COOL

Water Purification Project

August 1, 2007

To Whom It May Concern,

Water may be the world's most abundant resource, but the need for sanitary and clean water is exponentially increasing. Currently available water purification systems require large scale expensive facilities or disposable filters which require costly maintenance and replacement. Deaths in developing countries and rural areas have increased in the past ten years due to lack of clean water, and countries such as the United States have pledged to give over a billion dollars towards water related fields. Around the world there is a growing need and interest in clean water.

Attached is a proposal for a simple inexpensive water purification system. This device will be reusable, require little maintenance and contain minimal degradable parts. This is accomplished by using a windmill to translate mechanical input to electrical power. Heat created by a heating element boils water and removes 99.9% of all bacterial impurities. The proposed system will be competitive in the world market and most practical for non-industrial sized applications.

Sincerely,

Cheryn Engebrecht

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Colin Porterfield

COOL

Water Purification Project
Design Report

University of San Diego
ENGINEERING PROGRAMS

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Executive Summary

The COOL Water Purification Project uses two sources of energy to create potable water. For normal uses, wind will be used as a renewable energy source and for emergency situations a human powered mechanism provides an alternative energy source. This system will boil contaminated water, purifying it, and then condense the water as a potable source. The system will be simple, cost efficient, and require minimal maintenance.

Abstract

The goal of the COOL Water Purification Project is to make potable water using two sources of energy. For everyday use, the mechanism uses wind as a renewable energy source. Additionally, a human powered prototype was constructed and tested for the 2007 ASME Design Competition. Both cases convert mechanical power to electric power through the use of a generator. Electric current is run to a heating element located in the contaminated water, transferring heat, causing it to boil. The evaporated water leaves behind 99.9% of contaminants in the boiler producing mostly uncontaminated vapor. The water vapor created then condenses through a concentric tube heat exchanger and the result is potable water. The system will efficiently transmit heat to the water and all components of the device will be cost efficient and require minimal maintenance.

Acknowledgements

Dr. McGarry – Thank you for your encouragement and understanding. We appreciate all of the great advice on the heat exchanger and your dedication to making this class useful for our long-term professional development as well as our technical writing skills that we have all gained.

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Other Mechanical Engineering Faculty – Thank you for your assistance and expertise in all aspects of engineering. We appreciate your help, support, and interest in our project.

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Concept

The COOL water purification project provides a small, economical, water purification system that may be applied on a larger scale. The design has minimal moving parts, thereby reducing the risk of mechanical failure. The final device is driven from a windmill interface. The design easily separates waste and optimizes clean water output.

The COOL water purification project is intended to fulfill the requirements of the ASME design competition and then be adapted to use a renewable energy source. When adapted to a renewable energy source, this small scale water purification device will attempt to satisfy market needs for individual families who desire purified drinking water.

The purpose of this project is to design and manufacture a small scale water purification system which requires minimal maintenance and is cost efficient. Originally, a human powered bike will be used to power the purification system for the competition and a wind turbine will be used to adapt the system to renewable energy. The power produced will be converted into heat by using a resistive heating element which will be placed in a boiling chamber. Once the water is boiled, it is condensed in the heat exchanger and the system will collect the potable water. The final product of the COOL water purification system will provide potable water to people around the world.

Background

The motivation of the ASME design competition is from natural disasters like the recent hurricane in New Orleans and the lack of clean water in developing countries. More information about the motivation for the design competition can be found in Appendix B.

According to an article published by the Red Cross in March 2005, over 1.1 billion people lack access to safe drinking water. As a result, over 2.2 million people die from unsafe drinking water every year. Almost 90 percent of these deaths are children under the age of five. In fact, British Broadcasting News reports that 4,500-6,000 children die every day from water related diseases.

Existing water treatment processes include desalination plants, reverse osmosis water treatment plants, and household water purifiers. The large facilities are quite costly and require detailed know-how about the latest developments in the sanitation industry. All three methods require a membrane or filter, which translates to constant maintenance and a substantial amount of upkeep cost. The smaller household filters can usually only filter out certain strong smells and tastes, trivial problems for any family.

Many nations have realized the urgency of having potable water and are putting forth funds for supporting purification programs. For example, in response to a proposal by the United Nations, the Red Cross is going to spend 129 million dollars over the next ten years to provide clean water for more people. In a similar effort, the United States' Government has pledged to provide 970 million dollars over the next three years to improving access to clean water and increasing water productivity.

A group of four students have sought to design a device that can clean water efficiently and effectively. The initial design will be completed according to the specifications of the American Society of Mechanical Engineers Student Development Conference in 2007. The final design will use the competition as a guide for sensible improvements and adaptations to a renewable energy source, such as wind. The design will be completed by a mechanical engineering team representing the University of San Diego.

Professional and Ethical Responsibility of Project

The code of ethics, supported by the National Society of Professional Engineers, states an engineer must always, "hold paramount the safety, health, and welfare of the public." The goal then is to make the world a safer, cleaner and more energy conservative place to live. In the field of professional engineering, engineers are constantly faced with ethical decisions. It is important to incorporate these rules when working on design projects in the professional world. The COOL Water Purification Project is a great example of how ethics and professional responsibility are put into practice.

The overall goal of the COOL Water Purification Project is to supply families in need of clean drinking water with a continuous, low maintenance, potable water system that is both inexpensive and easy to install. This project is intended to address the needs of all humankind. It is understood that this product needs to be mass-produced to make a difference. Therefore, professional considerations such as manufacturing and shipping capabilities (size, availability of materials, cost) are taken into account.

Lifelong Learning Contribution of Project

Working on a design project with a group of people has many benefits and rewards. By exchanging ideas and creating a supportive group dynamic, more can be accomplished than when working alone. From working as a team, you learn many lifelong skills such as cooperative scheduling, respect for your teammates, building positive energy, and communication. Whether it is working with other students while getting a PhD or working within a certain department at a corporation, being part of creating a group dynamic is a beneficial experience for future situations.

Another benefit of working on a design project is getting exposure to how the design process works. Design projects prove that no matter how much planning is done, there are always situations when some part of the project does not go exactly as planned. There are often times when it seems like what is designed might not work and it may be time to go back to the drawing board. What this teaches is perseverance. Perseverance beyond getting caught up in stress and moving towards getting done what has to be done. Design projects can be very stressful and require intense amounts of work and dedication. This is also why having a good group dynamic is beneficial because it can help to keep the work environment comfortable. If the work environment is comfortable, everyone in the group will not only work harder, but they will also produce more than they would if they were uncomfortable.

Overall, the most important lifelong lesson to take away from this experience is that a positive group dynamic not only makes the project enjoyable, but more productive as well.

Global, Economic, and Environmental Impact

The COOL water filtration project is designed to meet the requirements of the ASME design competition and be adapted to meet the market need of clean drinking water. The development of a small scale water filtration system that does not require extensive maintenance is very significant to the global environment. Every year human beings create more waste that contaminates the environment. Not only does this pollute the environment, it also reduces the amount of clean water necessary for humans to survive. Availability of a small water purification device can alleviate the limited supply of water, especially in remote areas without having to add any additional sources of water

By providing the option to clean the available water resources, a large portion of the cost to bring in addition resources would be eliminated. Individuals should not be deprived the most abundant resource on the planet. A simple water filtration system can eliminate many deaths and provide a significant effort towards humanitarianism throughout the world.

Purpose and Overview of Project Report

The COOL water filtration project is intended to provide clean drinking water to anyone in need. The lack of clean water supplies could save countless lives every year. A small scale water filtration system could be brought into remote areas and provide the means of purifying previously contaminated water. Filtering local sources of water would eliminate the need to import large quantities from elsewhere, saving relief funds for alternate uses. The purpose of this project is to design and manufacture a small scale water purification system which requires minimal maintenance and is cost efficient. To power this system, human and wind power systems will be explored. This report describes the process and materials necessary to create a small scale water purification system. Detailed parts, materials, and design specifications are created according to industry standards. All design specifications have been produced to create a water purification system.

Literature Review

There are many water filtration products in existence today. However, none of these products fully satisfy the needs of families in rural areas with a lack of clean drinking water. All of the following products require either large sums of money or extensive maintenance, and some products don't even come with a guarantee of potable water.

There are many filters that claim to clean water (carbon filters, Brita filters). One type of filter that is in existence is the Brita water filter. This widespread at-home filtration system is very small and can quickly produce enough water for a household. However, the Brita water filter is only applicable to affluent countries because it can only filter aluminum (placed there by existing water treatment facilities during the chlorination process), and reduces the concentration of calcium, chlorine, magnesium, bad tastes, and odors. All of these operations are mere luxuries that affect only the taste and smell of water, but do not actually filter out bacteria or make the water safer to drink. In general, the Brita type water filters (Figure 1) count on desalination systems and/or industrial reverse osmosis plants to decontaminate the water.

Figure 1: Common Brita water filter

Reverse Osmosis is a common filtration system used by households and cities around the U.S. This process reverses diffusion by applying pressure on the highly concentrated side of a membrane causing all clean water to end up on the side of the membrane with low concentration of contaminants (as seen in Figure 2). These systems come in all sizes ranging from in-home, to city-wide. Reverse Osmosis (RO) is more useful to developing countries than the Brita system because even an at-home kit can eliminate up to 99.99% of microorganisms and up to 98% of dissolved solids, metals, and harmful chemicals from tap water. Both the in-home and city-wide osmosis systems require immense amount of pressure and are thus very expensive. The in-home RO kits cost between $200 and $500 per household. The total cost of a city-wide RO plant is around six million dollars (including control systems, bulk chemical storage, and laboratory facilities). This high cost is one of the major drawbacks of the city wide reverse osmosis plants. Both the at-home and city-wide systems require expensive maintenance and upkeep.

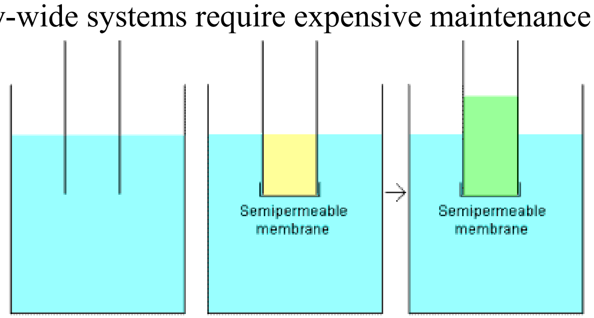


Figure 2: Reverse osmosis diagram

Figure 3: In-home reverse osmosis system

Desalination plants are similar in cost and functionality to Reverse Osmosis plants (Figure 4). Some of the desalination plants even use RO as a filtration process. Desalination plants can also use a three valve system that draw-in and push-out sea water through a membrane which separate the clean water from the salt concentrate (Figure 5).


Figure 4: Desalination plant

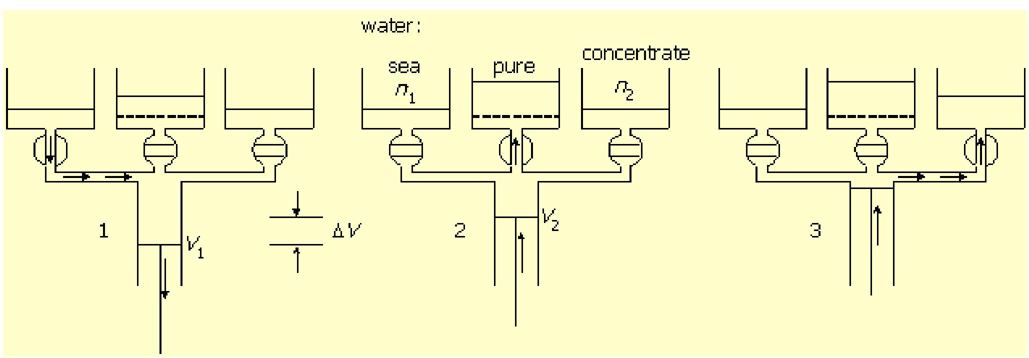


Figure 5: Desalination process using pressure/membrane system

Desalination plants might become essential to the world's potable water problem in the future because they allow us to take water from the ocean, extract the salt content, and produce potable water.

In the Rio Grand Basin Desalination Plant in the US, initial construction costs were $26.6 million; continued costs were $80,000 per year for administrative costs, and $1.6 million per year for plant operation and maintenance. Such costs are difficult for any country to bear. Some comparison of costs per day of desalination plants (specifically using RO) in developing countries in particular (in US dollars) is shown below. These prices only cover the cost of one cubic meter of water, which is about enough for one household per day.

Country	Capital Cost ($/m^3 per day)	Operation and Maintenance ($/m^3)	Production Cost* ($/m^3)[a]
Antigua	264-528	0.79 – 1.59	
Argentina		3.25	
Bahamas			4.60 – 5.10
Brazil	1454 – 4483		0.12 – 0.37
British Virgin Islands	1190 – 2642		[b]3.40 - 4.30
Chile	1300		1.00

Figure 6: Comparative costs of RO desalination

[a] Includes amortization of capital, operation and maintenance, and membrane replacement.
[b] Values of $2.30 - $3.60 were reported in February 1994.

In both Reverse Osmosis and the valve and membrane Desalination system, there is a need to maintain and replace filters on a regular basis. There is also a very large upfront cost and both require large amounts of energy to produce the high pressures needed to push the water through the respective membranes.

System Description

Water is typically purified in three different ways. It can be filtered through a membrane, chemically treated, boiled by lowering the pressure, or boiled with heat and then condensed (distillation). Since the first two of these purification techniques require maintenance, the following section will discuss the final two options.

Water can be boiled using a quick decrease in pressure, lowering the boiling temperature. Two plausible methods will be investigated in depth for this particular project. The first of these low-pressure designs is a spinning U-tube formation (Figure 7) which creates a vacuum using centripetal force. One arm of the U is connected to the center of a spinning disk and the other arm is on the outer perimeter. Because the outside arm is open to the air, as the water on the inner arm is forced downward, a vacuum forms which creates water vapor. To extract the clean water vapor from the rotating tube, a plunger in combination with a bearing mechanism would be used to empty the vacuum without changing structural integrity. This mechanism causes the design to be extremely difficult to manufacture and operate. Economically, this approach is very good considering the fact that all of the parts used are either glass or steel (both inexpensive materials). The energy required to spin the mechanism is small because the total weight of the materials are fairly light. However, the feasibility of this idea completely outweighs all of the positive elements.

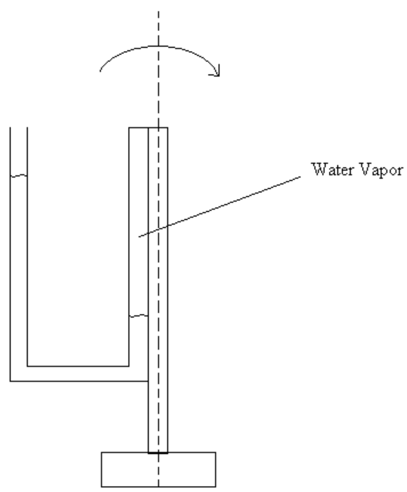


Figure 7: U-Tube

Another low-pressure design that is capable of boiling water at room temperature is a syringe and valve mechanism (Figure 8). As the syringe is forced open, it forms a vacuum which vaporizes the water. The syringe contains a small amount of dirty water and can only produce a certain amount of clean water vapor per cycle. This mechanism is easier to manufacture, but is just as difficult to design as the U-tube configuration. Economically, this method uses the same amount and type of materials as the U-tube. However, its major downfall is the energy required to overcome the large friction forces from moving the airtight syringe. This is a major drawback because it risks using the already limited available energy. As seen in Appendix C, if this method is used, the output would be very slow. Using either human power, or the equivalent power, it would take over 45 days to simply boil 200 grams of water.

