
9. Polluted water may not be added to the device once the initial charging is completed. Water may not be added during the course of the run.
10. Aside from minor amounts of water inside connective tubing or piping, all water inside the device must be held in no more than two polluted water reservoirs or heating chambers. All other water must show up in the calibrated output catch basin.
11. Any time the judges observe spilled “polluted” water they will require that the team clean up the spill, and the team will incur a 5% automatic decrease in the water weight value used in computing their score.
12. Each team must arrange to have the “outside temperature” bulb of a digital indoor/outdoor temperature gage (or its equivalent) in the water inside the still at all times during operation so that water temperature can be continuously monitored. If the “input” water is held in two chambers, then the estimated quantities in each chamber and the temperatures in each chamber must be displayed, kept track of, and given to the display and scoring officials. The digital temperature readout(s) must be easily readable by judges and nearby spectators.
13. Teams must attempt to condense any steam escaping from the human-powered still. The

weight of recovered condensate will be the major factor in the scoring.

14. The final quantity of distilled water will be determined by weight to at least the nearest 0,5 gm. Thus the collecting vessel in which any condensate will be collected must be weighed prior to the test in a dry state to determine its tare weight. All such vessels must be clearly marked with the team name and tare weight.
15. Any waste water (e.g., concentrated “polluted water” left in the still at the end of the run) must be collected by the team in a second vessel of some sort either during or after the run. All water issued to the team must be turned in to the judges and accounted for at the end of the run, not just the water distilled by the team.
16. The still must be empty and dry at the beginning of the test run, and as empty and dry as possible at the end of the run.

TESTING PROCEDURES

1. All contestants will be distilling at the same time. The timed test period for all teams will be 60 minutes. When the start signal is given teams may charge their devices with the “polluted” water and begin operating their device.
2. Teams may split work input times among themselves in any way they see fit. It is not required that all team members participate in this. Any person providing the work input must be a bone-fide member of the design team, not someone recruited only for the work input part of the contest. All teams will be required to fill out and sign a report form at the contest indicating the date at which the team was formed and started work, the dates on which each team member joined the team, and very brief descriptions of the contributions of each team member to the project. Large variances between the team formation date and the individual team joining date, or evidence of little or no contribution to the project may be grounds for possible elimination as an operator of the device. Such elimination will be at the discretion of the judging team, is final, and is not open to challenge.
3. A team member with a physical disability which would prevent him or her from operating the team’s device may be replaced by a substitute of “average” physical ability. Substitutes must be approved by the judging team at the contest, and substitutes need not come from the same school as the design team.
4. Only one team member may operate the device at any one time. Multiple simultaneous operators are not allowed.
5. As the test period proceeds roving judges will continuously record the current water temperatures each team is reaching. Temperatures reached in each device will also will be reported on a timely basis to a central scorer for entry on a spreadsheet by volunteer (student) runners. A student “runner” may not report values for a team from his or her own school. Entered on the spreadsheet prior to the start of the run will be the weight of water charged into the still at the start of the heating process and information on any splits in storage location within the device. As the run proceeds a score representing total thermal gain of and condensate collected by each team will be projected in bar-graph format in as close to real-time as possible on a large screen for everyone to see as the contest progresses. (Note that this displayed score will not include the size and weight factors, and the projected scores must be treated as provisional, not final contest scores.)
6. Any condensate from the still must be collected in a clean, clear vessel calibrated in one milliliter steps and supplied by the team. If and when the team begins to distill water across into the receiving vessel (and the temperature of the still thus reaches a stable point) the runners will begin to report the volume of the condensate to the nearest 0.5 ml as well as the current temperature.
7. At the end of the 60 minutes and at a signal from the time-keeper the receiving containers for any distilled water will be removed and may be covered. The containers will then be moved to the measuring location, where the quantity of any distillate will be determined by weighing.
8. In order to be counted in the scoring, distilled water should be visually color-free.
9. Teams are also responsible for accounting for all of the water they were issued for charging their stills. At the end of the run all teams are responsible for recovering all of the water from their device and taking it to the measuring station along with any of the water they were given that they have not used. The judges will check the total weight of

CONTACTS

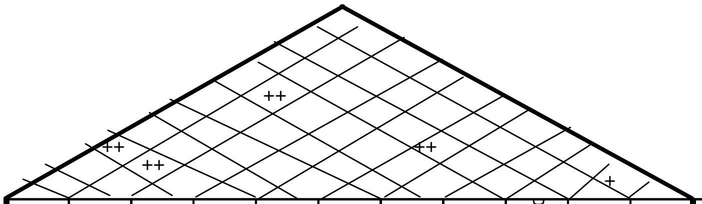
Kemi Oluwanifise

APPENDIX B – QUALITY FUNCTION DIAGRAM

Relationships

++	Strong Positive
+	Medium Positive
-	Medium Negative
- -	Strong Negative

Quality Function Development (QFD)



(+) => more is better
(-) => less is better

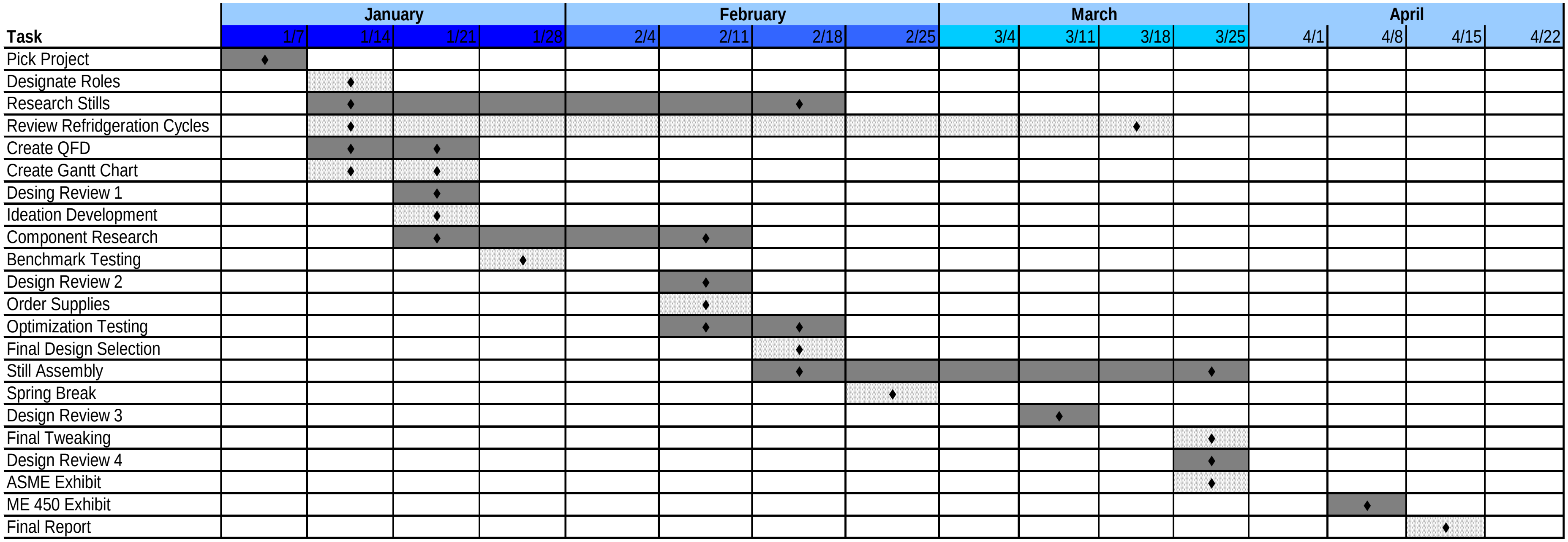
Benchmarks

	Weight*	Surface Area of Heating Element	Surface Area of Cooling Element	Size of Water Reservoir	Volume of Water Heating Reservoir	Materials' Weight	Thermal Properties of Materials	Insulation	Angle of Condensing Plate	Thermal Conductivity of Condensing Plate Surfac	Nominal Components	Quick assembly fittings		*Merit Water Still*	*EPSEA Solar Stil*	
Vaporize Water	10	10			10		10	5						9	7	
Condense Water	10		10		10		10	5	7	10				9	7	
Contain Dirty Water	10			8	4									10	7	
Contain Purified Water	10			10					10	10				10	7	
Produce Energy with Human	7						5									
Maximize Ease of Human Input	5	10	10		-5		8	3			5					
Minimize Size Parameters	3	-1	-1	-8	-5		2		-2					5	-3	
Maximize Ease of Assembly	2					8		-2				8				
Durabilility	5					-2		-1			5				5	
Stability	5	2		4	4	4			-1						8	
Visibility	3			3	5			-3		-3						
Low Weight	8	-2	-2	-5	-4			-1			5			3	-8	
Measurement Unit		m2	m2	ml	ml	gm	mu	u3	deg	W/mK	units	units				
Target Value		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A				
Importance Rating		**5**	**7**	**6**	**3**	**10**	**1**	**8**	**4**	**2**	**9**	**11**				
Total		141	131	136	188	26	281	98	159	200	90	16				
Normalized		0.10	0.09	0.09	0.13	0.02	0.19	0.07	0.11	0.14	0.06	0.01				

Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

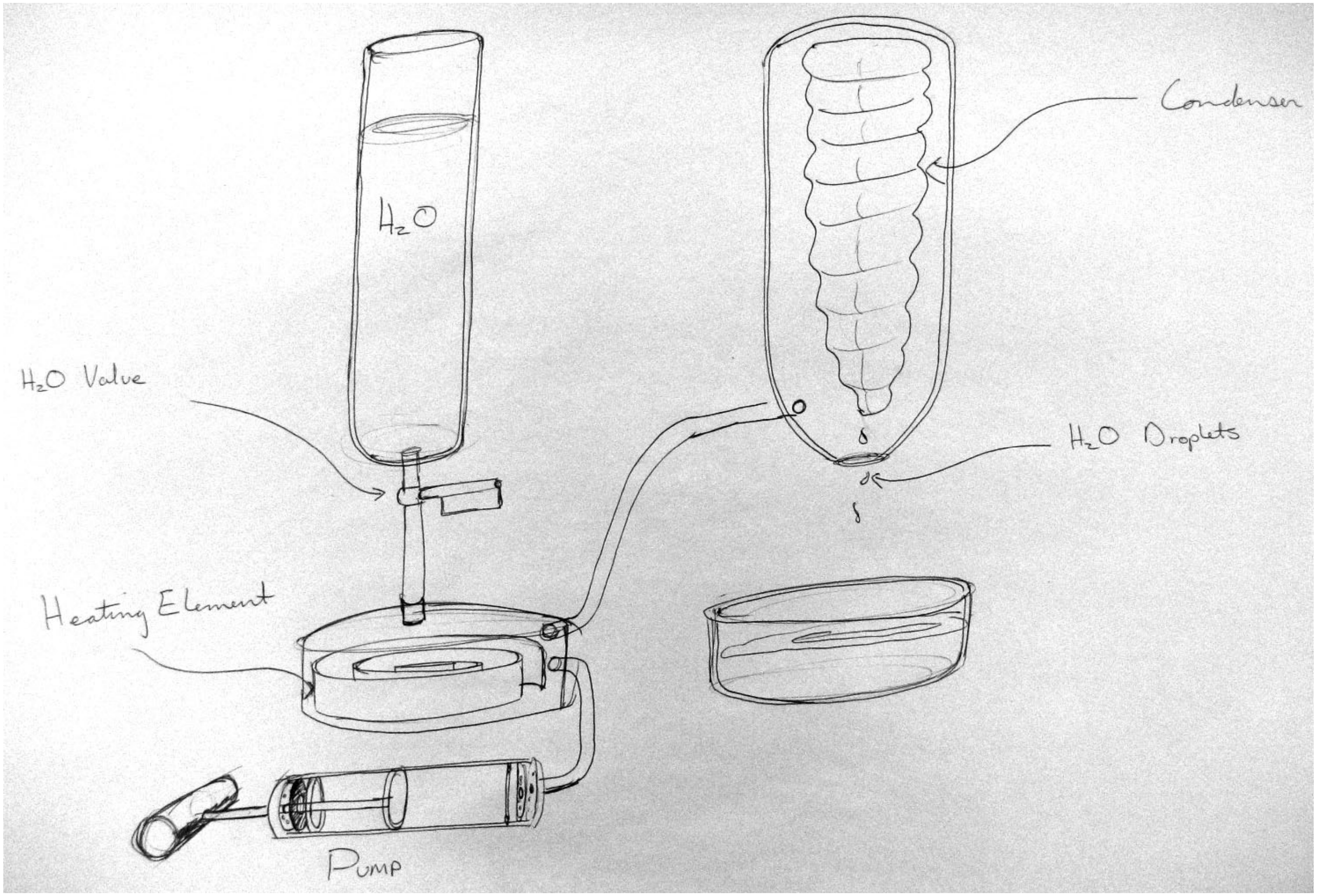
***Weights are figured on a scale of 1 to 10**
(ten being most important)

APPENDIX C – GANTT CHART

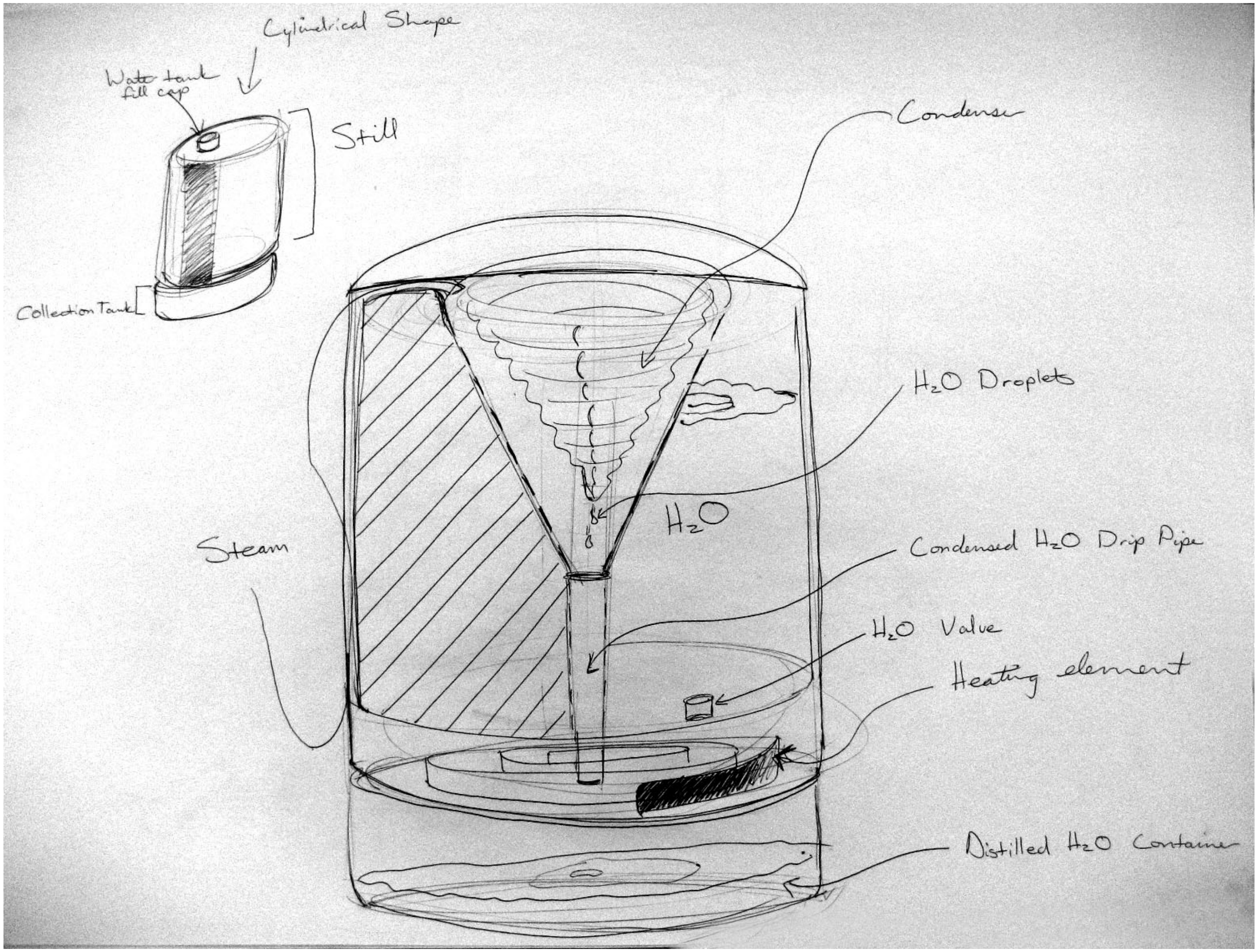


	January				February				March				April			
Task	1/7	1/14	1/21	1/28	2/4	2/11	2/18	2/25	3/4	3/11	3/18	3/25	4/1	4/8	4/15	4/22
Pick Project	▓ ♦															
Designate Roles		░ ♦														
Research Stills		▓ ♦	▓	▓	▓	▓	▓ ♦									
Review Refridgeration Cycles		░ ♦	░	░	░	░	░	░	░	░	░ ♦					
Create QFD		▓ ♦	▓ ♦													
Create Gantt Chart		░ ♦	░ ♦													
Desing Review 1			▓ ♦													
Ideation Development			░ ♦													
Component Research			▓ ♦	▓	▓	▓ ♦										
Benchmark Testing				░ ♦												
Design Review 2						▓ ♦										
Order Supplies						░ ♦										
Optimization Testing						▓ ♦	▓ ♦									
Final Design Selection							░ ♦									
Still Assembly							▓ ♦	▓	▓	▓	▓	▓ ♦				
Spring Break								░ ♦								
Design Review 3										▓ ♦						
Final Tweaking												░ ♦				
Design Review 4												▓ ♦				
ASME Exhibit												░ ♦				
ME 450 Exhibit														▓ ♦		
Final Report															░ ♦	

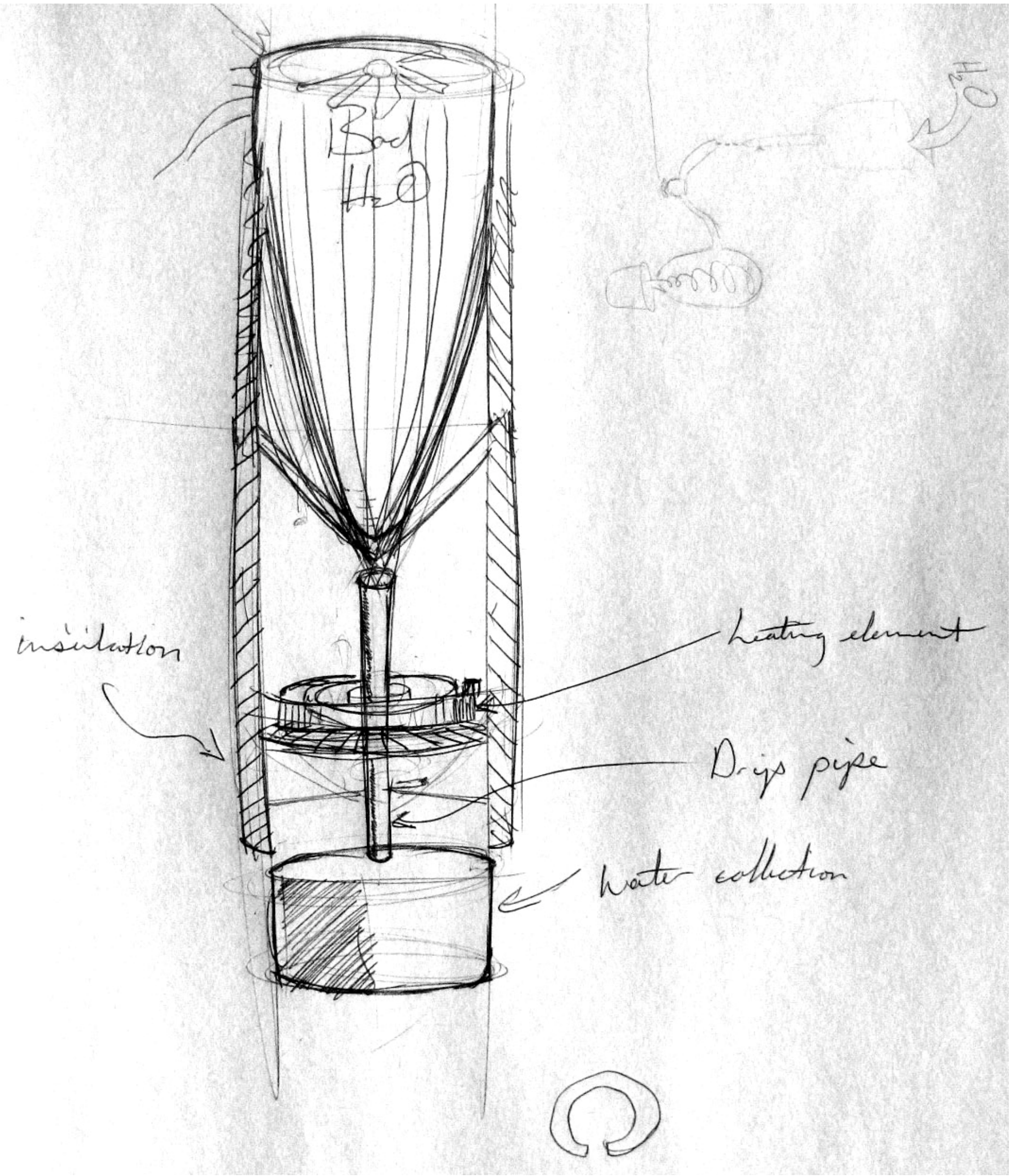
APPENDIX D – CLASSICAL INDUSTRIAL WATER STILL



APPENDIX E – WELDED VERTICAL STILL



APPENDIX F – VERTICAL STILL WITH INTERNAL INSULATION



APPENDIX G – DRIP TEST RESULTS

450 drip test

elevation 140 cm
# of sprays 5

model #		time(s)	radius	comments
1		7.51	9	multiple drip locations
		4.36	12	
		4.32	13	
	avg	5.396667	11.33333	
2		3.64	14	large water retention
		3.87	13	
		3.6	10	
	avg	3.703333	12.33333	
3		3.34	12	
		3.64	15	
		3.87	14	
	avg	3.616667	13.66667	
4		3.47	12	
		3.37	13	
		3.19	14	
	avg	3.343333	13	
5		4.53	15	flew off at angles
		5.13	13	
		4.36	13	
	avg	4.673333	13.66667	
6		4.37	7	large water retention
		3.51	8	
		4.23	10	
	avg	4.036667	8.333333	