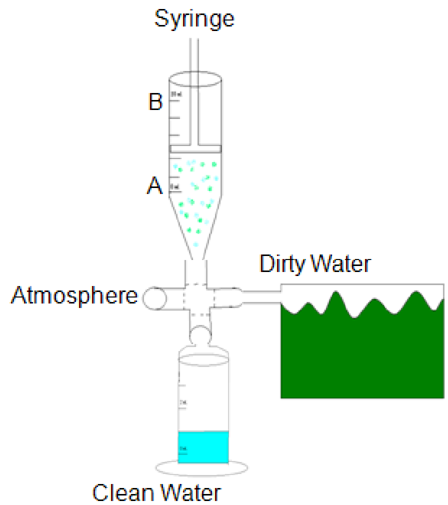


Figure 8: Syringe and valve low-pressure mechanism

The third design takes energy from the source and turns it into heat. In this method, most of the energy obtained by a generator can be translated to a resistance wire, heating the dirty water. The water then boils and evaporates, leaving all contaminants behind. Appendix D uses this method and compares the output of human power to the output of a windmill. This data shows the windmill model is much more efficient (because a human would probably drink more water than they would produce) and much more productive.

The COOL water purification system is composed of a windmill, a heating element which converts electrical energy into heat energy, a boiler, and a heat exchanger. The windmill is mounted on a stand made to withstand the high wind conditions. The stand is 16ft when in operation to ensure the windmill receives a clean air flow. The windmill is attached to the heating elements via electrical wire routed to inside the air-tight boiler where the heat energy vaporizes the contaminated water. Inside the boiler, a float control system regulates the water level of the boiler so that the heating elements supply enough energy to the water to make it boil. When the vapor exits through the top of the boiler, it flows through the inner pipes of the heat exchanger where it releases its heat to the contaminated water entering the boiler as it condenses. The energy in the system is thus conserved and the flow rate of the water being vaporized increases.

A prototype of this system was made using human power instead of wind power, for an ASME design competition. A similar permanent magnet generator was attached to the heating element and preliminary test of all systems were done. The prototype proved a renewable energy source was needed to boil the water, considering the amount of water consumed by the human than was more than produced. Wind power offers a clean and efficient way of supplying renewable energy.

Diagrams of End Result

ASME Design Competition

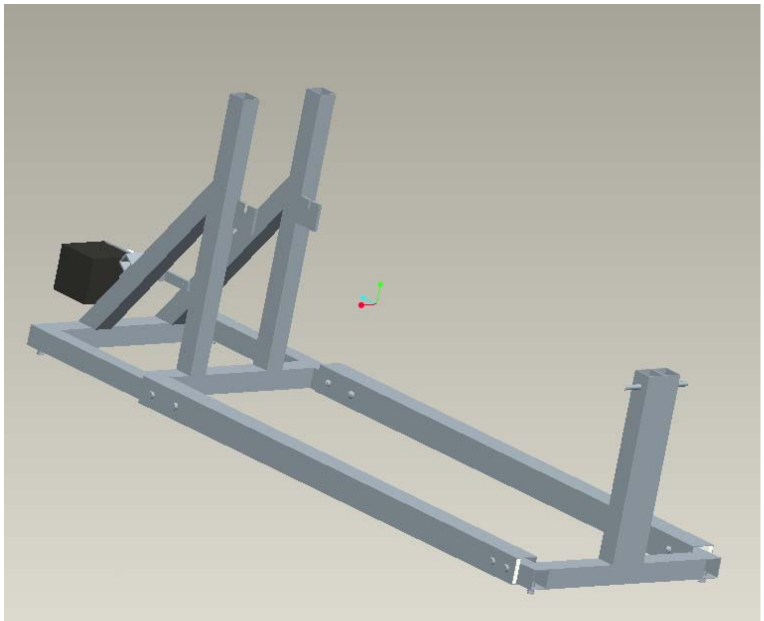


Figure 9: Bike stand assembly

To meet ASME design specifications, a prefabricated bike was mounted to a collapsible stand. A prefabricated bike was used because the design of a biking apparatus with multiple gearing stages is outside of the building time for the human powered interface. To stabilize the bike in the lateral direction, a length of 18" tubing is used as cross supports in multiple locations along the length of the bike keeps it from tipping over. The bike stand accommodates the axle to axle distance of about 42", and both of the axle's supports are rigid.

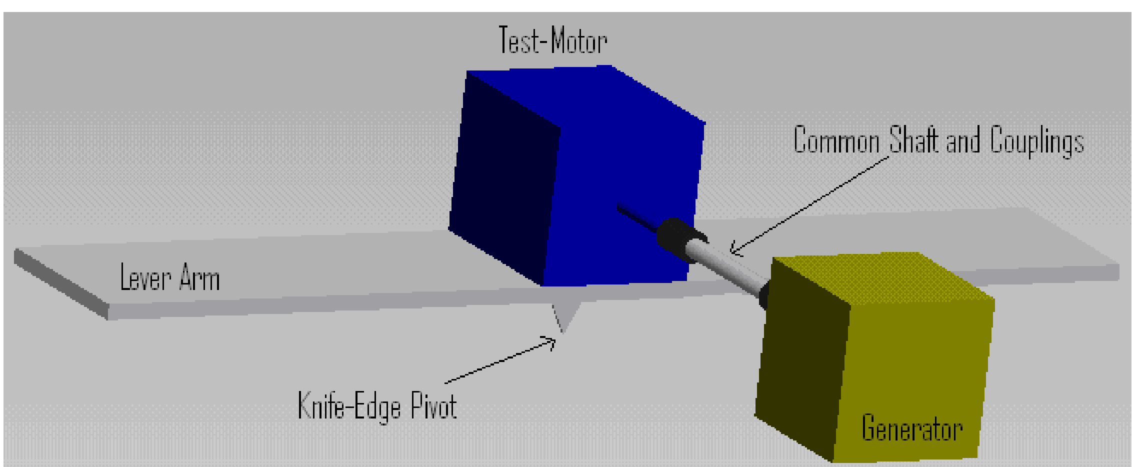


Figure 10: Generator efficiency test rig

A test rig is designed to measure the mechanical input power and the electrical output power. By comparing these two quantities the efficiencies of the different generators are calculated. In addition, this test rig is used to size an efficient resistor for the purification system.

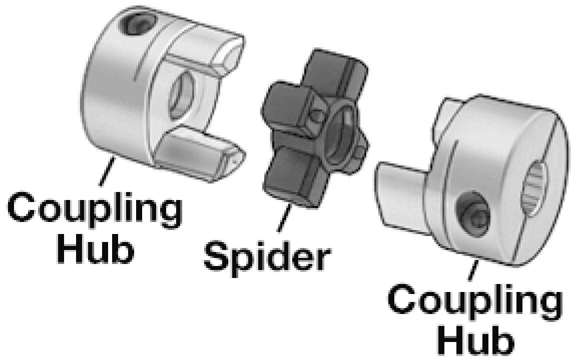


Figure 11: Flexible shaft coupling

The generators and back driven motors are tested for efficiency by linking them shaft-to-shaft with a test-motor and variable speed control. Both the test-motor and each generator required flexible shaft couplings that connected them to a common shaft.

Windmill

Figure 12: Air-X Windmill

Air-X Marine Windmill is used as the renewable energy power source for this water purifying system. The windmill is corrosion resistant and has an internal safety regulator that will shut the windmill off in dangerous wind conditions. The electrical power generated by the windmill will be transformed into heat that will boil water.

Figure 13: Loma Hall

The windmill is mounted on the roof of Loma Hall in an area with minimal obstructions. The windmill is only visible from a few areas on campus. The electrical wires will be run down a vent into Loma 311 where they will be connected to the heating element inside of the boiler and heat exchanger system.

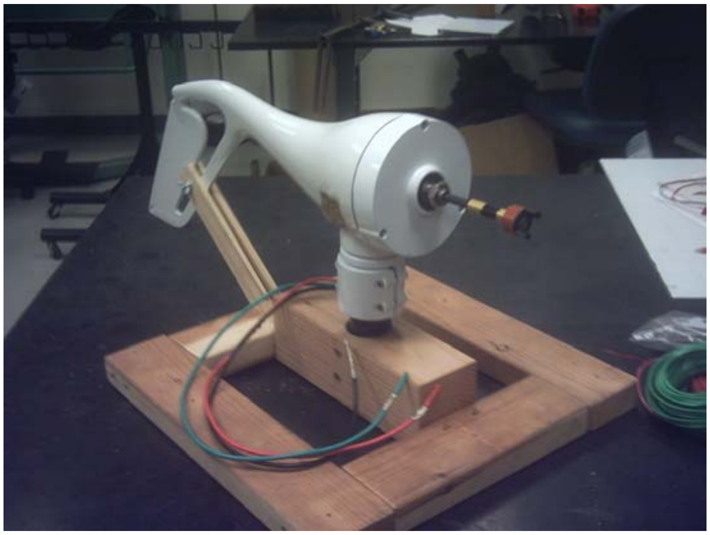


Figure 14: Windmill generator test rig

A test rig is constructed to secure the windmill and dampen vibrations when linked to the test-motor. The test-motor connects to the rotor of the windmill generator through a common shaft and motor couplings. The electrical output leads are connected to the heating coils with an ammeter and voltmeter to measure the output power.

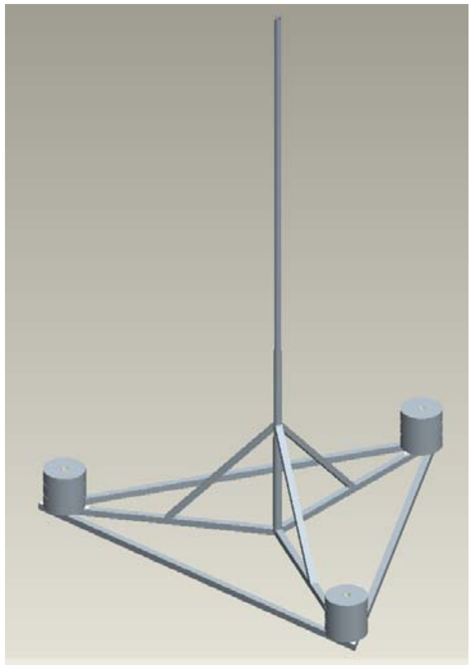


Figure 15: Windmill stand

The windmill stand offers a strong base for the Air-X windmill that will be mounted to it. It can withstand a horizontal force of 150 lb at 10 ft and it fits all requirements of construction and visibility set forth. It has a telescoping pole so that the stand can be raised higher during operation and lowered while it not in operation. The triangular base utilizes a unique technique for keeping the windmill from tipping. By using weights on the three corners, any moment that can be applied to this windmill will use at least one of these stacks of weight to counteract the moment created by the wind.

Boiler

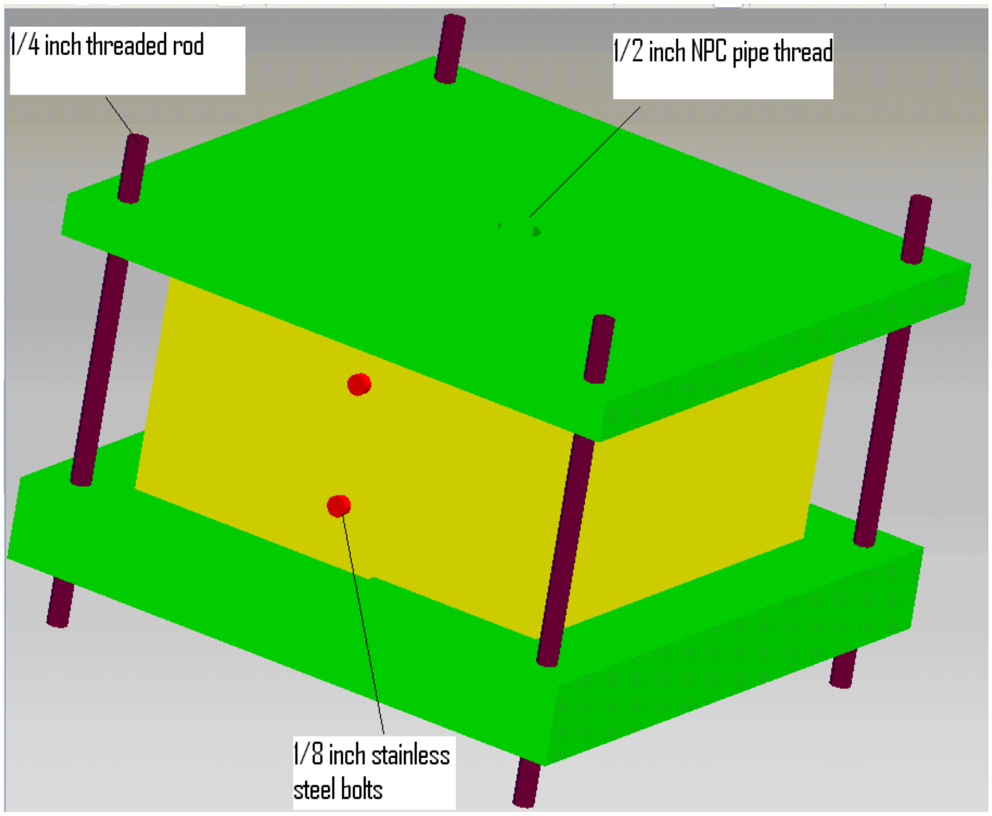


Figure 16: Boiler

A boiler is constructed to house the heating element and enclose the evaporation process. Contaminated water enters the boiler from the bottom through a pipe from the heat-exchanger. The heating element then heats the water until it vaporizes and the vapor then leaves the system through a pipe at the top of the boiler. The entire system is insulated to reduce losses and corrosion resistant to preserve longevity in the water rich environment.

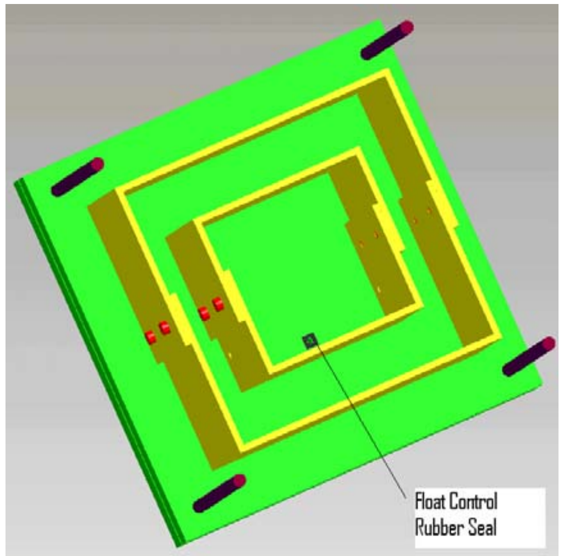


Figure 17: Double pane insulation system

The boiler is designed to minimize heat losses to the environment. To do this a double pane insulation system is created by creating two similar dimensioned boxes varying in scale placed within one another. This double pane system will greatly minimize heat losses to the environment increasing vaporization efficiency. A small hole is drilled on the top layer of the bottom of the boiler where a small rubber o-ring is placed at the water inlet.

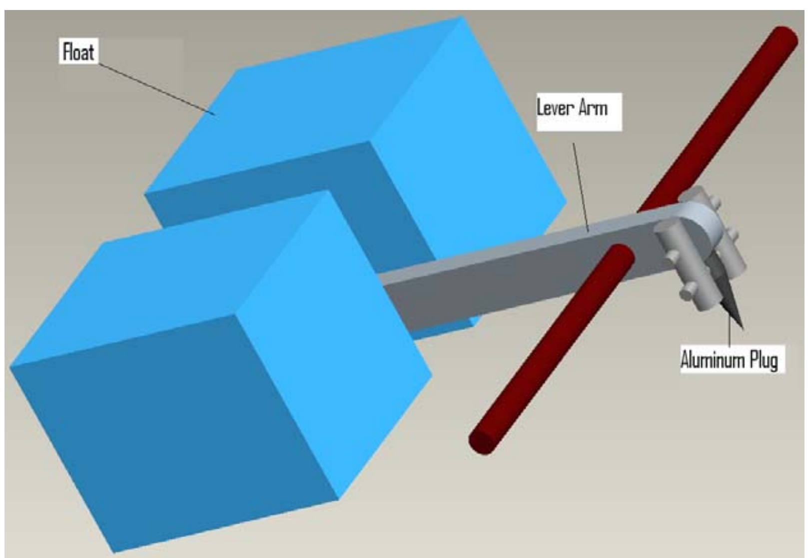


Figure 18: Flow control

A flow control system is utilized to regulate the flow of water into the boiler. As the water level in the boiler rises, the float rises in the water pushing down the aluminum plug into the rubber o-ring located at the water inlet. When the aluminum contacts the rubber plug it creates a seal, stopping the flow of water into the boiler. The water level in the boiler then drops as the water continues to vaporize, lowering the float and thus lifting the aluminum rod to allow more water to flow into the boiler.