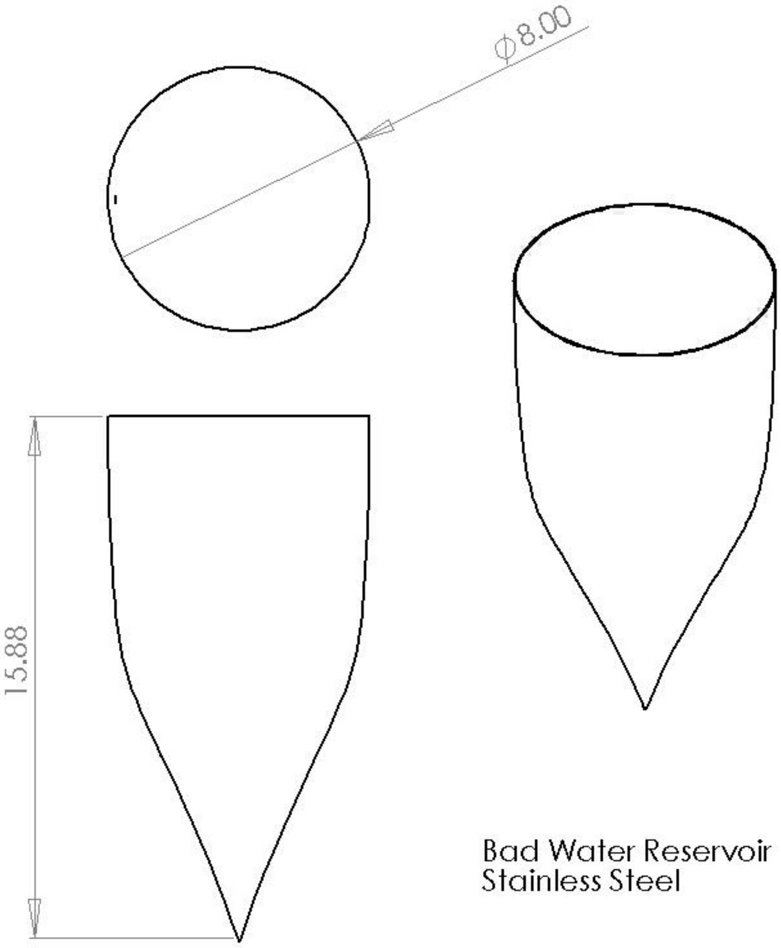
APPENDIX H – BILL OF MATERIALS

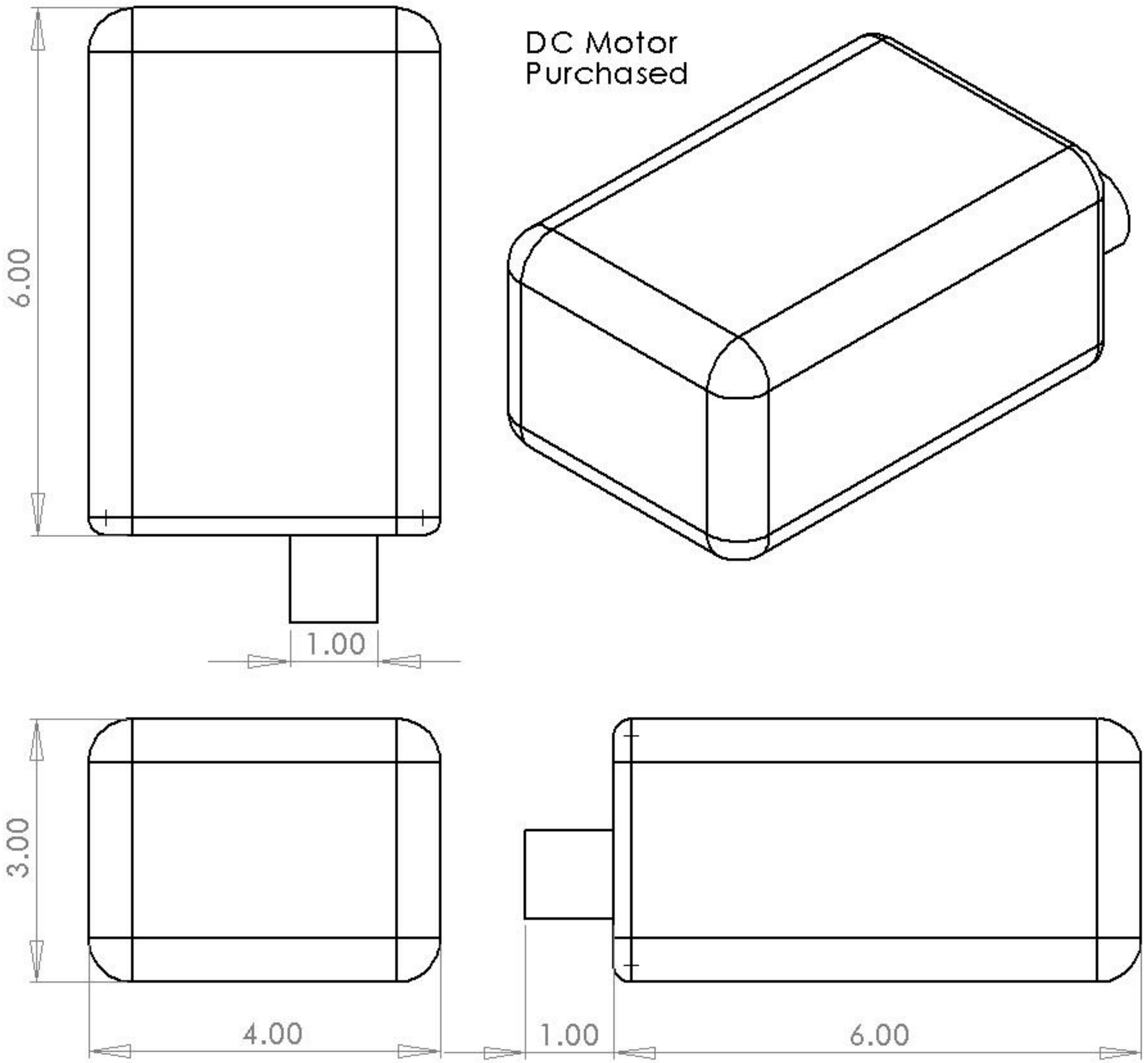
DESCRIPTION	TYPE P-Purchased M-Manufactured	VENDOR / MATERIAL SUPPLIER	CATALOG/VENDOR #	MATERIAL	QTY.	UNIT COST	TOTAL COST
Vent pipe	P	Home Depot			1	$3.32	$3.32
25' poly	P	Home Depot			1	$2.49	$2.49
washers	P	Home Depot			1	$1.58	$1.58
valve	P	Home Depot			1	$6.50	$6.50
cxc needle	P	Home Depot			1	$5.86	$5.86
hinge	P	Home Depot			1	$2.59	$2.59
hinge 3.5"	P	Home Depot			1	$3.97	$3.97
flexfixmetal	P	Home Depot			1	$9.97	$9.97
insulation	P	Home Depot		fiberglass	1	$3.94	$3.94
						Tax	$2.41
						Total	**$42.63**
1/2 DPFlange	P	Home Depot			1	$1.95	$1.95
PVC ball valve	P	Home Depot			1	$2.65	$2.65
Funnel	P	Home Depot		galvanealed steel	2	$4.47	$8.94
						Tax	$0.81
						Total	**$14.35**
metal sheet	P	Alro Metals Plus		stainless steel	1	$15.80	$15.80
						Tax	$0.95
						Total	**$16.75**
Typr 304 stainless steel sheet 12X12	P	McMaster-Carr		stainless steel	1	$12.67	$12.67
Typr 304 stainless steel sheet 12X24	P	McMaster-Carr		stainless steel	2	$25.38	$50.76
Super High Temperature Heat Rope	P	McMaster-Carr	3641K24	resistance wire covered with fiberglass braid	1	$16.72	$16.72
						Shipping	$9.25
						Total	**$89.40**
Food colors	P	Meijer			1	$3.49	$3.49
morton salt	P	Meijer			1	$0.55	$0.55
play doh	P	Meijer			3	$1.67	$5.01
folding stool	P	Meijer			1	$9.99	$9.99
						Tax	$0.90
						Total	**$19.94**
Folding stools	P	Meijer			3	$8.99	$26.97
Thermometer	P	Meijer			1	$11.99	$11.99
						Tax	$2.34
						Total	**$41.30**
Batteries	P	Meijer			1	$6.39	$6.39
Thermometer	P	Meijer			1	$11.99	$11.99
						Tax	$19.48
						Total	**$37.86**
blanda bowls	P	IKEA		stainless steel	3	$2.99	$8.97
						Tax	$0.54
						Total	**$9.51**

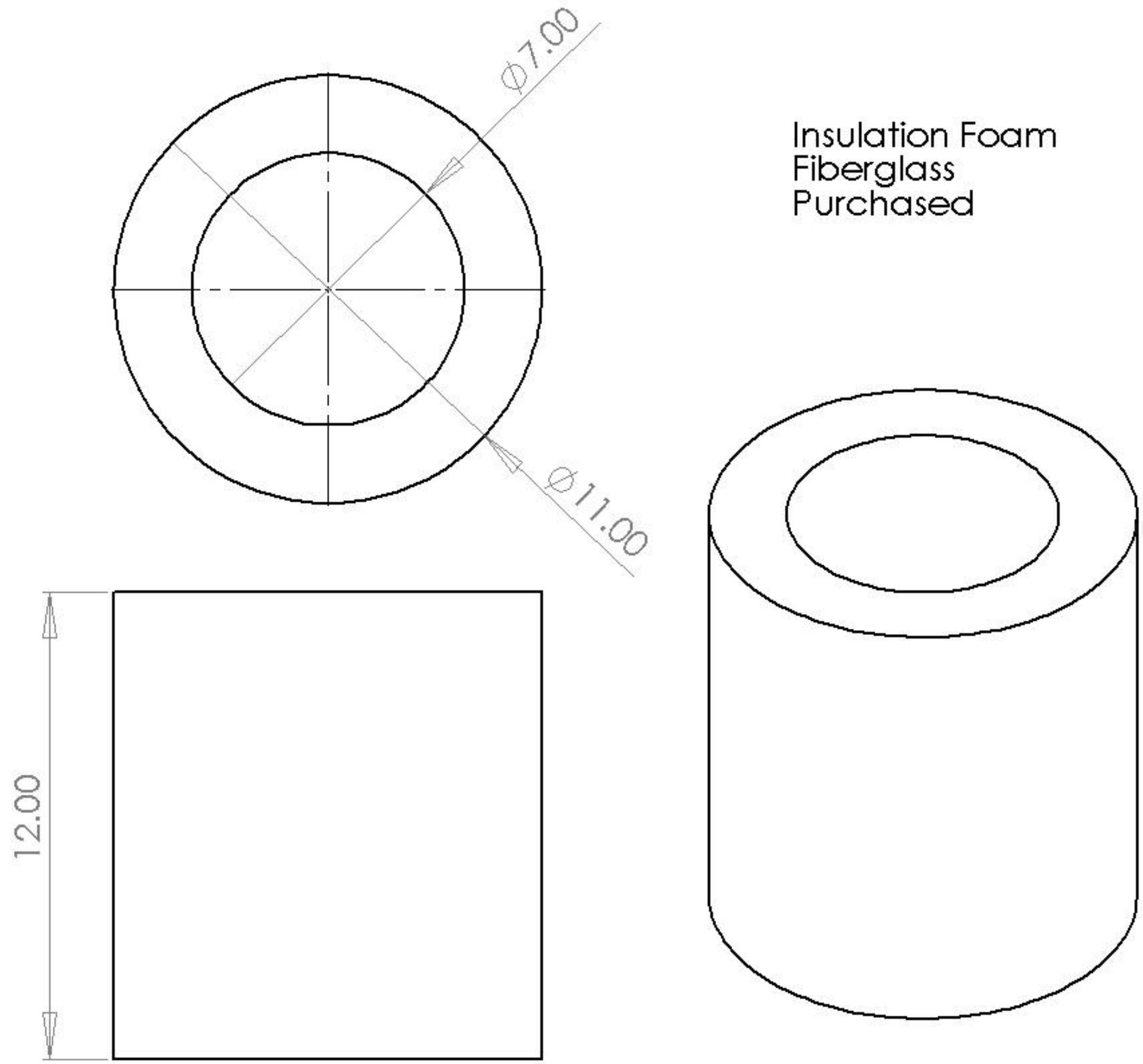
DESCRIPTION	TYPE P-Purchased M-Manufactured	VENDOR / MATERIAL SUPPLIER	CATALOG/VENDOR #	MATERIAL	QTY.	UNIT COST	TOTAL COST
Bike	P	Demetria Becharas		metal components	1	FREE	**FREE**
Fl dry lube	P	Ann Arbor Cyclery			1	$8.95	$8.95
						Tax	$0.54
						Total	**$9.49**
Shimano	P	Ann Arbor Cyclery			1	$19.95	$19.95
Labor	P	Ann Arbor Cyclery			1	$4.00	$4.00
Axil Spacer	P	Ann Arbor Cyclery			1	$1.99	$1.99
Size and/or I	P	Ann Arbor Cyclery			1	$4.00	$4.00
						Tax	$1.32
						Total	**$31.26**
Spray bottle	P	Bed, Bath, and Beyond			1	$3.99	$3.99
Iron	P	Bed, Bath, and Beyond			1	$19.99	$19.99
Coffee maker	P	Bed, Bath, and Beyond			1	$19.99	$19.99
						Tax	$2.64
						Total	**$46.61**
50 ml cylinder	P	Home Training Tools		glass	1	$2.50	$2.50
100 ml	P	Home Training Tools		glass	1	$3.20	$3.20
250 ml	P	Home Training Tools		glass	1	$3.50	$3.50
500 ml	P	Home Training Tools		glass	1	$5.20	$5.20
250 ml beaker	P	Home Training Tools		glass	1	$0.90	$0.90
400 ml	P	Home Training Tools		plastic	1	$1.10	$1.10
1000 ml	P	Home Training Tools		plastic	1	$1.50	$1.50
50 ml	P	Home Training Tools		plastic	1	$3.85	$3.85
150 ml	P	Home Training Tools		plastic	1	$3.85	$3.85
Tripod 6"	P	Home Training Tools			1	$4.25	$4.25
						Shipping	$37.72
						Total	**$67.57**
Shirts	P	Steve and Barrys			4	$9.98	$39.92
						Tax	$2.40
						Total	**$42.32**
Tripod 9"	P	Cole-parmer			1	$30.00	$30.00
						Total	**$30.00**
Electric Scooter Motor W/ 11 Tooth Sprocket	P	Electric Scooter Parts	MOT-24250x2750		1	$39.95	$39.95
						Shipping	$10.27
						Total	**$50.22**
Pedal Powered Prime Mover Plans	P	David Butcher			1	$50.00	$50.00
						Total	**$50.00**
						TOTAL	**$599.21**

APPENDIX I – HEATING ELEMENT OF COFFEE MAKER

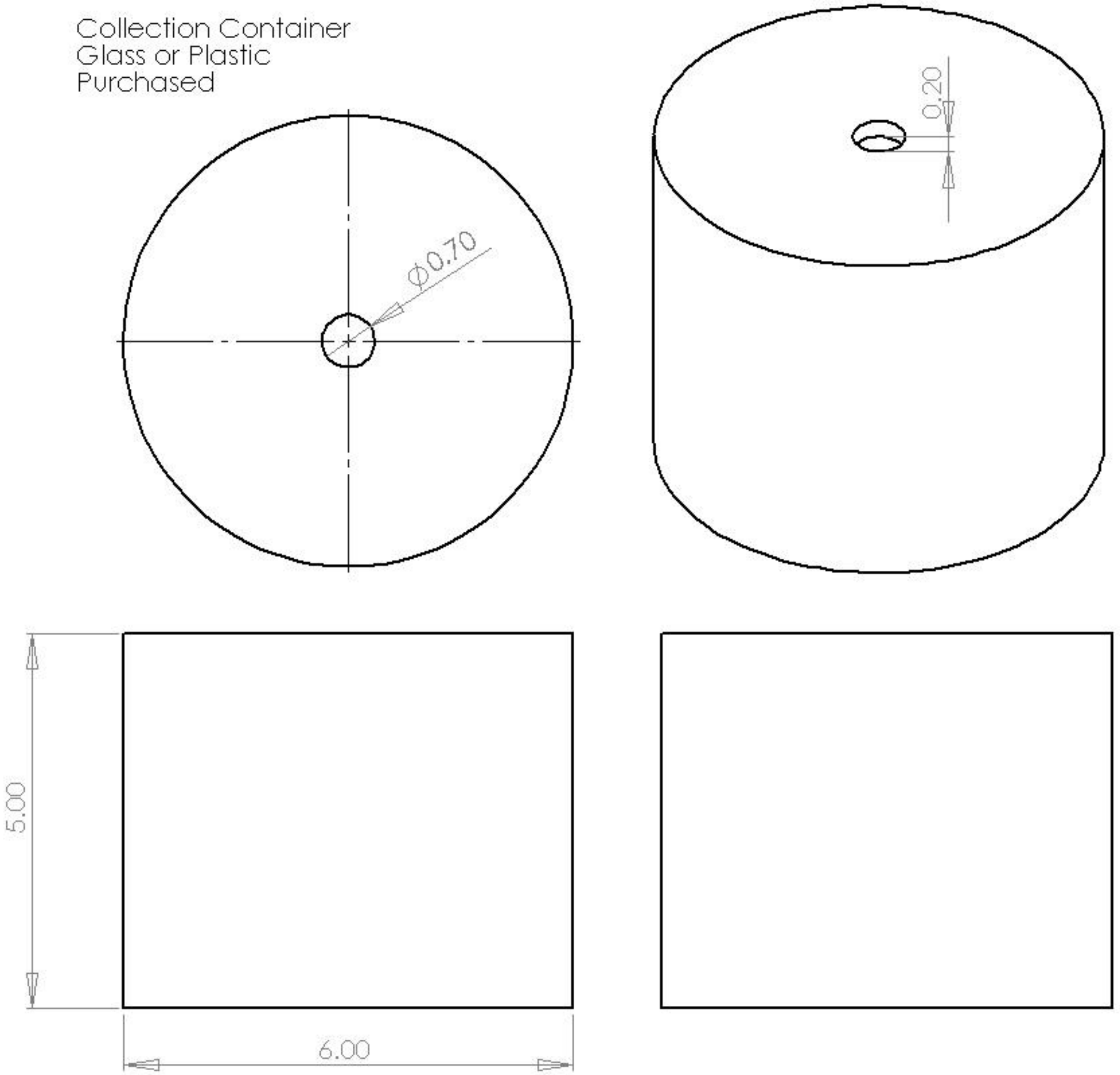
APPENDIX J – DIMENSIONED BLUE PRINTS



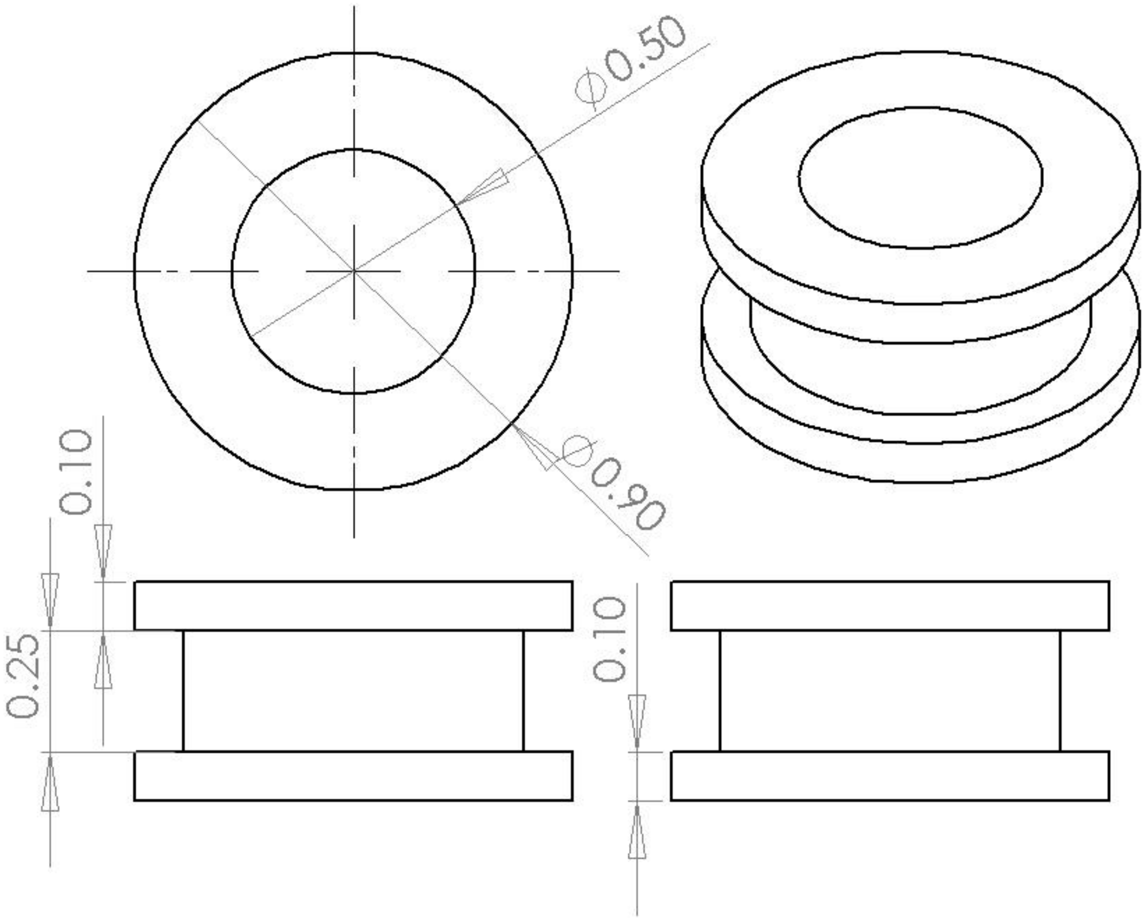

DC Motor
Purchased
6.00
1.00
3.00
4.00
1.00
6.00

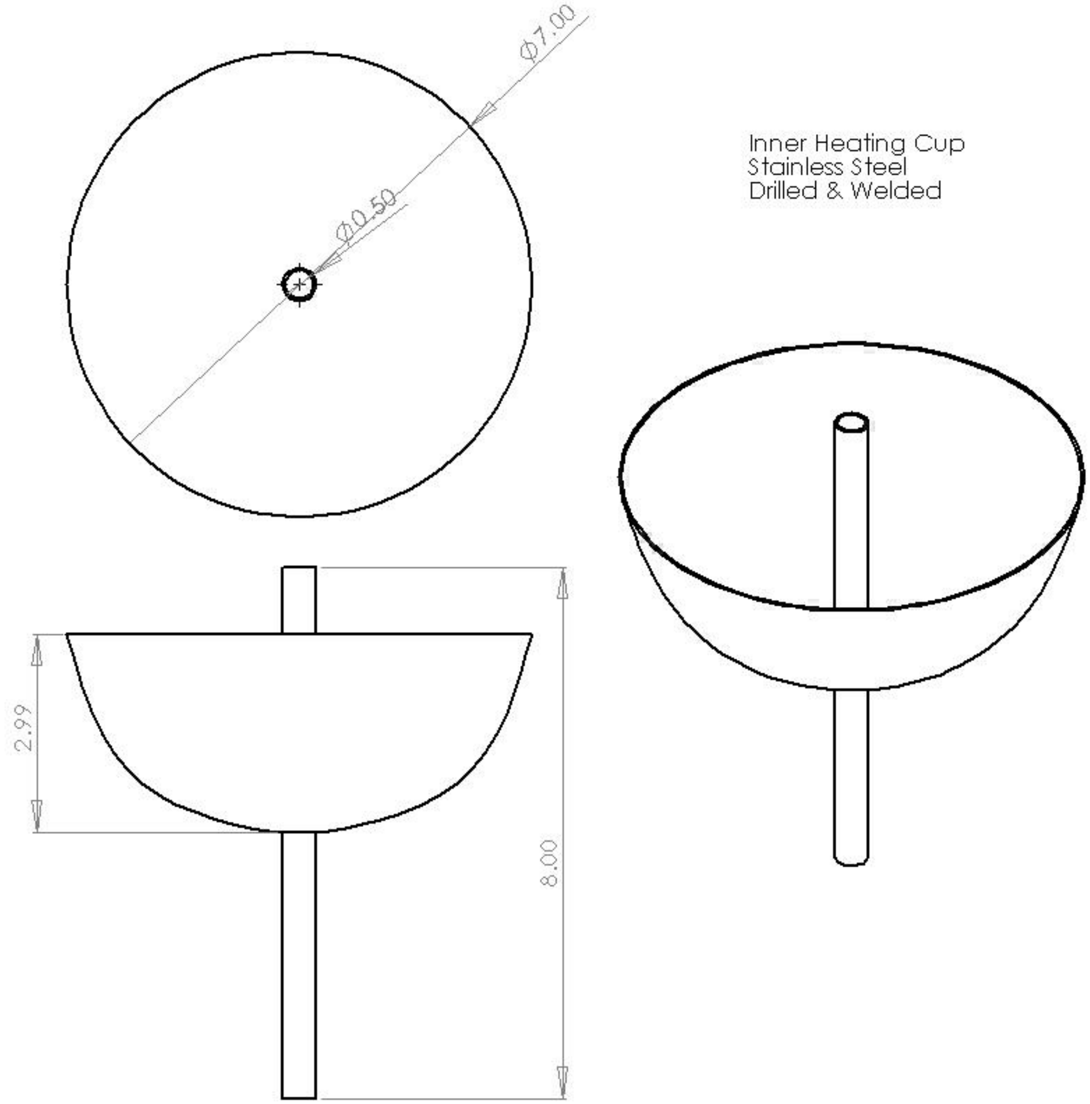