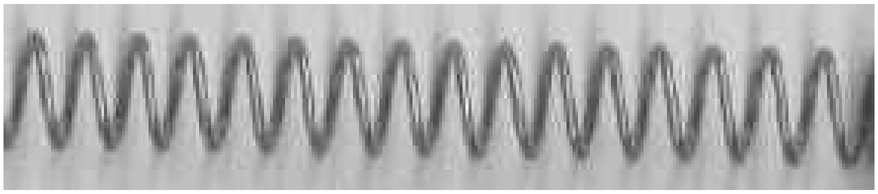


Figure 19: Nichrome resistance wire

Nichrome resistance wire is used as the heating element inside of the boiler and heat exchanger system. The resistance wire will receive the electricity produced by the windmill and convert it into heat. Various resistances are tested for efficiency using the testing rig above.

Heat Exchanger

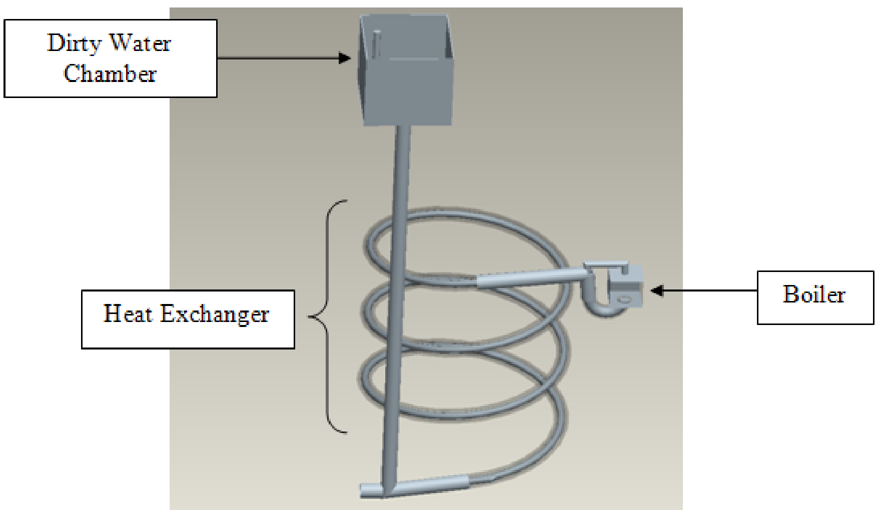


Figure 20: Heat exchanger

The overall heat exchanger configuration (Appendix A for complete dimensional drawings of heat exchanger) is shown in the above figure. The height difference between the dirty water chamber and the boiler allows gravity to carry the contaminated water up through the heat exchanger. The spiral design saves space and still creates some flexibility for construction purposes.

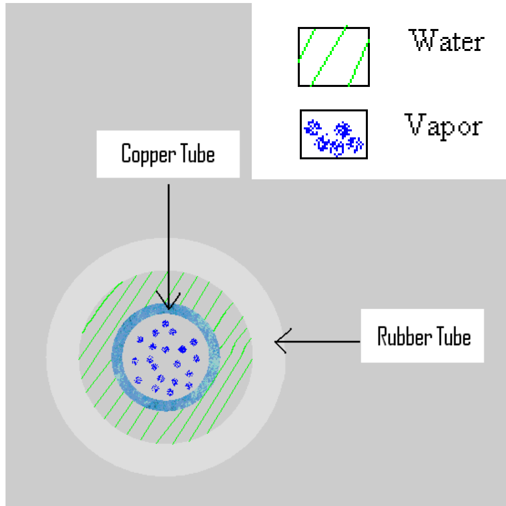


Figure 21: Counter-flow heat exchanger cross-section

The cross-section of the counter-flow heat exchanger shows the manner in which the contaminated water and the clean vapor are separated. The tubes are about 2.5 meters in length and provide a way in which both products may be transported from the dirty water chamber, to the boiler to the clean water outlet.

Overall Design

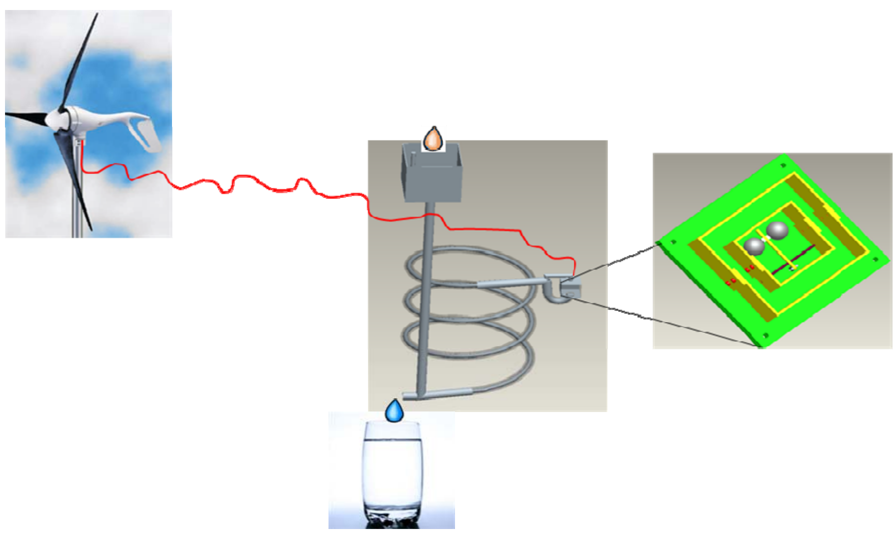


Figure 22: Overall system diagram

The above diagram shows how all parts of the COOL water purification system fit together to create potable water from contaminated water. The windmill provides renewable energy to the boiler where that energy is converted to heat which boils (and purifies) the water held inside. The heat exchanger transports all contaminated and clean water to and from the boiler and adds yet another energy saving technique into the system.

Specifications

ASME Design Specifications

- Purifies water
- Must use a water still
- No filters
- Entirely human powered
- Lightweight
- Fits standard shipping requirements
- One hour run time

Human Power Stand

- Ergonomic Correct riding position
- Rigid frame and stand
- Collapsible stand easily integrated with prefabricated bike
- Compact Design
- Efficient belt-pulley system using an 80" belt and has a center to center distance of 16"

Human Power Generator

- Rated power between 200-250 Watts
- Produces 200 Watts at or below 3000 rpm
- Efficiency of at least 75%
- Dimensions under 6"x6"x6"
- Weighs less than 10 lbs
- Face mount

Major Design Considerations

- Inexpensive
- Portable device that purifies water
- No filters (per ASME specifications)
- No materials which require extensive or expensive maintenance
- Simple clean water extraction (vapor collection) to be as simple as possible
- Avoid many moving parts

Windmill Stand

- Withstands maximum horizontal load of 150 lb.
- Taller than any obstruction
- Collapsible (transport from basement to roof)
- Meet aesthetic requirements of USD

Windmill Generator

- Converts wind energy into electricity

- Corrosion resistant
- Safe
- Provides enough power to boil water at average San Diego wind speeds
- Relatively inexpensive
- Lightweight and small
- Easy assembly
- Capable of withstanding stormy conditions

Boiler

- Capable of receiving current from an exterior source to a heating element
- Effectively encase the resistance wire
- Minimize the amount of heat loss from the water/vapor system to its surroundings
- Not to hinder the path of the vapor through the top of the inner chamber
- Minimized the water level to heating element ratio
- Regulate the water inlet flow rate
- Withstand the corrosive nature of water
- Take temperatures of approximately 212°F.

Heat Exchanger

- Able to transport contaminated and purified water separately
- Condense vapor
- Efficiently pre-heat water
- Compact
- Flexible
- Leak resistant

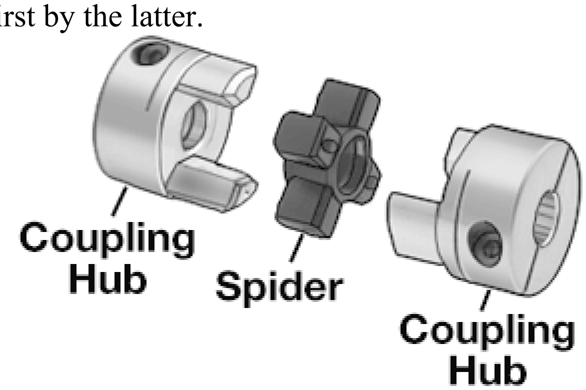
Functional Description

ASME Design Competition

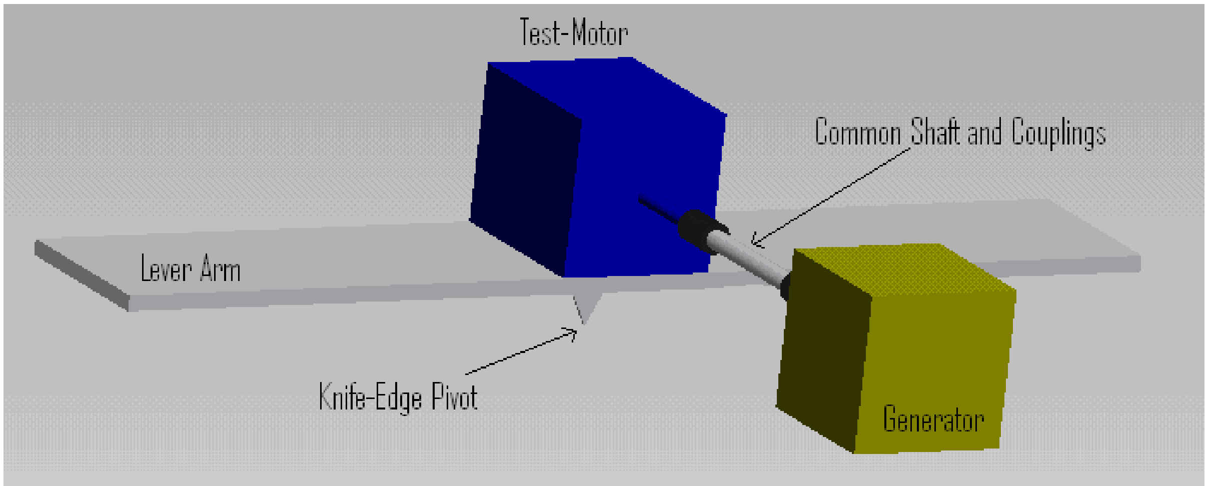
Nomenclature

F	=	Force [N]
m_{eff}	=	Mass [kg]
g	=	Acceleration of gravity [m/s^2]
T	=	Torque [Nm]
d_l	=	Distance [m]
ω	=	Angular velocity [m/s]
P_{in}	=	Input power [W]
P_{out}	=	Output power [W]
I	=	Current [A]
V	=	Voltage [V]
R	=	Resistance [Ω]
η	=	Efficiency [%]

For the ASME design competition, every generator and back driven motor was tested for efficiency by linking them shaft-to-shaft with a test-motor and variable speed control. Both the test-motor and each generator required flexible shaft couplings that connected them to a common shaft. The generators' efficiencies were calculated by measuring the output power and input power and dividing the first by the latter.



Flexible shaft coupling



Generator efficiency test rig

Due to losses associated with the test-motor, it was necessary to measure the mechanical power coming out of the test-motor to find the generator's input power. The torque and speed of the test-motor were measured to find the mechanical power to the generator. In order to measure torque the test-motor was mounted on the middle of a long board. Directly under the test-motor a knife-edge pivot was used to support the weight, transmit torque, and eliminate friction losses. At one end of this board a weighing scale was used to find the force acting on the edge of the lever arm by applying Newton's Second Law (Equation 2).

$$F = mg \tag{2}$$

The torque was then calculated by multiplying the force by the length of the lever arm (Equation 3).

$$T = Fd_l \tag{3}$$

The speed of the test-motor was then measured with a laser tachometer, available in the mechanical engineering labs. The multiple of the torque and the angular velocity, along with careful unit conversions, equaled the input mechanical power for the generator (Equation 4).

$$P_{in} = T * \omega \tag{4}$$

To measure the output power, a voltmeter and ammeter were connected to the output leads of the generator. The ammeter was connected in series with the resistive load (heating element), while the voltmeter was connected in parallel to the resistive load. The product of the voltage and the current in the circuit equaled the output electrical power of the generator (Equation 5).

$$P_{out} = IV = I^2 R = \frac{V^2}{R} \tag{5}$$

Finally, the generator efficiency was calculated by taking the ratio of the output power and input power (Equation 6).

$$\eta = \frac{p_{out}}{p_{in}}(100) \tag{6}$$

Nomenclature

L = Length of the belt [in]

C_d = Center Distance [in]
R_1 = Radius of the Pulley [in]
R_2 = Radius of the Wheel [in]
ϕ_1 = Wrap Angle of the Pulley [°]
ϕ_2 = Wrap Angle of the Wheel [°]
α = Angle from zero to the wrap angle [rad]

An essential part of the human powered design is to have the correct belt length for the back wheel pulley system. Since the radius of the wheel and the pulley are known, an iterative solution of varying the center distance can be done to find the belt length (Equation 1).

$$L = 2\sqrt{C_d^2 - (R_2 - R_1)^2} + R_1\phi_1\left(\frac{\pi}{180}\right) + R_2\phi_2\left(\frac{\pi}{180}\right) \quad (1)$$

Where:

$$\alpha = \frac{R_2 - R_1}{C_d} \quad (1a)$$

$$\phi_1 = 180 - 2\alpha \quad (1b)$$

$$\phi_2 = 180 + 2\alpha \quad (1c)$$

Along with belt length, the human powered device has to meet some other requirements that do not necessarily require calculation. First, the device should be integrated with a wheel and pulley system to spin the generator. The pulley system should have enough tension so there is little to no slip between the pulley and the belt. Second, the design should be ergonomically correct for the best power output. Third, the frame should be able to be compact and it should have the ability to collapse into smaller parts. Fourth, the interface must be designed and built in a time span of three months so it is ready for the 2007 ASME design competition. Fifth and most important, the frame for the biking motion should be rigid and able to handle the stresses that are applied to it by the human.

Windmill Generator

The Air-X Marine windmill is the optimal power source for the water purification system. It is specifically made for outdoor use with corrosion resistant coatings and internal safety regulators that will shut down the windmill in dangerous wind conditions, above 35 mph. The windmill produces its maximum power of 400 Watts at a wind speed of 28 mph, but also produces power at lower wind speeds. Based on research from the 2006 Weather Almanac, the average wind speed in San Diego is around 11 mph and possibly higher around the coast.

Nomenclature

Cp = Power Coefficient
TSR = Tip Speed Ratio
ρ = Density of Air (kg/m^3)
A = Windmill Swept Area (m^2)
R = Windmill Blade Radius [m]
U_∞ = Wind Speed [m/s]

w_r = Windmill Rotor Speed [rad/s]
w_{RPM} = Windmill Rotor Speed [rpm]
$P_{Theoretical}$ = Theoretical Power [W]
$P_{Experimental}$ = Experimental Power [W]
I = Current [A]
V = Voltage [V]
η = Efficiency [%]

The Air-X Marine windmill is tested for proper operation as suggested by the supplier, Southwest Wind Power. In addition, the windmill is tested to size a resistor that would optimize efficiency at expected wind speeds. The test-motor and the windmill generator require a flexible shaft coupling that connects them to a common shaft (Figure 23). The windmill generators efficiency is calculated by measuring the output power comparing it to the calculated theoretical power.