Ø7.00
Ø11.00
12.00
Insulation Foam
Fiberglass
Purchased

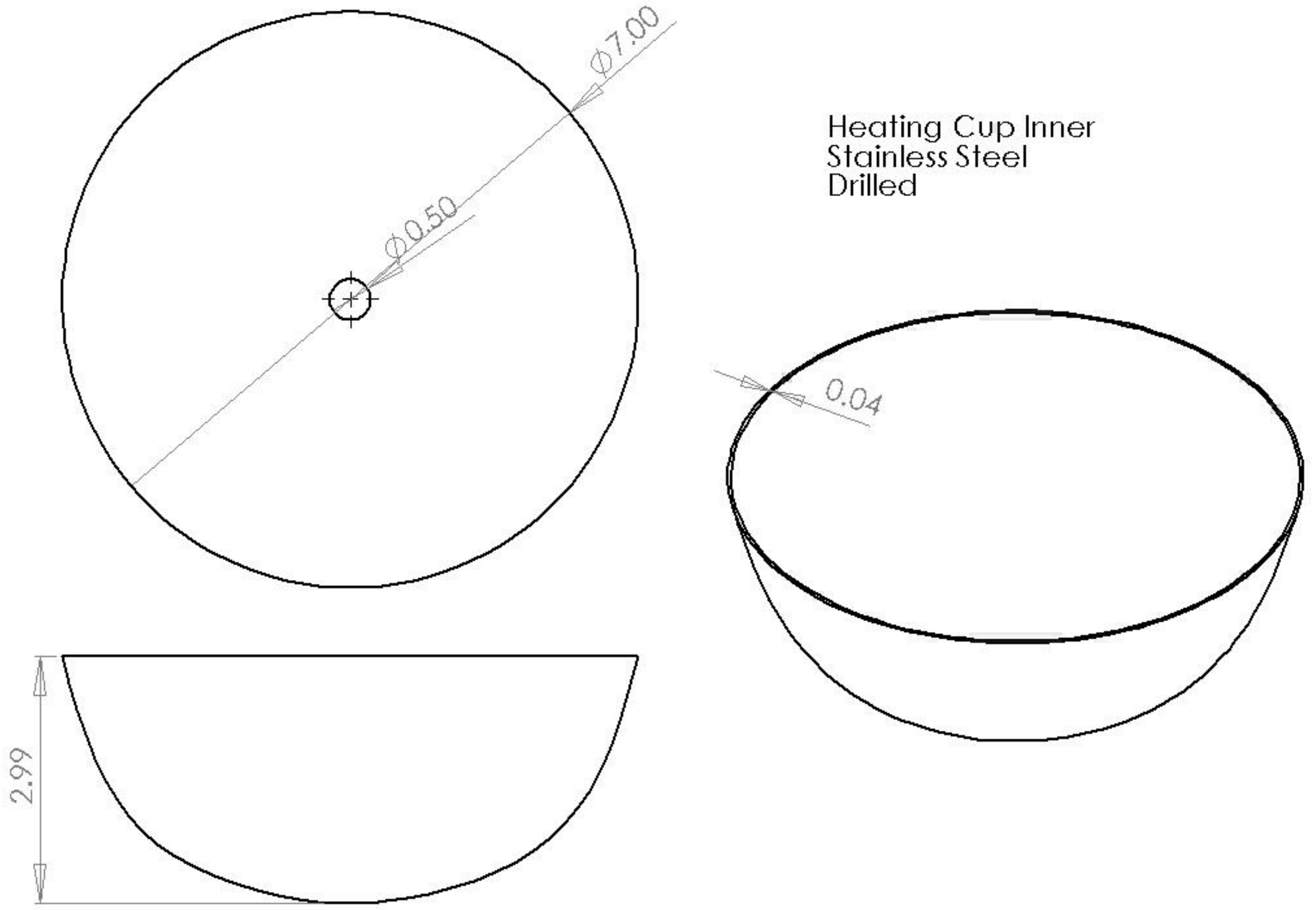

Collection Container
Glass or Plastic
Purchased

Collection Container Washer
Rubber
Purchased



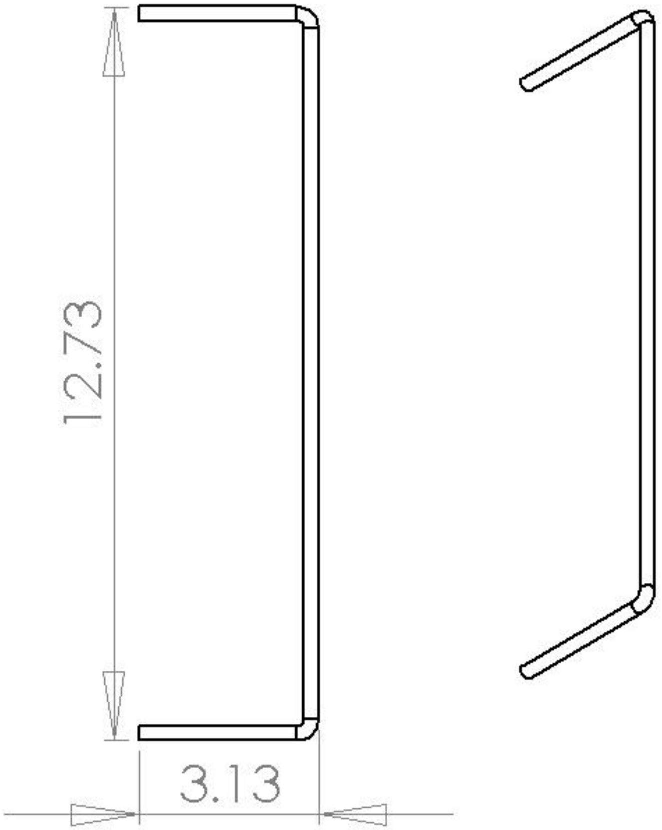