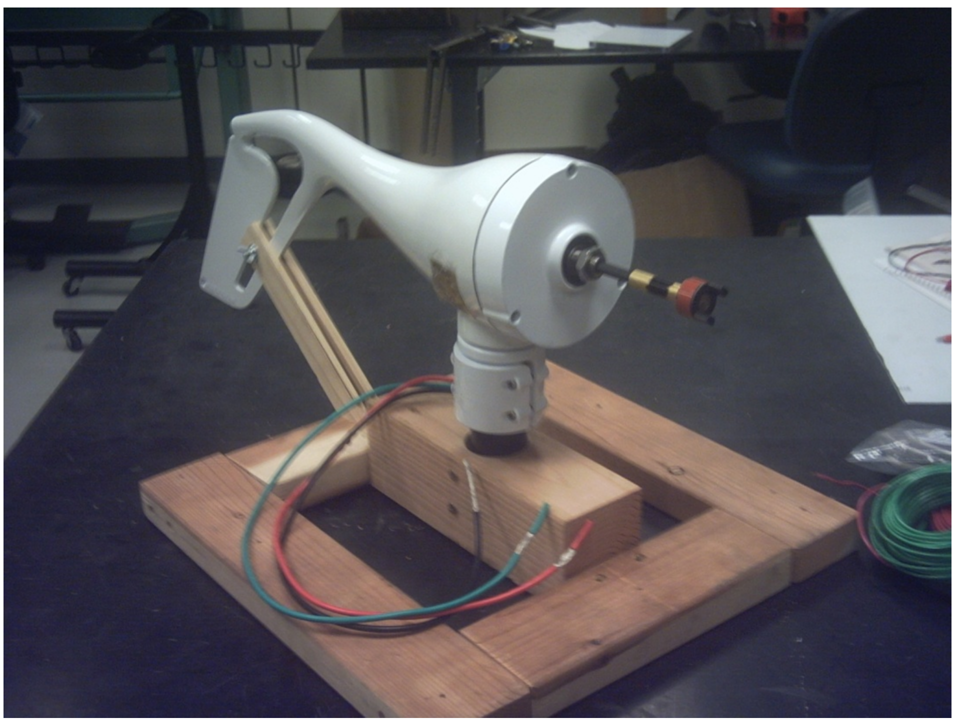


Figure 23: Windmill generator test rig

The theoretical power is calculated using the density of air, the swept area of the windmill blades, the windmill power coefficient, and the wind velocity. Since the density of air, the swept area, and the power coefficient are all constants, the theoretical power simplifies to an equation that is only a function of wind velocity which can be simulated by a test-motor (Equation 7).

$$P_{Theoretical} = \left(\frac{1}{2}\right)\rho A C_p U_\infty^3 \quad (7)$$

To simulate the wind speed, it is necessary to know the tip speed ratio (TSR). This ratio is a characteristic of the windmill that relates the wind speed to the rotor speed of the windmill generator. The following equation for the TSR shows the linear relationship between the wind speed and the rotor speed (Equation 8).

$$TSR = \frac{w_r R}{U_\infty} \qquad (8)$$

A test-motor is used to spin the windmill generators rotor, and simulate the expected wind speeds. Rotor speeds are calculated by acquiring research of expected San Diego wind speeds, multiplying it by the TSR, and converting it into rotations per minute (Equation 9).

$$w_{RPM} = U_\infty (TSR) \frac{60}{2\pi R} \qquad (9)$$

To measure the output power, a voltmeter and ammeter are connected to the output leads of the generator. The ammeter is connected in series with the resistive load (heating element), while the voltmeter is connected in parallel to the resistive load. The product of the voltage and the current in the circuit is equal to the experimental electrical power of the generator (Equation 10).

$$P_{Experimental} = IV = I^2 R = \frac{V^2}{R} \qquad (10)$$

Finally, the efficiency for each resistor is calculated by taking the ratio of the experimental electrical power and calculated theoretical power (Equation 11).

$$\eta = \frac{p_{Experimental}}{p_{Theoretical}}(100) \qquad (12)$$

Since the windmill is being mounted on the roof of Loma, the wire length and gauge are considered and included in the testing. The wires run through a vent on the roof of Loma Hall into Loma 311 where they will be hooked up to the boiler and heat exchanger system. The measured length from the windmill to Loma 311 was 80 ft. Using this approximate length a gauge size was selected for 95% energy transmission efficiency (Figure 24).

Wire Length (ft)	Gauge Size (AWG)
0-45	8
45-90	**6**
90-135	4
135-225	2
225-285	1
285-375	0

Figure 24: Wire gauge sizing table for average wind speed of 11 mph

A wire gauge of 6 AWG is selected to achieve 95% energy transmission efficiency through the circuitry of the system. The 6 AWG THHN or THWN stranded copper wire was selected. This wire is not rated for outdoor use and will need to be run through electrical conduits in order to protect it from UV rays and water condensation. Lastly, the circuit is connected to an electrical ground located on the roof of Loma for lightning protection.

Included in the circuitry are a 50 Amp kill switch, 50 Amp time-delay fuse, and a purification system disconnect (Figure 25).

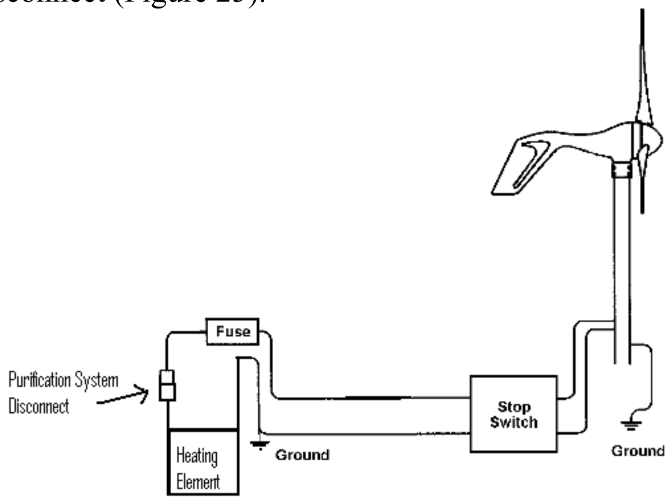


Figure 25: Windmill water purification system circuit diagram

The kill switch will be mounted on the stand of the windmill and will short circuit the windmill so that it is incapable of spinning. The fuse is a last resort safety precaution incase of high wind conditions and the internal regulator fails the system. If the fuse blows it will break the circuit and prevent any dangerous electrical conditions. The purification disconnect will be placed in Loma 311, and is for simple maintenance and short term disconnects. This disconnect will open the circuit and should only be used in short time increments, less than 24 hours. If the windmill is to be disconnected from the system for a long period of time the kill switch should be used instead of the purification disconnect, to prevent excessive wear. All connections in this circuit are soldered. The kill switch and fuse are placed in an electrical box that is weatherproof and are mounted on the windmill stand.

The specification sheet for the windmill generator can be found in Appendix E. Several sets of data are completed by varying the simulated speed and resistance. Graphs of these tests display trends that help to optimize the design and selecting the most efficient resistance for boiling water. Since the wire has a line resistance, it is included and kept constant for the resistor sizing tests.

The resistor sizing tests measured the electrical outputs of the windmill generator with eleven different resistors at several different simulated wind speeds (Table 26). The simulated wind speeds are based on the average San Diego wind speed of 11 mph, and ranged from 5 mph to 15 mph.

Resistance (Ohms)	Average Efficiency (%)
0.3	71.3
0.4	72.3
0.5	66.9
0.6	**73.3**
0.7	63.5

Figure 26: Resistor efficiency test

The resistor efficiency test results displayed that the 0.60 ohm resistor has the highest efficiency. To increase the confidence that this resistor war optimal for this system the efficiencies were plotted at the lower than average wind speeds (Figure 27).

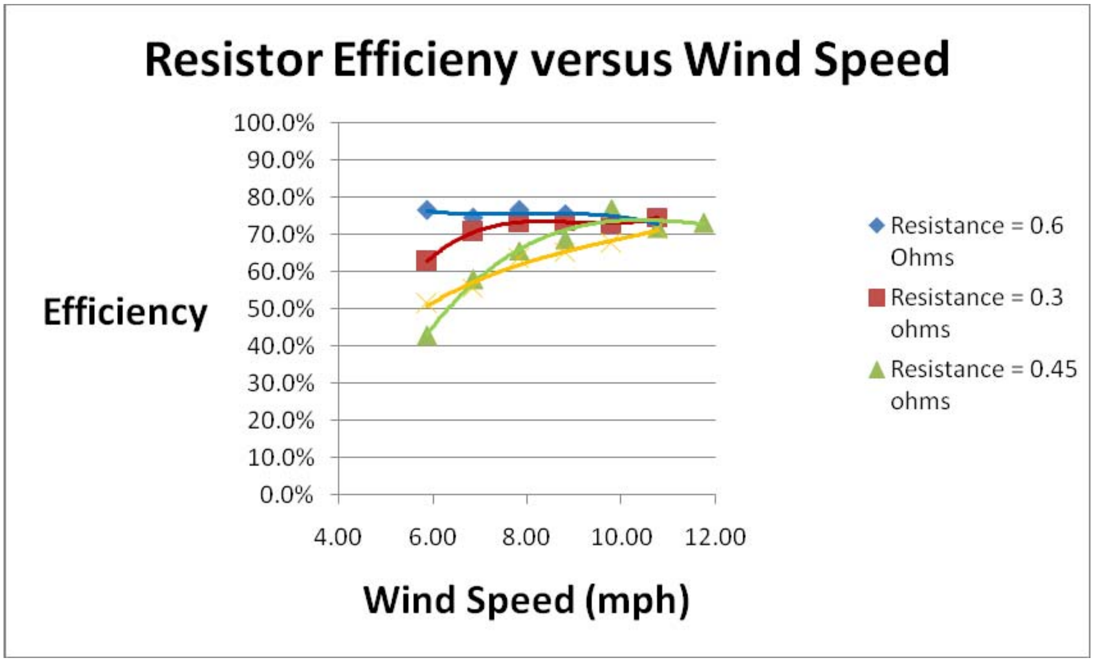


Figure 27: Resistor efficiency at low wind speeds

The 0.6 ohm resistor displayed efficiencies between 75%-80% for lower than average wind speeds. These efficiencies will prove that the windmill will still be producing adequate power to the water purification system at low wind speeds.

The next step was producing a power curve for the 0.60 ohm resistor (Figure 28). When compared to the power curve provided by the manufacturer it was almost identical (Figure 29). This shows the efficiency of the resistor and increases reliability in the manufacturer for giving accurate information on their specification sheets. From this data it is found that a continuous wind speed of 8 mph is needed to compensate for the initial start-up speed of the windmill and thermal energy losses, in order to boil water.

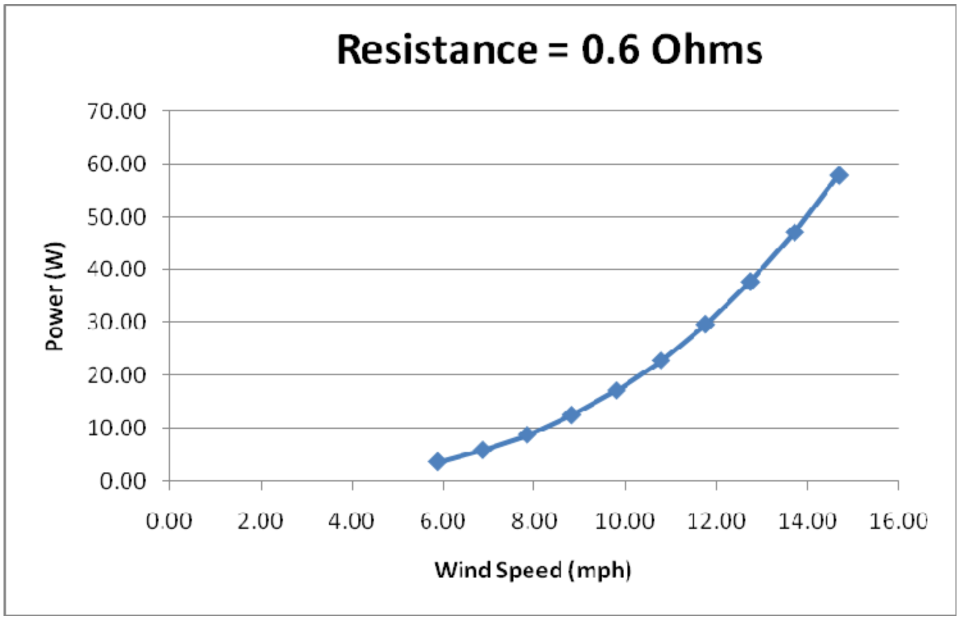


Figure 28: Resistor test power curve

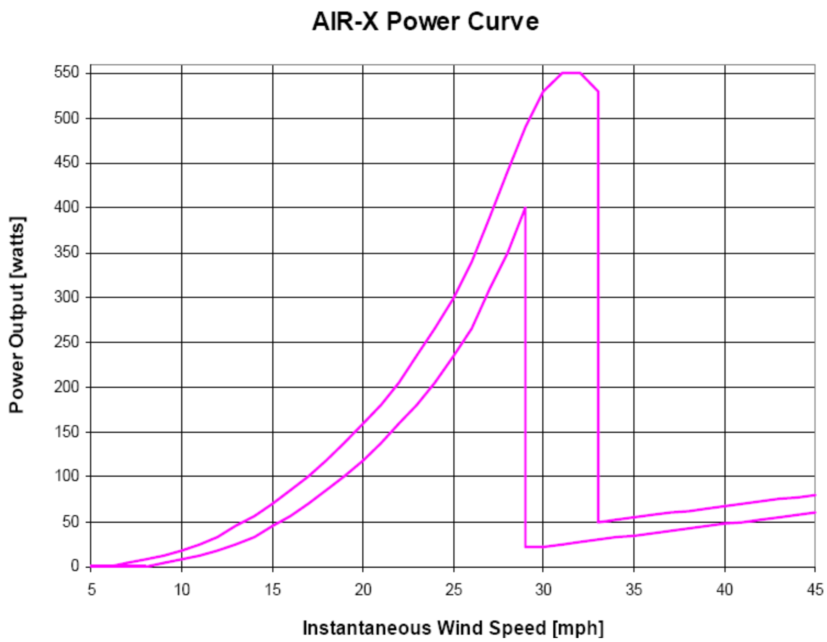


Figure 29: Air-X marine windmill power curve

A large benefit to the tests performed on the resistor is that information about the electrical output was measured based on simulated wind speed. Therefore, a plot of the electrical output versus wind speed can be created (Figure 30). This plot will be very useful when testing the completed system because the electrical readings can be used to find the wind speed. This will allow students to monitor wind speed from Loma 311 as opposed to on the roof. This also saves money because there is no longer a need for an anemometer to measure the wind speed.