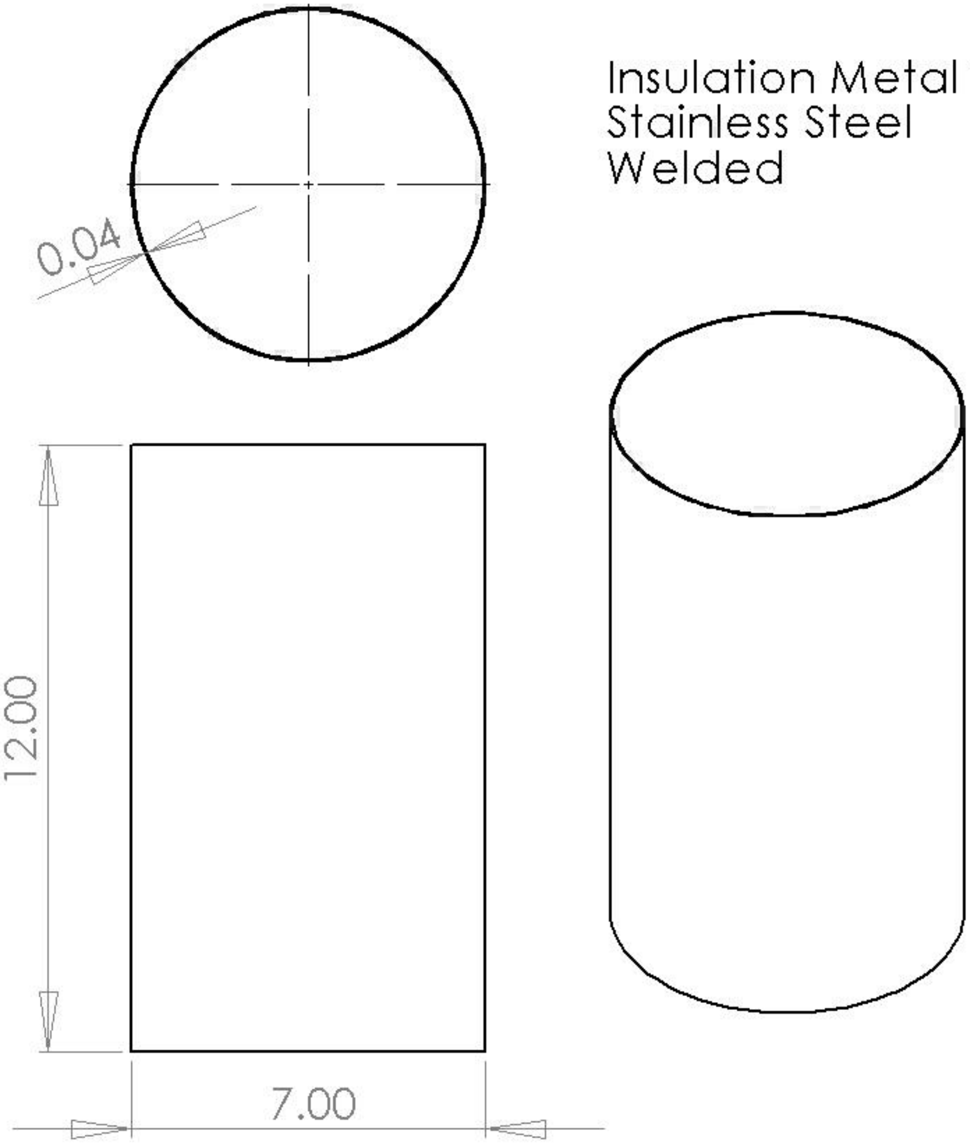
Inner Heating Cup
Stainless Steel
Drilled & Welded



Heating Cup Inner
Stainless Steel
Drilled

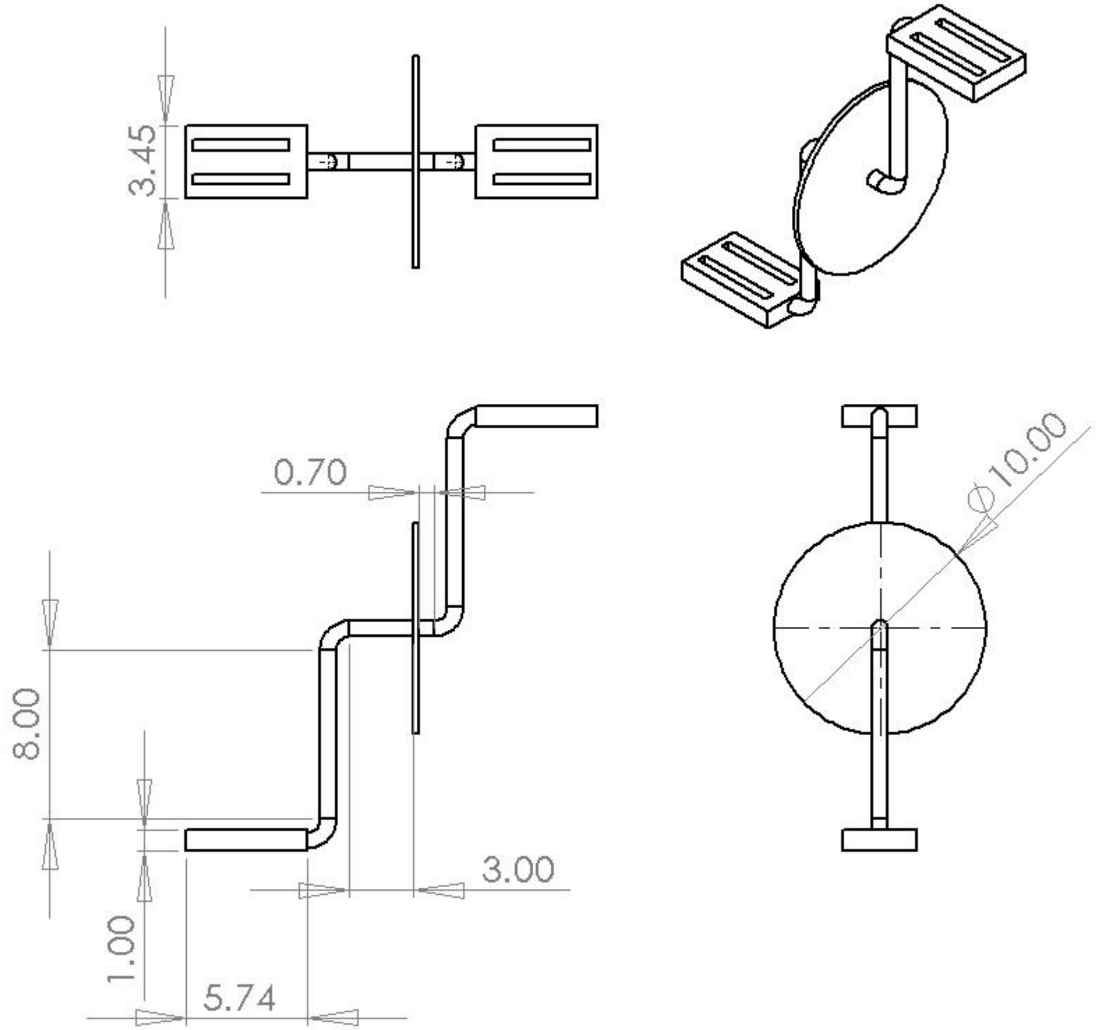
Inlet Tube
Stainless Steel
Cut & Welded
.02" Thickness
.25" Diameter