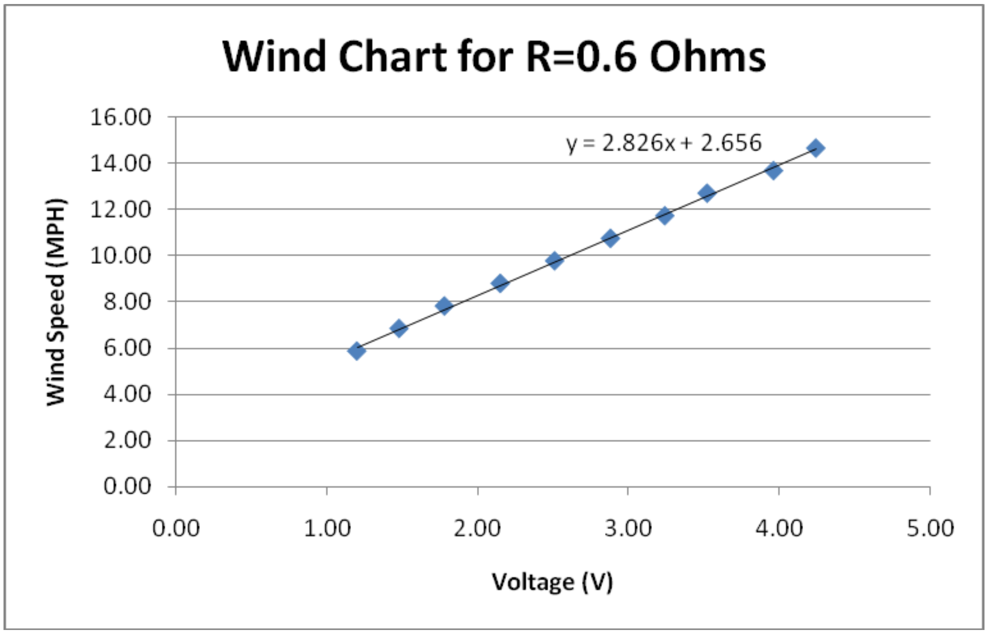


Figure 30: Wind speed chart versus voltage output

Windmill Stand

Three ideas for the stand included a square based stand that would be very similar to the stands that exist on the Loma roof, a triangular based stand with weights on all three corners, and a pole mounted to one of the preexisting structures on the roof. All designs were presented to Roger Manion, the head of the facilities department at the University of San Diego.

The first design which included a square based stand would be something similar to Figure 31. This means that cinder blocks would be used as weights to keep the windmill from tipping over. The design is rather complex due to the amount of angle iron that would be used and the construction time would be too long for this project. The square stand would also require a lot of weight around the perimeter of the base. Seeing that the main concern for the windmill stand is to withstand the 150 lb horizontal load, the square stand was not the optimal choice.

Figure 31: Stand on the Loma roof

The triangular stand is designed such that the weights are concentrated on the three corners of the windmill. No matter which way the windmill is pushed by the wind, there is always at least one set of weights if not two that counter balance the moment caused by the wind. The design is also very simple considering how much time it will take for construction and the amount of supplies needed for construction. Also, the triangular based stand does not require any extra attachments to the roof. Because of its ability to withstand a horizontal load as well as its ease of construction, the triangular based stand is the optimal choice of a free stand.

The pole mounted to a preexisting structure would be very easy to construct and it would be strong enough to withstand the force requirements of the wind mill stand. Some possible locations for this type of pole could have been any of the HVAC units on the Loma roof. However, this design was thrown out because the facilities department disapproved of altering any of the units on the roof.

Since the free stand was the only option for the windmill stand, the triangular based stand is the best fit for our requirements. To ensure that the stand would not tip at 150 lb of horizontal force, a free body diagram must be drawn for the entire system so that a moment analysis can be done see Figure 32.

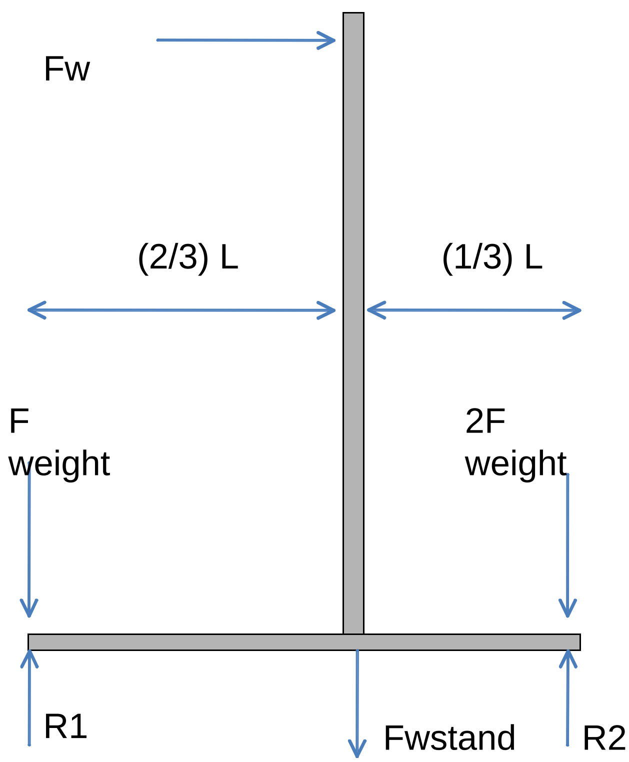


Figure 32: Free body diagram of stand

The moment analysis is used to calculate the necessary weight that is needed at the corners as well as the length of all the sides of the stand. In order to calculate the maximum length and weight, the moment analysis was done where the distance from the post to the edge of the stand was the smallest as seen in Figure 32. All masses, volumes, and moments were calculated using equations 13,14,15,16, and 17.

$$M = Fd \qquad (13)$$

$$F = ma \tag{14}$$
$$m = \rho V \tag{15}$$
$$V = \pi r_o^2 h - \pi r_i^2 h \tag{16}$$
$$V = lw_o^2 - lw_i^2 \tag{17}$$

What is unique about the triangular base is this smallest length is directly counter balanced by the longest length from the center, which is connected to weights on the end. Using an iterative technique of varying the weight on the corners, the length for each side was calculated to be 9.88 ft and the weight needed at each of the corners was 90 lb.

Once the lengths were calculated, the final design for the stand could be made. In order to fit the remaining design requirements, the stand cannot be particularly visible and it needs to be high enough so that there are no obstructions blocking the wind flow. To make the stand high enough but also have reduced visibility, the stand was made to have a telescoping pole (Figure 33).

Figure 33: Telescoping pole joint

The pole is 16 ft high when the windmill is in operation and 10 ft high when it is not in operation. The two poles are 1 ½" and 2" schedule 40 pipe, where the 1 ½" pole attaches to the windmill mount. This is the size that the mount is made for on the Air-X windmill. The outer pipe has two holes drilled at a 120° angle for each other so the telescoping pole is securely fastened and fully constrained within the bigger pole. This ensures that the telescoping pole will be securely fastened to the base.

To join the three long lengths of the triangle to the cross bars that will be attached to the windmill, a special joint had to be made. The joint must be able to securely fasten all members coming to it and it must accommodate for the 90 lb of weight that needed to be added to the corners. The final design for these joints uses six bolts to fasten all the members together and it has a tube welded to the top so that weights can be added (Figure 34). This type of joint offers a simple, easily built strong joint that fulfills all the requirements necessary.

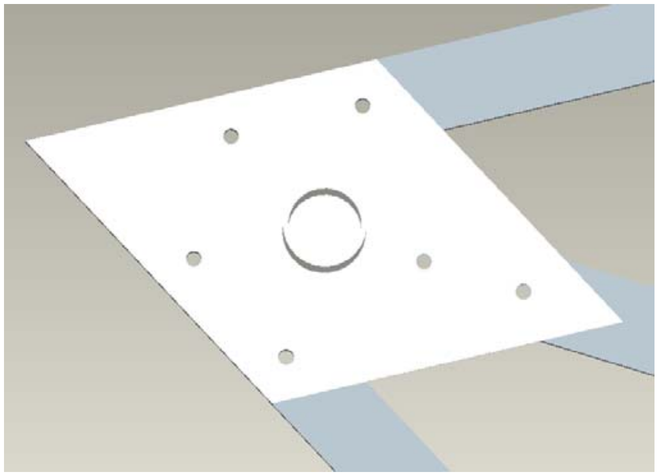


Figure 34: Windmill stand joints

Each cross bar has one piece of steel welded at a 45° to connect with the center post about 3 feet from the ground. By adding a joint at this location as well as at the ground, the center pole is securely fastened to the stand. If there was only one joint or the other, the center pole would not be fully constrained. The joints three feet from the ground use a 3” long, 1 ½” piece of square tubing that is welded at a 45° angle on the pole. This slides into the 2” square tubing used for the cross bars and the joint is bolted together with a single 3/8” bolt. The bottom joints between the cross bar and the center pole use pieces of 4”, 2” square tubing that has the top cut off of it. This allows holes to be hand drilled from the top so that two 3/8” bolts can be used. Note that all joints that use bolts could have been welded, however the stand had to be collapsible so it can be transported onto the roof after it was constructed. Bolted joints offer the best compromise for a strong joint and the components have the ability to be disassembled into smaller parts.

The final stand design is seen in Figure 35. The stand will be tested once everything has been integrated together. Obviously if the windmill should fall for any reason, it would fail its test and would require a new design. The windmill stand also must be painted with a rust resistant and weather resistant coating in order to protect it from being damaged.

Figure 35: Windmill Stand

Boiler

Nomenclature

L = length [m]
K = thermal conductivity constant [W/mk]
$\dot{q}$ = heat rate [W]
R = thermal resistance [Ω]
T = temperature [K]
η = efficiency [%]

Constants

$k_{polycarbonate}$ = .220 W/mk
k_{air} = .023 W/mk

Thermal efficiency of the boiler is an essential aspect of the system. Any loss of heat to the surrounding environment results in probable condensation and loss of clean water. The double pane boiler design uses air between the inner and outer chamber to insulate the inner chamber and reduce heat loss. Thermal efficiency is then evaluated for the double pane insulation, modeled as uniform temperature distributions. Using the thermal resistance derivation of Fourier's Law (Equation 18), the heat output through the two walls and insulated air is evaluated.

$$\dot{q}_{out} = \frac{\Delta T}{\sum R} \qquad (18)$$

Both the walls and the insulated air are modeled as constant temperature gradient walls. Therefore the thermal resistances can assumed to be conduction and are then evaluated for both cases (Equation 18a).

$$R_{cond} = \frac{L}{kA_S} \qquad (18a)$$

Equation 18a is then substituted into Equation 18 yielding Equation 18b. Notice there is a factor of two for the wall thermal resistance because there are two walls in the double pane system.

$$\dot{q}_{out} = \frac{T_1 - T_2}{2\frac{L_{wall}}{k_{wall}A_{wall}} + \frac{L_{air}}{k_{air}A_{air}}} \qquad (18b)$$

Heat loss is then calculated to determine the thermal efficiency (Equation 19) of the double pane system. The total heat rate, from Equation 20, represents the effective energy transferred to the water after the small losses through the double pane system.

$$\eta_{eff} = \frac{q_{out}}{q_{in}} 100 \qquad (19)$$

$$\dot{q}_{Tot} = q_{in} - q_{out} \qquad (20)$$

Similarly, heat loss is evaluated at the top and bottom of the boiler, the only difference being the lack of air and the extra wall insulation. Inserting the new conduction formula into Equation 21 then gives the heat loss from the top and bottom of the boiler.

$$\dot{q}_{out} = \frac{T_1 - T_2}{\dfrac{L_{wall}}{k_{wall} A_{wall}}} \quad (21)$$

Polycarbonate with a wall thickness of 1/8th inch was chosen for both the inner and outer chambers walls because of its ability to be bent in a metal bender without cracking or yielding. The ability to bend the polycarbonate in the u shape (Figure 36) reduces the total number of joints. The final product of this design only has two joints on opposite sides of each other, which can be bonded with acrylic epoxy and reinforced with two stainless steel bolts (Figure 37).

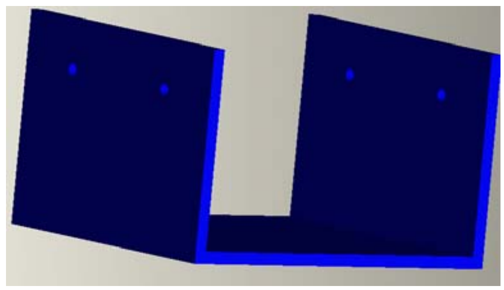


Figure 36: Boiler U-shape

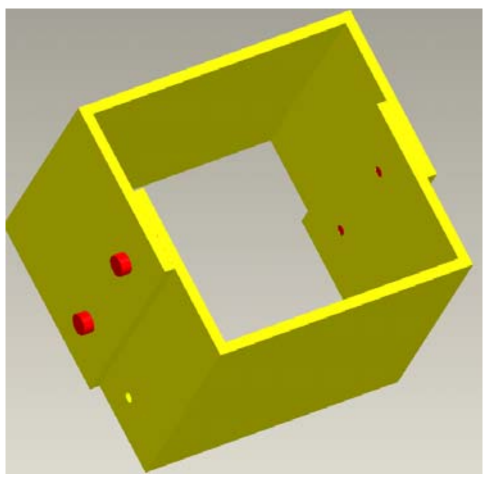


Figure 37: Boiler connection method

Sizing of the boiler was chosen for ease of use and optimization of coil arrangement. The inner chamber dimensions are 3" x 3" and the flow control mechanism is 2.5" long (Appendix A). The square set-up is optimal for construction and maintenance of the flow control. A maximum height of 2.5" is chosen to limit the distance the vapor has to travel while still allowing enough space for the flow control system.

From this design, thermal efficiencies of the 1.0" double pane and the top/bottom pieces can be compared (Figure 38). Given a power input of 200W, there are significantly higher losses from the top and bottom than from the double pane insulation sides. This calculation is done without accounting for insulation wrapping, which should significantly reduce the heat losses in these areas.

Part	Length of Insulation	Heat Input	Heat loss per side (q)	Total side heat loss	Total Power	% Loss
Sides	1 in (2.54cm)	200 W	0.32 W (x4)	1.28 W	198.72 W	0.64%
Top / Bottom	0.5 in (1.27cm)	200 W	7.50 W (x2)	15.00 W	185.00 W	8.11%

Figure 38: Thermal efficiency calculations

The top and the bottom of the boiler are also made with polycarbonate. However, increased widths are necessary for integration with the pipe fittings of the heat exchanger. Both the top and bottom are to be drilled and tapped with a 0.75” NPC pipe thread for connection to pipe fittings from the heat exchanger. A width of 0.5” was chosen to ensure a proper seal and give the boiler a strong base. In between the bottom of the chambers and the bottom piece connected to the heat exchanger, a 0.25” square piece of polycarbonate was cut for integration with the float control system (Figure 39). This piece has a 3/8 inch hole drilled in it to fit a similarly sized piece of Ultra-Strength Neoprene o-ring rubber with a hardness durometer rating of 50A. This piece is then sealed here as part of the float system, to create a seal when the aluminum plug comes in contact with it (Figure 40).

The top and bottom pieces are then drilled on the four corners with a 1/4" bit, with the top also threaded for a1/4” threaded rod (Figure 39). Four equal lengths (6”) of threaded rod are then cut and screwed into the top of the boiler to permanently connect the top of the boiler with the heat exchanger assembly. This allows the bottom of the boiler assembly to be removed for maintenance, while creating an easy assembly process by tightening the threaded rods.

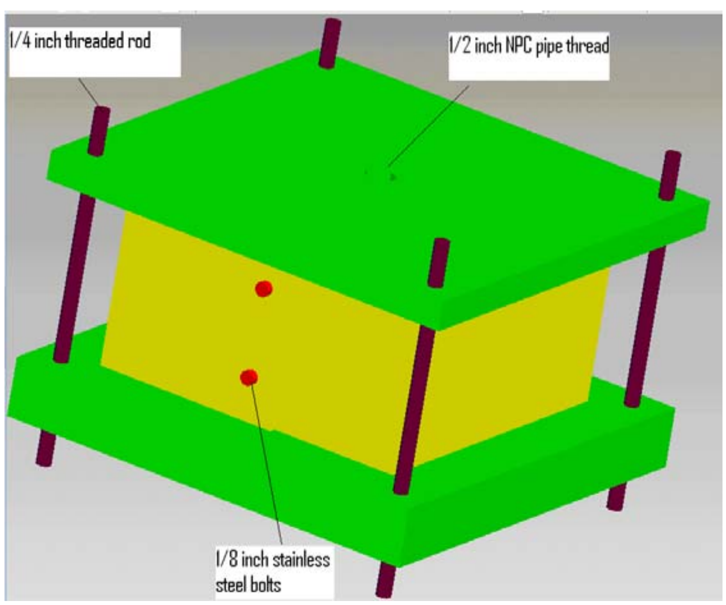


Figure 39: Boiler exterior design

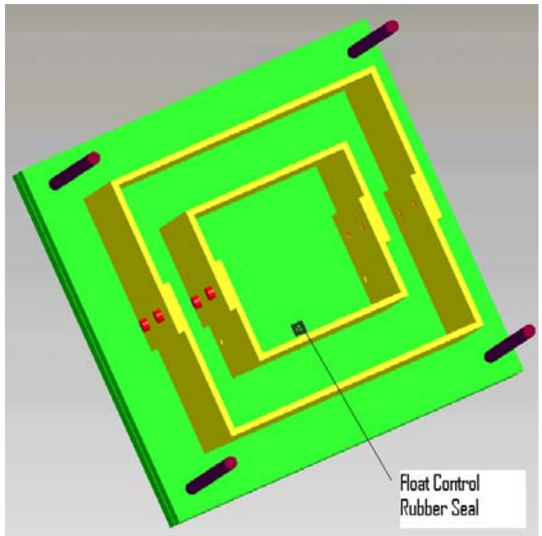


Figure 40: Interior design of boiler

Nomenclature

A	= inlet area [cm^2]
d	= diameter [cm]
F	= force [N]
k	= spring constant
g	= gravitational constant
x	= displacement [m]
L	= length [cm]
m	= mass [g]
P	= pressure [kg/ms^2]
V	= volume [cm^3]
ρ	= density [g/cm^3]

Constants

V_{alum} = .14593 cm^3
V_{air} = 3.67566 cm^3
$V_{submerged} \approx V_{air}$
g = 9.81 m/s^2
δ_{alum} = 2.7 g/cm^3
δ_{water} = 1 g/cm^3

The float control system to regulate water flow is evaluated for optimal lever arm positioning to ensure leak control. This is done by making the pivot point of the arm in a position so that when the float is raised the force down on the water inlet system is at least 5 times greater than the force from the water inlet pressure.

The buoyancy force from the float can then be calculated (Equation 22).

$$F_{float} = (\rho_{water} - \bar{\rho}_{float})(g)(V_{submerged}) \quad (22)$$

This force is then compared to the opposing force from the water inlet force. Pressure from the change in water height from the water feeding the system, to the inlet into the boiler creates a force upon the float control mechanism (Equation 23).

$$P = \rho(g\Delta h) \tag{23}$$

Next, the force from the water pressure is calculated (Equation 24).

$$F_{inlet} = PA \tag{24}$$

$$A = \pi\left(\frac{d}{2}\right)^2 \tag{24a}$$

By assuming a preset pivot arm length, the exact location of the pivot can be found (Equations 25 and 26). Equation 25 describes the sum of the moments about the pivot point and Equation 26 describes the total length of the pivot arm.

$$\sum M_P = -F_{water}L_2 + F_{float}L_1 = 0 \tag{25}$$

$$L = L_1 + L_2 \tag{26}$$

During construction of the float, it was found that creating a float which optimized inner volume while maintaining a minimum weight was quite difficult. Construction of the float either increased weight and minimized inner volume, or was not water proof and eventually failed at 212°F (Figure 41). Due to the difficulty of brazing sheet metal, creation of the bronze floats was very difficult. Float 1 (Figure 41) shows an example of a working float, however in order to effectively seal the float the inner volume was significantly reduced from what was desired. This decreased the buoyancy of the device, causing it to sit too low in the water, not producing the desired force down on the pivot. The second float is a good example of exactly how hard it was to braze the bronze together. Designs such as this one which require a lot of brazing were never water tight and always failed during testing. Float 3 went with away from the sheet metal, using a piece of cork coated with wax. This float functioned superbly, however the wax coat failed during testing and the cork absorbed water. The final float design went back to the bronze; however it was chosen to be joined with glue rather than brazing. Unfortunately the glue failed at a much lower temperature than boiling and the float failed.

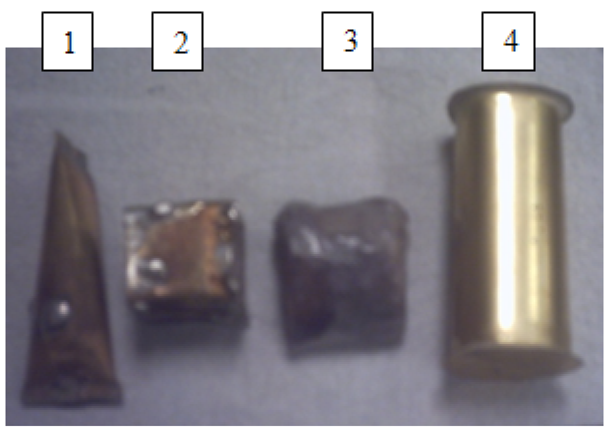


Figure 41: Float prototype

The float was then redesigned with the same water displacement concept in mind. This time however, instead of using buoyancy to counteract the weight of the float a small spring was placed in the boiler. In this design the float is constructed out of two ½” pieces of polycarbonate glued together with dimensions of 2.5x1.25. The spring force would account for the weight of the float, allowing the force displacement of the water to raise the float and plug the water inlet (Figure 42).

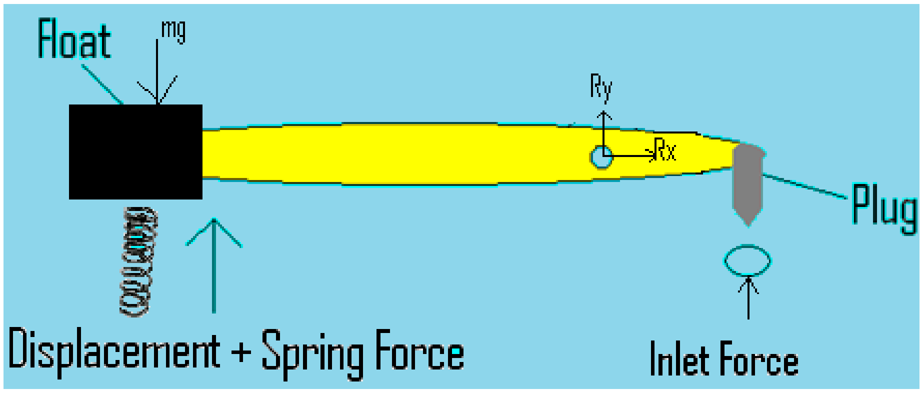


Figure 42: Flow control free body diagram

The final float design uses a comparatively large volume float to displace the largest volume of water, creating a large enough force on the plug to create a water tight seal (Figure 43).


Figure 43: Final float design

Once again the desired upward (float) force is five times greater than that of the water inlet force. To solve for the actual float force, the spring to counteract the weight of the chosen float needed to be sized and the spring constant evaluated. Several different forces are applied to the spring and the displacement is then measured to find the spring constant.

$$F = kx \tag{27}$$

After finding this spring force, the displacement of the spring is found at three pivot positions; fully closed, just about to open, and fully open. The Δx is then found to calculate the downward force of the pivot on the water inlet.

$$\Sigma M_{pivot} = -L_1(-mg + gV\rho + k\Delta x) + L_2 R_y = 0$$

$$\Delta x = \frac{L_2 R_y}{L_1 k} + \frac{mg}{k} - \frac{gV\rho}{k} \tag{28}$$

The initial reaction force Ry is the upward force from the float and it is to be five times greater than the water inlet force. Once the change in the x is calculated for the three states, a better understanding of the float is known.

Finally, the actual spring displacement is measured to find the non-theoretical float force on plug in the fully closed position. The solutions for the buoyancy force equations above are as follows:

$$\rho_{float} = .107194 \frac{g}{cm^3}$$

$$F_{float} = .03219N$$

The solutions for the pressure force equations are as follows:

$$\Delta h = .508m$$

$$P = 4983.48 \frac{kg}{ms^2}$$

$$F_{water} = .0888N$$

Solving the moment equation yields a pivot position of 2.149 from the left of the arm

	Length (cm)
Before Pivot	5.46
After Pivot	0.89
Total	6.35

Figure 44: Buoyancy calculations

Due to the redesign of the flow control mechanism, the pivot position previously calculated was used to choose a spring length and float volume to replicate the conditions of the buoyancy device. To do this the spring constant of the chosen spring was measured using a displacement vs. force experiment (Table 45).

Trial #	x (in)	mass (g)
1	.087	11.1
2	.174	21.7
3	.261	33.2

Figure 45: Spring constant evaluation

The change in x at the three pivot position is then found using Equation 27 (Figure 46). This concurs with expectations, because the spring is always compressed even at equilibrium, with the compression decreasing as the displacement force increases.

Pivot Position	Compression in x (in)
Fully Closed (1xforce)	.201
Fully Closed (3xforce)	.220
Fully Closed (5xforce)	.239
Almost Open	.293
Fully Open	.394

Figure 46: Change in x at the three pivot positions

The flow control mechanism was then tested and the actual displacement measured when the float was fully closed. From this the following forces were found (Figure 47)

F_{spring}	.314 N
F_{float}	.251 N
$F_{gravity}$	.491 N

Figure 47: Flow mechanism forces

This resulted in a force ratio of 6.425 (Figure 48), meaning the displacement force from the float was 6.425 times that of the water inlet force. This value more than exceeds that of the 5 times previously sought.

Volume of float (m^3)	Spring Constant (kg/s^2)	Water Inlet Force (N)	Downward Force (N)	Force Ratio
2.56 X 10^-5	49.05	8.877E-2	0.570	6.425

Figure 48: Flow mechanism force ratio

Heat Exchanger

The main purpose of the heat exchanger is to provide a tube long enough for the water vapor to give off the heat necessary to condense the vapor and turn it into a liquid. With this feature, the vapor will not be lost to the environment before it is collected. The other main goal of the heat exchanger is to use that heat energy which is being given off by the vapor and use it to pre-heat the contaminated water which has not yet flown into the boiler. The materials chosen for the boiler optimize this interaction. The heat exchanger has also been designed to be compact, flexible and leak resistant which provide for quick and easy construction. The dimensions and complete design of the heat exchanger can be seen in Appendix A.

Nomenclature

A = cross sectional area of flow [m^2]
c_p = specific heat [kJ/kg K]
d_i = diameter (or equivalent diameter) of tube holding respective fluid [m]
ΔT = change of temperature of water [°C]
h_{fg} = enthalpy required to change water to vapor [kJ/kg]
h_i = convection coefficient [W/m^2K]
h_{total} = total enthalpy required to boil water from room temperature [kJ/kg]
K = thermal conductivity constant [dimensionless]
$\dot{m}$ = mass flow rate of water and water vapor [mL / hour]
Nu = nusslet number [dimensionless]
P = power [W]
$\dot{q}$ = rate of heat transfer to the water [kJ/sec]
r_i = radius of tube holding respective fluid [m]
ρ = density [kg/m^3]
v = velocity [m/s]

Constants
Nu = 3.66 for laminar, fully developed, uniform T_s
h_{fg} = 2258 kJ/kg
K = See Appendix F

The overall goal of the heat exchanger equations is to determine an appropriate length for the heat exchanger. The length required should be long enough to condense the vapor coming out of the boiler (so that clean-water collection is possible with a device that is open to the air), but as short as possible so that space constraints are taken into consideration and so that money is not wasted on materials. A secondary goal is to make the heat exchanger long enough to heat the room temperature water as warm as possible in order to make the boiling process produce a faster flow rate.

Many problems arise when considering heat transfer equations that deal with phase changes. When deciding on constants and cp values, all values have to be estimated using educated guesses. In order to estimate the approximate length of the heat exchanger, the maximum amount of heat the vapor can release is determined. The overall enthalpy required to raise water from room temperature to 100 degrees Celsius *and* change the phase from water to vapor can be calculated by using Equation 29. (See Appendix F for estimation of cp value).

$$h_{total} = c_p \Delta T + h_{fg} \quad (29)$$

The mass flow rate of both the water and the water vapor will be regulated in the float control system of the boiler. For that reason, Equation 30 shows the average mass flow rate of *both* the water and the water vapor.

$$\dot{m} = \frac{P}{h_{total}} \quad (30)$$

Using the mass flow rate and the enthalpy given off from the vapor as it turns to liquid, the rate of heat transfer to the water can be calculated (Equation 31).

$$\dot{q} = \dot{m} h_{fg} \quad (31)$$

Using the rate of heat transferred to the water calculated in Equation 31 and the thermal resistance derivation of Fourier's Law, the total resistance can be calculated (Equation 32).

$$\dot{q} = \frac{\Delta T}{\sum R} \quad (32)$$

The total resistance is calculated by adding the resistances of the inner wall, through the wall, and the outer wall of the copper pipe dividing the water and the water vapor. For the inner and outer sections (not the through section) of the copper wall, the convection resistance is used (Equation 32a).

$$R = \frac{1}{h_i A_i} \text{ for convection} \quad (32a)$$

The convection coefficient is calculated using the Nusslet number and estimated thermal conductivity constant along with an estimated diameter (which takes into consideration the copper tube which takes up considerable flow area from the water) (Equation 32b). The reasoning behind the estimations for these values can be seen in Appendix F.

$$h_i = \frac{NuK}{D_i} \quad (32b)$$

For the resistance through the wall, the conduction equation for resistance is used (Equation 32c).

$$R = \frac{1}{kA_i} \text{ for conduction} \tag{32c}$$

For both the convection and conduction resistances, the surface area is calculated using Equation 32d. This particular step is very important because this is where the total length of the system is calculated (as it is the only unknown).

$$A = 2\pi(r_i)L \tag{32d}$$

Although the equations mentioned previously are useful, the educated guesses that were made are not necessarily 100 percent correct. To provide another option for determining the length of the heat exchanger, the computational fluid dynamics package, Fluent, can be used to model the temperature flows as well. By seeing when the temperatures of the substances even out, an estimation of the length of the heat exchanger can be made.

Although some educated guesses are taken in Fluent, they are different from the estimations made in the previous equations. One calculation that needed to be determined previous to creating the Fluent model is the velocity of each of the fluids (Equation 33).

$$v = \frac{\dot{m}}{\rho A} \tag{33}$$

In this equation, the area calculated uses the cross-sectional area of the tubes (Equation 33a). The equivalent radius used for the liquid water is similar to the equivalent diameter used in Equation 32b.

$$A = \pi(r_j^{\ 2}) \tag{33a}$$

The basic elements of the grid used in the Fluent model can be seen in the figure below (Figure 49).

Figure 49: Solid sections of the heat exchanger

The results from equations 29 to 33a are displayed in Figure 50.

Start Temp. of water (° C)	Final Temp. of water (°C)	Total Enthalpy (KJ/kg)	Rate of Heat Transferred (kJ/kg)	Length of tube needed to condense vapor (m)
Calculations				
20	99	2588	0.17	19
20	80	2509	0.18	18
20	60	2425	0.19	18
60	80	2342	0.19	17
60	99	2421	0.19	18
97	99	2266	0.20	16

Figure 50: Tube length calculations

The fastest heat transfer rate and shortest heat exchanger length occur when the temperature difference is the smallest. Regardless of the temperature difference, the overall temperature rise shortens the necessary length of the heat exchanger. More specifically, it is important to note that all of the calculated lengths occur around the same distance of approximately 17 meters.

The Fluent model shows a different solution to the problem. Using the second order-upwind method, energy equation, and a 10^{-6} value for residual convergence, it was found that the heat exchange was only taking place within the first two meters of the heat exchanger. As seen in Figure 51, the temperature of the vapor decreases down the length of the heat exchanger (which represents 2 meters).