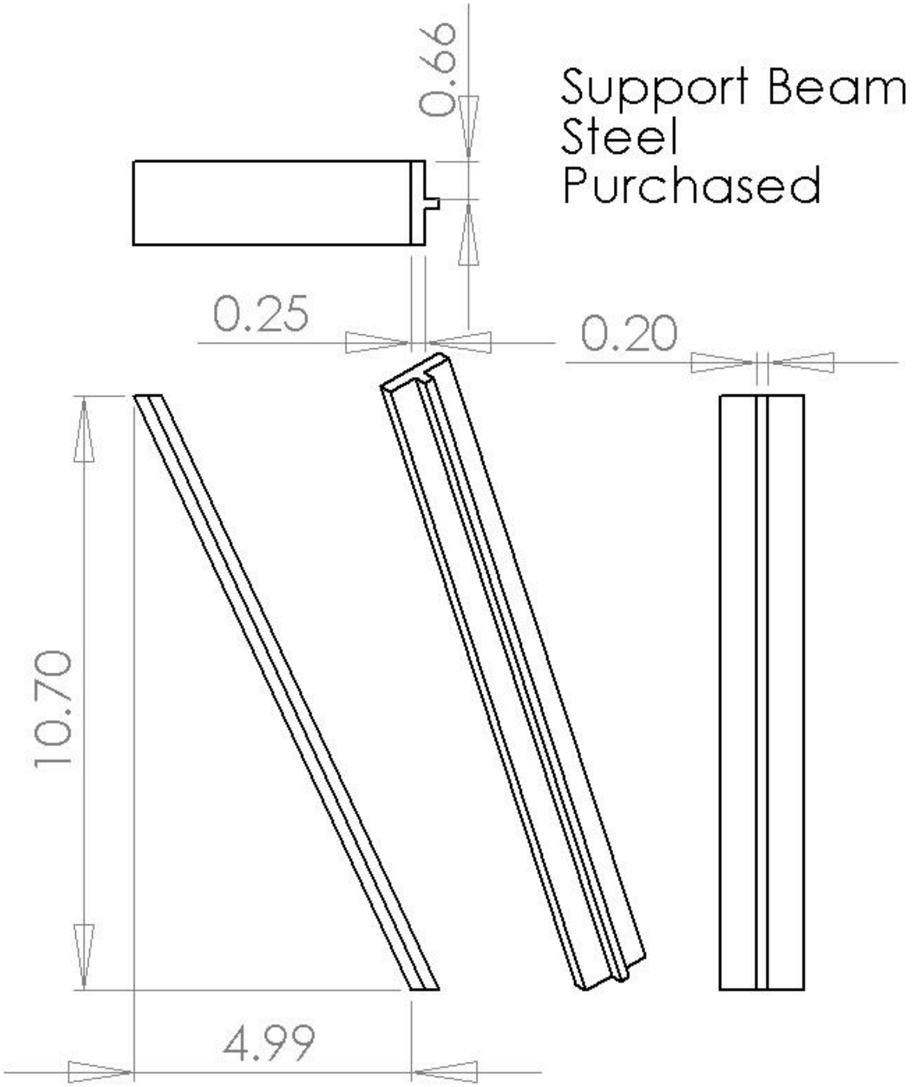




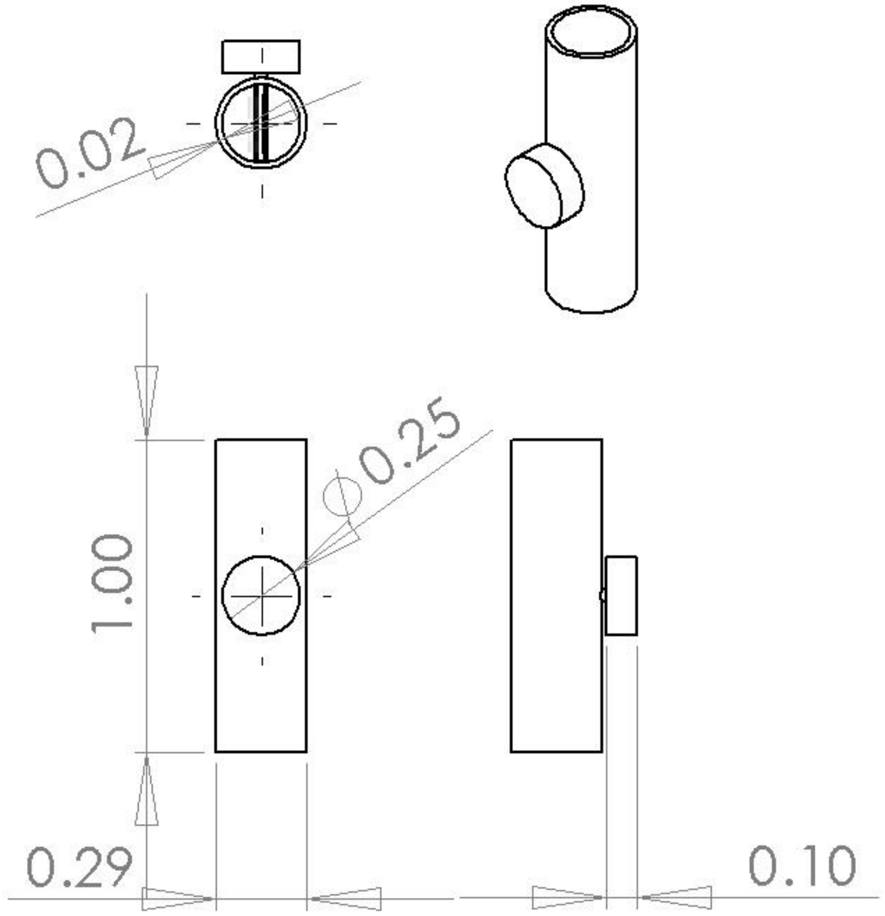
Insulation Metal Tube
Stainless Steel
Welded

Bike Crank & Pedals
Purchased

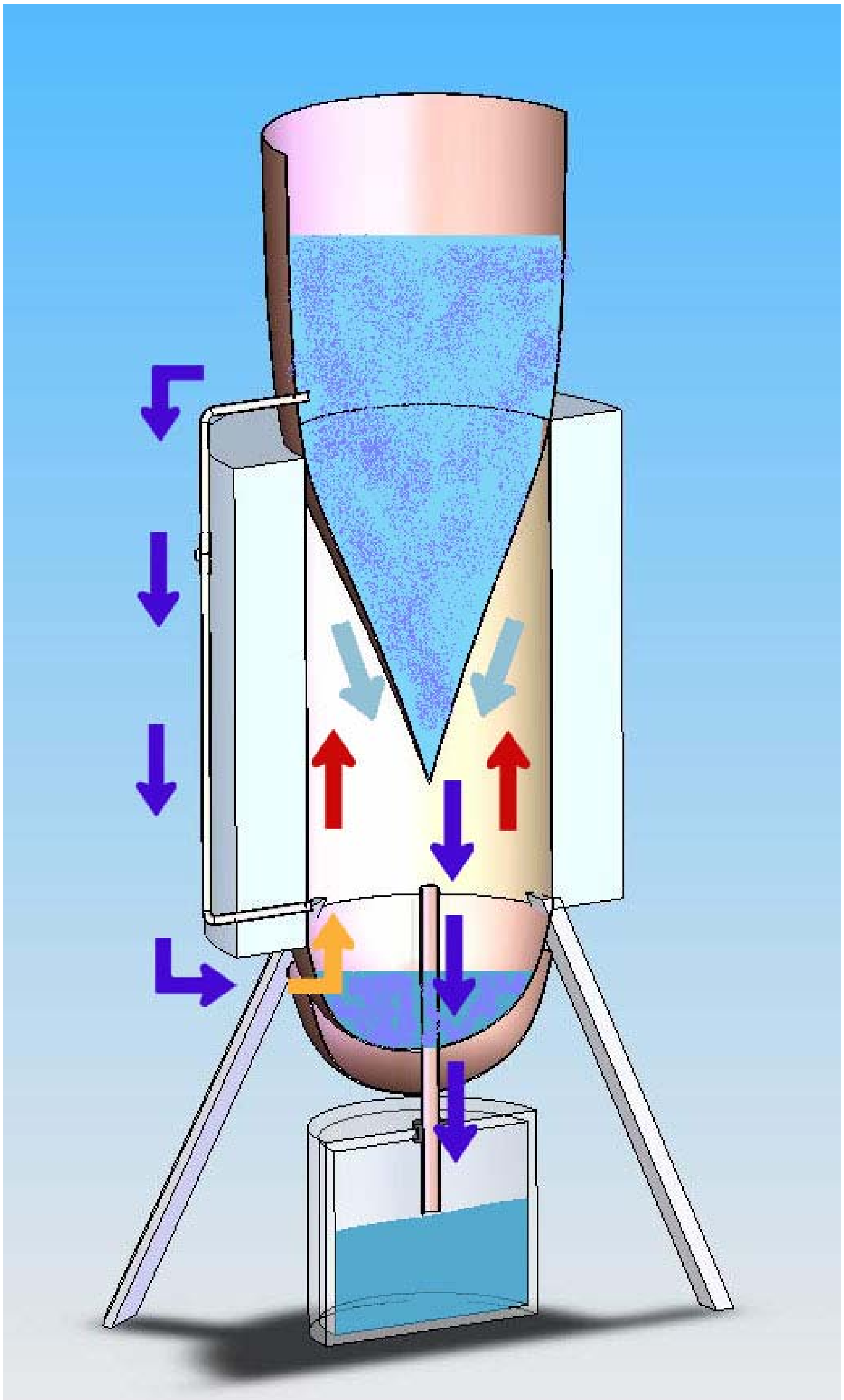



Support Beam
Steel
Purchased
0.66
0.25
0.20
10.70
4.99

Inlet Tube Flow Valve
Purchased



APPENDIX K – HYDROBLUE WATER EXCHANGE PROCESS



APPENDIX L –DEBUT OF HYDROBLUE AT ASME CONFERENCE

APPENDIX M – DISSECTED HEATING CHAMBER