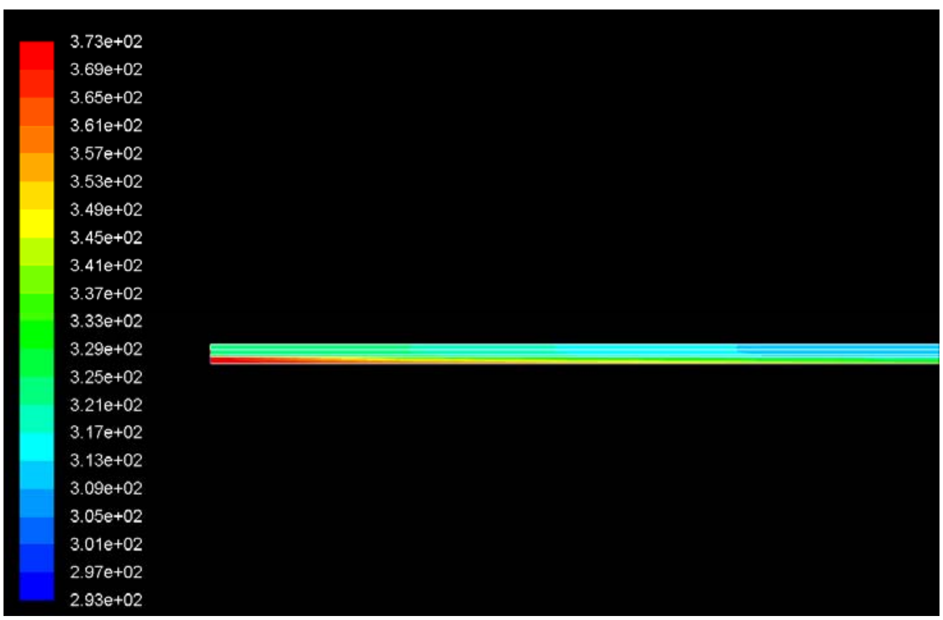


Figure 51: Contour plot of heat exchanger in Fluent

At the zero-meter mark in Figure 52 the vapor enters the heat exchanger and the warmed water exits. The vapor starts to cool significantly before the length of 2 meters. (Axis 1 represents the centerline of the vapor tube.)

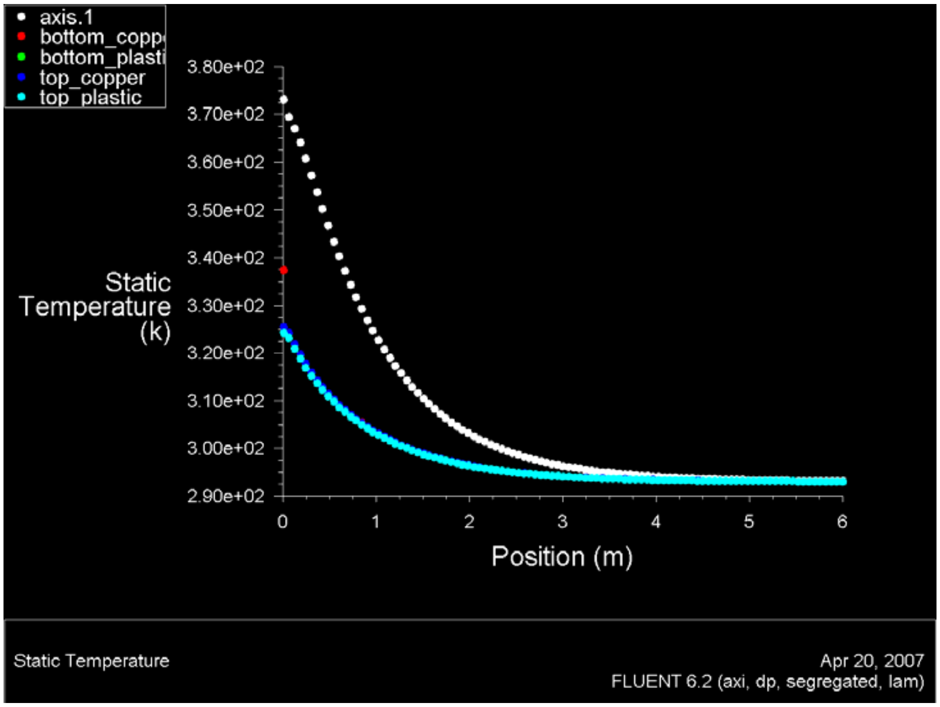


Figure 52: Temperature diagram of water and vapor along tube

The Fluent model does not take into consideration the phase change of the vapor and is therefore not entirely accurate. The model assumes only water vapor properties throughout the vapor zone; therefore the water vapor at any temperature under the boiling temperature is modeled as having water vapor properties. There is no simple equation which could give a good approximation of how much vapor actually condenses and how much does not condense at any given location. However, this model is accurate in that it takes into account the correct heat transfer properties of the tube walls as well as heat transfer properties of the water.

The two methods of calculations provide a very different final length for the heat exchanger. In cases like this an engineer is simply expected to make an educated decision. The Considering both sets of calculations, the total length of the heat exchanger is chosen to be about 3 meters. The outer tube is made of 1inch cross woven rubber-like spa tubing. The inner tube of the heat exchanger is made of both solid and flexible 0.5 inch copper tubing. To construct the heat exchanger solid tubing is soldered to flexible tubing intermittently. When all sections are completely pulled straight, the outer spa tubing can be slipped over the copper with ease. The cross woven aspect of the spa tube makes a scrunching motion possible, which allows for the fittings on the end of the copper tubing to be soldered as well. To connect the heat exchanger to the contaminated water chamber and boiler, barbed fittings are inserted into PVC fittings with ¾ inch threaded end. For the sections of the heat exchanger where the spa tubing is connected directly to straight PVC, regular PVC fittings with *blue weld-on 16* glue to hold it together.

The overall configuration of the heat exchanger with the contaminated water chamber and boiler can be seen in Figure 53 (See Appendix A for complete dimensional drawings of heat exchanger).

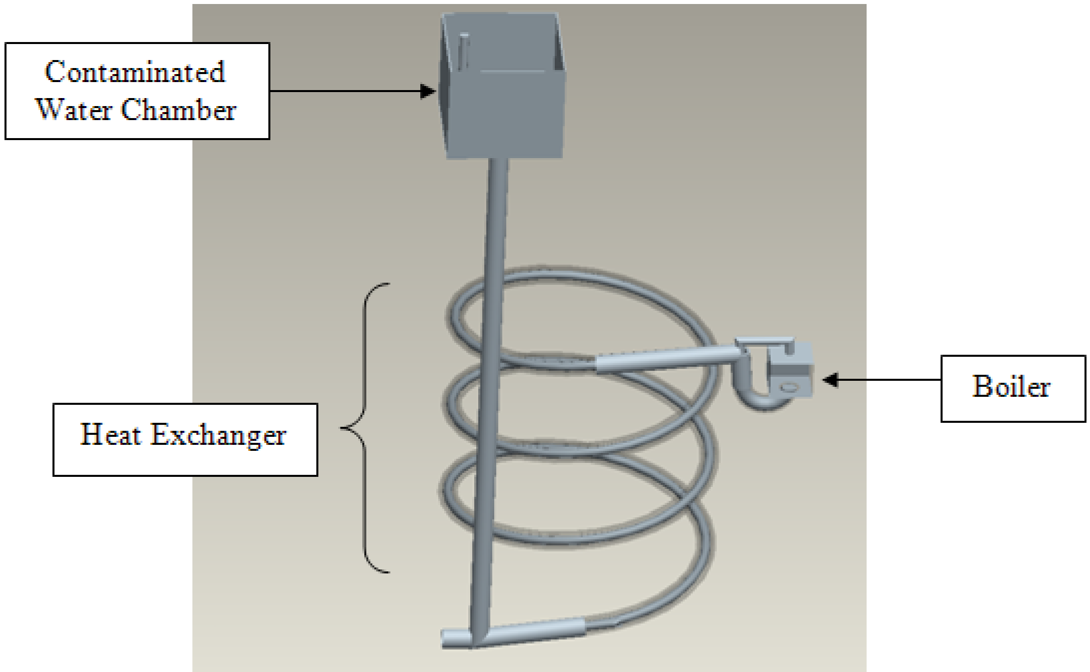


Figure 53: Overall heat exchanger configuration

Testing and Evaluation

ASME Design Competition

Testing of the human powered interface took place during the ASME design competition that took place in March of 2007. The test showed that the integrated system was capable of producing clean water from a still. This prototype was tested successfully at the design competition. This fully integrated test verified the functionality of the boiler and heat exchanger system.

Windmill Generator

Testing of the windmill includes verification that the circuit was hooked up correctly and the windmill is operating correctly. The circuitry is tested by checking the resistance of the system when the stop switch is in the on and off position. When the stop switch is in the off position, the windmill is short circuited and the resistance read 25 KΩ from the internal regulation circuit of the windmill. When the stop switch is in the on position the resistance read 0.6 Ω, which is the chosen resistance of the heating element (and the path of least resistance). These tests confirmed that the stop switch circuit is fully functional and connected properly.

The operation of the windmill is tested and monitored for 1 full week. A voltmeter is connected to the output leads of the windmill. Power is confirmed to be produced from the windmill when the rotor is spinning. This tested is accomplished using hand radios to communicate between a person on the roof with the windmill and a person in the lab with the purification system and voltmeter. It is confirmed that the voltmeter read zero when the windmill is not spinning and then the voltmeter read positive voltage when the rotor of the windmill is spinning. This test verified that the operation and power production of the windmill is working correctly.

When connected to the purification system, the power output of the windmill proved to be unreliable and does not produce enough power to boil water. The windmill does not receive enough wind to spin consistently and did not receive the expected average wind speeds that San Diego records. Location and height of the windmill seem to be the key factors preventing the expected wind speeds.

A hand held anemometer was purchased from La Crosse Technology, to investigate this lack of wind. It is confirmed with extensive testing using the anemometer that the location where the windmill is mounted receives on average 5.9 mph. This is not adequate for our system because the necessary start up speed of the windmill is 7 mph. Additionally, an average of 5.9 mph is more than 2 mph less than reported average for San Diego, 8 mph. When considered power output, wind speed has a cubic effect and if the windmill is receiving less than 75% of the average wind speeds it greatly reduces our power output potential. This investigation has found that 25% of our wind speed is being obstructed.

With further investigation, a boundary layer analysis it can be shown that the windmill is inside of a large boundary layer that is greatly reducing wind speeds. In this analysis the roof tops and tree tops between Loma Hall and the west side of campus (most common direction of wind) are considered to be a flat plate. A seventh power derivation of external turbulent flow is used to approximate the height of the boundary layer.

$$\frac{\delta}{x} = 0.382\left(\frac{\upsilon}{Ux}\right)^{1/5}$$

$Where:$

$\delta = height\_of\_boundary\_layer$

$x = horzontal\_dis\tan ce$

$\upsilon = vis\cos ity\_of\_air$

$U = unobstructed\_wind\_velocity$

This equation is used with the assumptions that the unobstructed wind speed is 8m/s, the air viscosity at 72 ®F is 1.66E-4 ft^2/s, and the distance from Loma Hall to the west side of campus is 2040 ft (measured with a pedometer). It is found that the height of the boundary layer with these conditions is approximately 16 meters. In order to receive unobstructed wind speeds and produce enough power the windmill needs to be mounted above this boundary layer. Currently the windmill is mounted at a height of 5.3 meters. As a result, the wind speed at this height, inside of the boundary layer, is obstructed and reduced greatly. Seeing as how a 16 meter stand on the top of Loma Hall would be very difficult to accomplish, it is evident that the windmill needed to be mounted in a different location. Unfortunately, the windmill stand did not meet its two main requirements of a location and a height at which the air flow is not disturbed. However, it is believed that had the windmill been mounted at a location and height that did not have obstructed wind, it would produce adequate power to boil water.

In order to test the purification system and attempt to create clean water, it is suggested that a different power source is used. The purification system can be plugged into a variable power supply that simulates the power output seen in the testing of the windmill at average San Diego wind speeds.

Windmill Stand

The windmill stand testing consisted of assembling the stand on the roof and seeing if it could withstand the forces applied to it and to see if the wiring inside of the stand would work. In conclusion, the stand was able to fully telescope to the desired height of 16 ft and withstand the wind speeds that existed from July18th till July 26th. Although these wind speeds were the lowest that the windmill could possibly encounter, the windmill was designed to be able to withstand wind speeds of over 100 mph. The wiring within the stand has functioned properly and the necessary lengths of extra wire needed for the stand to telescope were correct. The only problem with the wiring was it was not very flexible and it was very difficult to move through the stand when the windmill was raised. One adverse effect of the testing was the components of the stand rusted within a day of being painted. This did not affect the function of the windmill but may in the future if the rust is not contained and neutralized.

Boiler

Once construction is finished a visual inspection of the boiler, with particular attention paid to the inlet from the heat exchanger, will be performed to ensure the system is free of leaks. Water is left in the system for five days and the visual test showed no loss of water from the system.

Heat loss was then tested through temperature measurements taken at a variety of times. Water inside the boiler is brought to a boil and then heat input is stopped while temperature measurements are taken. It was found in three identical tests that the boiler lost 9 degrees C in approximately 6 minutes, yielding a heat loss of 1° C per minute. Complete heat loss of 100°C down to room temperature, 20°C, would take approximately 53 minutes from initial heat input removal. This rate was found to be too high for the intended purpose of receiving minimal heat input over a long period of time. Meaning temperature increase from low heat input would dissipate before the water in the boiler rose to the required 100°C. This loss is deemed to be unacceptable and results from the lack of insulation on the top and bottom of the boiler. More insulation is then necessary to ensure proper thermal insulation and long term use.

The float control system is then evaluated in two different scenarios, the first being when the water is boiling and the second when it is not. Water is filled in the entire system, with the dirty water input 20 inches above the boiler input for maximum water pressure at the boiler input. The flow rate is then monitored by measuring change in water height vs. time. If the boiler maintained its maximum designed height level in both scenarios the test was considered a success.

The float control was found to work perfectly when the water was not boiling, although the flow rate was slightly lower than expected. Once the water began to boil consistently over long period of time, it was found the float did not behave as expected. The Nichrome resistance wire was found to be so effective, at high power input levels the water boiled faster than the float control mechanism would allow. This resulted in decreased water levels and eventually forced the system to be shut-down once the water level dropped below the resistance wire. The float control system was viewed to be a partial success. At maximum power input levels the water inflow was not as great as the water loss to vapor, resulting in a decrease in water level. However the system performed perfectly at lower to no power input levels.

Heat Exchanger

In order to ensure a working heat exchanger, leak tests were performed at each joint – both during manufacturing and after months of handling. To perform these tests, water is pushed through the system at a particular point and left there for over 24 hours. If at any point during that time a drop of water falls from the system, the leak is properly fixed using either 'Weld-On #16 clear solvent cement for joining Acrylic' or 'Weld-On blue glue for joining PVC'. This test was performed on all joints numerous times throughout the semester and all leaks were fixed before final testing of entire integrated system.

During construction of the heat exchanger, all soldered joints are tested before insertion into the outer spa tubing. By running water though all of the copper tubing prior to final construction, each joint can be carefully examined and re-soldered if need be. Although this test did find some leaks, all problem areas were fixed before further construction.

The outer tubing and connections in the heat exchanger are tested after full construction of heat exchanger, but before integration of entire system. Throughout the term of the project, leaks are found and fixed. (For the ASME competition there was a lot of handling as the heat exchanger and its components were put to the test.) Even after extensive handling most of the joints hold up perfectly. The few joints which still need attention after extended periods of time can easily be repaired with more PVC glue.

To test the actual activity of exchanging heat, the temperature is taken at half-meter intervals along the heat exchanger. This test is performed at the exact instant the water in the boiler reaches boiling temperature (100°C) and each 15 minutes thereafter. As seen by Figure

54, the temperature reads room temperature in the heat exchanger as the water just reaches boiling (because no vapor has yet to leave the boiler.

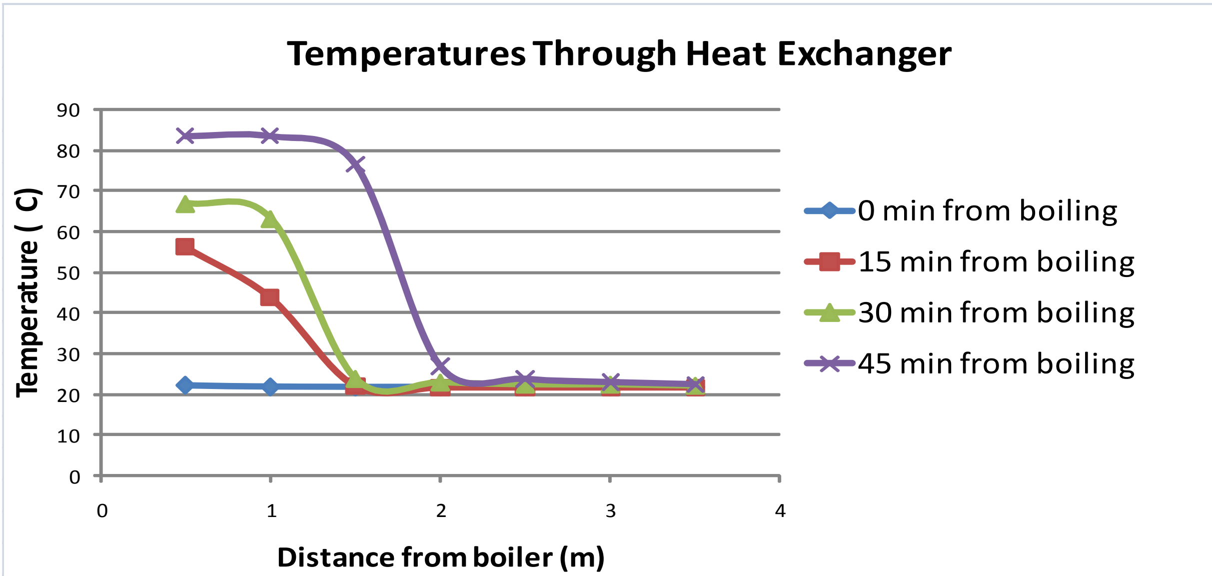


Figure 54: Heat exchanger temperatures

Does Design Meet Design Requirements?

ASME Design Competition

The prototype taken to the ASME design competition was successful in producing potable water from the still. No filters were used and the system was entirely human powered. Also, the prototype fit the size and weight requirements specified by the ASME competition rules.

Windmill Generator

The windmill generator purchased from Southwest Windpower provides an efficient way to convert renewable wind energy into electricity for the water purification system. It is a small windmill designed for home use and has necessary protection from environmental factors such as rain, storms, high winds, and corrosion. It is properly wired with a kill switch, fuse, and safety regulators inside of the windmill to meet all safety requirements. Based on the power curve and lab testing, the generator provides enough electricity to boil water at average San Diego wind speeds. The windmill is relatively inexpensive when compared to similar products and was purchased at a discounted non-profit rate through ASME. It also meets the requirements of being small and lightweight, only 13 lbs. It has easy step by step assembly and operation instructions.

Windmill Stand

One of the biggest design considerations of the windmill stand was whether or not it could withstand a horizontal load of 150 lb. The testing did not have wind speeds that would produce these types of forces but the stand was designed to withstand this type of loading. Under the wind conditions that did exist during testing, the stand was successfully in providing a rigid base for the windmill.

A problem that we ran into with wind generation was the windmill was not tall enough. This did not fulfill the design requirement of the windmill be taller than any obstruction so it had a clean airflow. The windmill was higher than any of the structures on the roof but it was not high enough to be outside of the boundary layer created by Loma itself. Considering that the windmill had to fit the aesthetic requirements of University of San Diego, the height of 16 ft above the building was the highest it could have been built before it was extremely noticeable. This height also makes it possible for a human to change the height of the windmill without any equipment other than a wrench. The windmill does see some wind at 16 ft, however a boundary layer calculation shows that the windmill must be 50 ft above the building in order to receive a completely unobstructed airflow. Once again, it was the best possible solution given the parameters of the project. Nevertheless, being this height along with being painted, the stand fulfilled the necessary aesthetic requirements. Overall, the windmill stand satisfied most of its design requirements with a few exceptions.

Boiler

The boiler is designed to eliminate the use of filters, pressure, or friction to purify and vaporize contaminated water. The boiler effectively allows current to be run through a heating element to heat water, eventually vaporizing it and eliminating all contaminants. A double pane insulation system is designed to minimize the amount of heat loss to its surroundings, however significant losses are still found out of the top and bottom. Therefore additional insulation is added to the boiler to minimize energy loss.

The entire design is made as small as possible, to minimize the water level to heating element ratio, while still allowing enough space for construction and maintenance. This increases heating element efficiency, having the resistance wire heat the minimum amount of water possible. Finally this system has its vapor outlet on the roof, to not hinder the path of the vapor to the heat exchanger. Small condensation does occur away from the circular outlet to the heat exchanger. However, these losses are minimized once the temperature in the inner boiler chamber increases.

The flow control mechanism is designed to regulate the water level within the boiler to maximize the water level to heating element ratio. The preset water level is slightly above the top of the heating element to ensure water is covering the heating element at all times, to prevent heating of the air within the boiler and possible damage. From testing however, it is found the actual water level is slightly higher than desired, decreasing the heating element efficiency.

All components within the boiler are constructed from non corrosive materials to minimize degradation. Similarly, all components of the flow control sub-assembly can withstand the boiling temperature of water, approximately 212°F.

The heating element chosen for this design is Nichrome resistance wire. This wire is permanently mounted in the boiler to prevent accidental contact to any surface producing unwanted damage. The position placement however, is slightly off-center to account for the flow control mechanism. This decreasing heating efficiency and does not meet of the design goals. The optimal wire resistance is found through testing at the expected wind speeds as seen later in the testing section.

Heat Exchanger

The main goal of transporting dirty and clean water separately is obtained through the design of the heat exchanger. As seen in Figure 55, the PVC T-joint at the top of the boiler is designed to allow the vapor to escape and continue on its unobstructed path downward to the clean water chamber, while the dirty water can travel in the opposite direction through to the inlet/bottom of the boiler.

= Spa tubing holding contaminated water

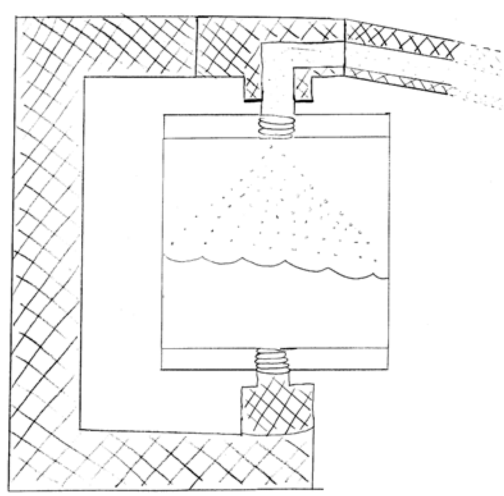


Figure 55: Close-up view of boiler connections to heat exchanger

The copper tubing used as the solid barrier between the clean vapor and the contaminated water is one of the most thermally conductive, solid materials on the market today.

Based on the temperature testing that was done on the heat exchanger (Figure 55), it is evident that the contaminated water was in fact pre-heated by the clean vapor and that the energy was being conserved throughout the system.

Through production of the previous (old) heat exchanger, it is found that production and manufacturability is much easier when you have as little joints as possible. Figures 56 and 57 show how the new design for the heat exchanger allows for clear visibility as well as reduces the number of joints created by manufacturing.

Figure 56: Old heat exchanger

Figure 57: New heat exchanger

Based on the outcome of the leak tests, it is determined that the heat exchanger meets the "no leak" requirement.

Accomplishments

ASME Design Competition

- Produced enough power to boil 112 mL of water
- Provided a platform which was collapsible and ergonomic
- Verified the functionality of the heat exchanger
- Verified the functionality of the boiler

Windmill Generator

- Optimized power efficiency
- Tested various resistors and sized electrical wire
- Produced power curves for windmill when connected to 0.6 ohm resistor
- Created a wind speed chart based on voltage output
- Verified proper wiring of windmill through stand into stop switch and into L311
- Verified proper operation of windmill
- Created easy plug-in interface between windmill and purification system
- Verified wind speed versus voltage chart, with data collected from an anemometer
- Investigated probable causes for lower than expected wind speeds

Windmill Stand

- Able to withstand 115 mph of wind.
- Has the ability to adjust the height of the windmill.
- Painted and located so that it fits aesthetic requirements.
- Constructed in the Loma basement and was able to be transported to the roof for assembly.

Boiler

- Leak free
- Minimized inner area to optimize heating efficiency
- Houses float control mechanism
- Can withstand boiling temperature environment
- Regulates the water to a preset level
- Provides a simple vapor outlet

Heat Exchanger

- Transports both dirty and clean water separately from dirty water chamber to boiler to clean water chamber
- Preheat contaminated water
- Keeps as much energy as possible within the system

- Easy to manufacture
- Leak resistant

Future Work

ASME Design Competition

This design was used as a prototype for the 2007 mechanical engineer senior design project. The human powered interface will be exchanged with a renewable energy source. The boiler will be modified to improve thermal insulation. The heat exchanger will be more extensively tested and modified to increase efficiencies.

Windmill Generator

Future work on the windmill generator includes long term testing, relocation of windmill, and testing during different times of the year. The windmill should be tested for a longer period of time to check the durability and long-term power output, kWh/month. The location of the windmill is currently inside a boundary layer and receives very little wind, only occasional gusts capable of reaching the start up speed. It is recommended that future tests be conducted at a different location where the wind speed is unobstructed. Finally, the windmill should be tested at different times throughout the year because of the variation in average monthly wind speeds. Unfortunately, July has the slowest average wind speeds for San Diego and it is predicted from historical trends that other months in the year will have higher average wind speeds.

In addition, it is suggested that the purification system be connected to a different power source to test the system and attempt to produce clean water. The purification system can be plugged into a variable power supply that simulates the power output seen in the lab testing of the windmill at average San Diego wind speeds. This will allow the boiler, float control, and heat exchanger to be tested for proper operation. Also, data on the temperatures along the heat exchanger, and water output flow rates can be collected and analyzed to quantify the overall performance of the COOL Water Purification Project. Lastly, the cleanliness of the output water can be tested (pH and nitrate levels) to verify that it is in fact purified as it travels through the system.

Windmill Stand

The biggest concern about the windmill is that it is rusting already. The best preventative action would be to repaint all the components of the stand within a year so that the rust does not spread. Another problem that needs to be taken into consideration is a different gauge wire to connect to the windmill. The amount of effort it took to raise the windmill was substantial and a small gauge wiring would accommodate that problem.

Boiler

The boiler/float control assembly was found to be slightly less durable than designed. Materials and design specifications should be modified to ensure longevity of the float control mechanism. Rust, waste, and sturdiness problems were found from long term use of the boiler system. Design of a maintenance schedule and instruction manual could reduce the chance of failure due to long-term use.

Heat Exchanger

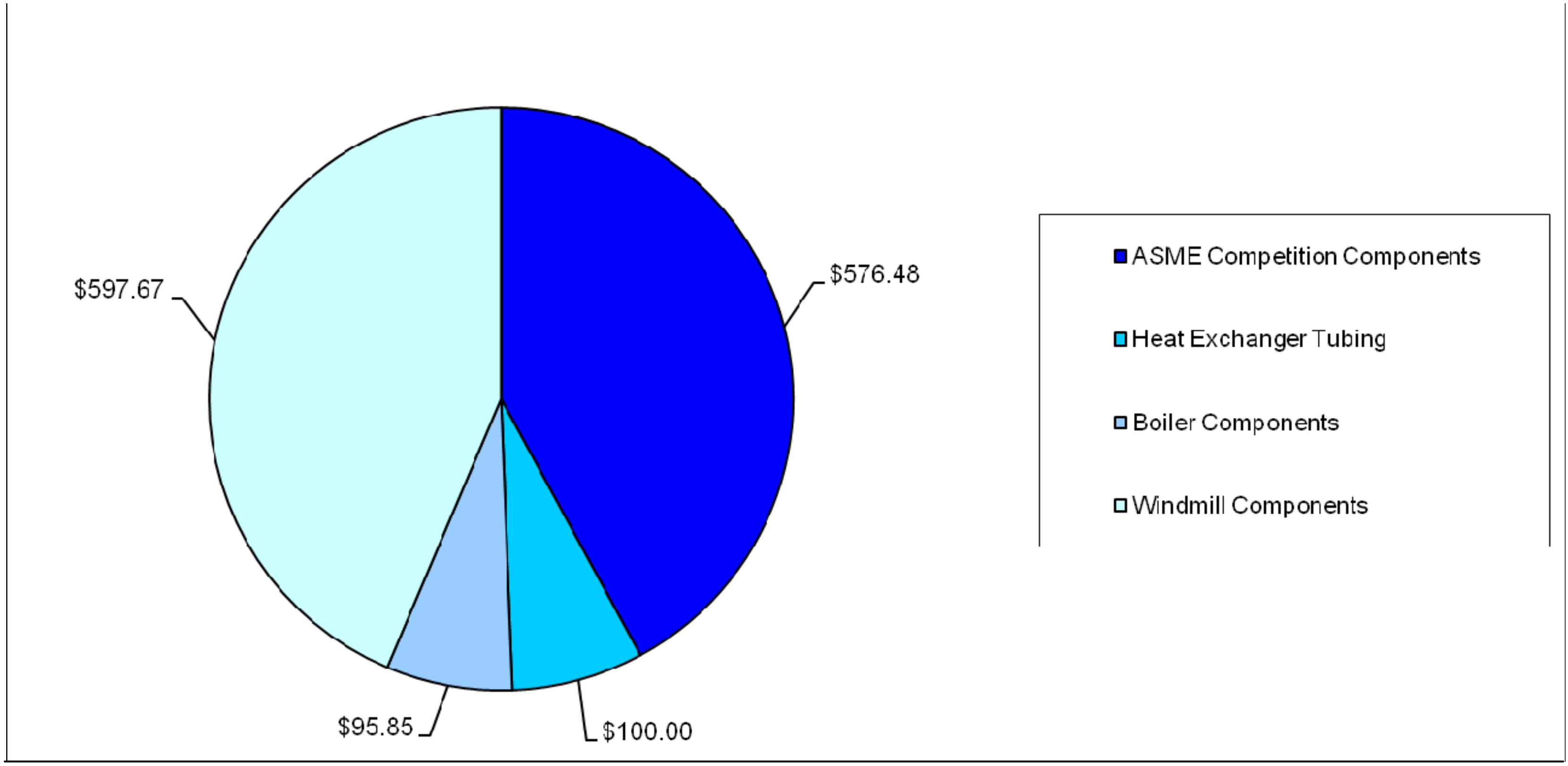
Although the heat exchanger succeeds in accomplishing its design requirements, there are some things which could be improved that we not foreseen to be a problem. The copper tubing and tin solder seem to create a bit of rust residue towards the bottom of the heat exchanger. In the future, a less rust-affected metal could be used as an inner tube (such as stainless steel). Although a rounding bender would need to be used to create the bends instead of just being able to bend the tube by hand.

Also, in the future, it would be worth testing the heat exchanger for much longer periods of time and seeing how the system would react if the vapor did reach the 'overflow coils' in the top of the contaminated water chamber. On the same token, it would be interesting to see how the system would be affected if the heat exchanger was shorter by a meter (hypothesis based on length of heat exchanger needed to condense vapor).

Water Purity

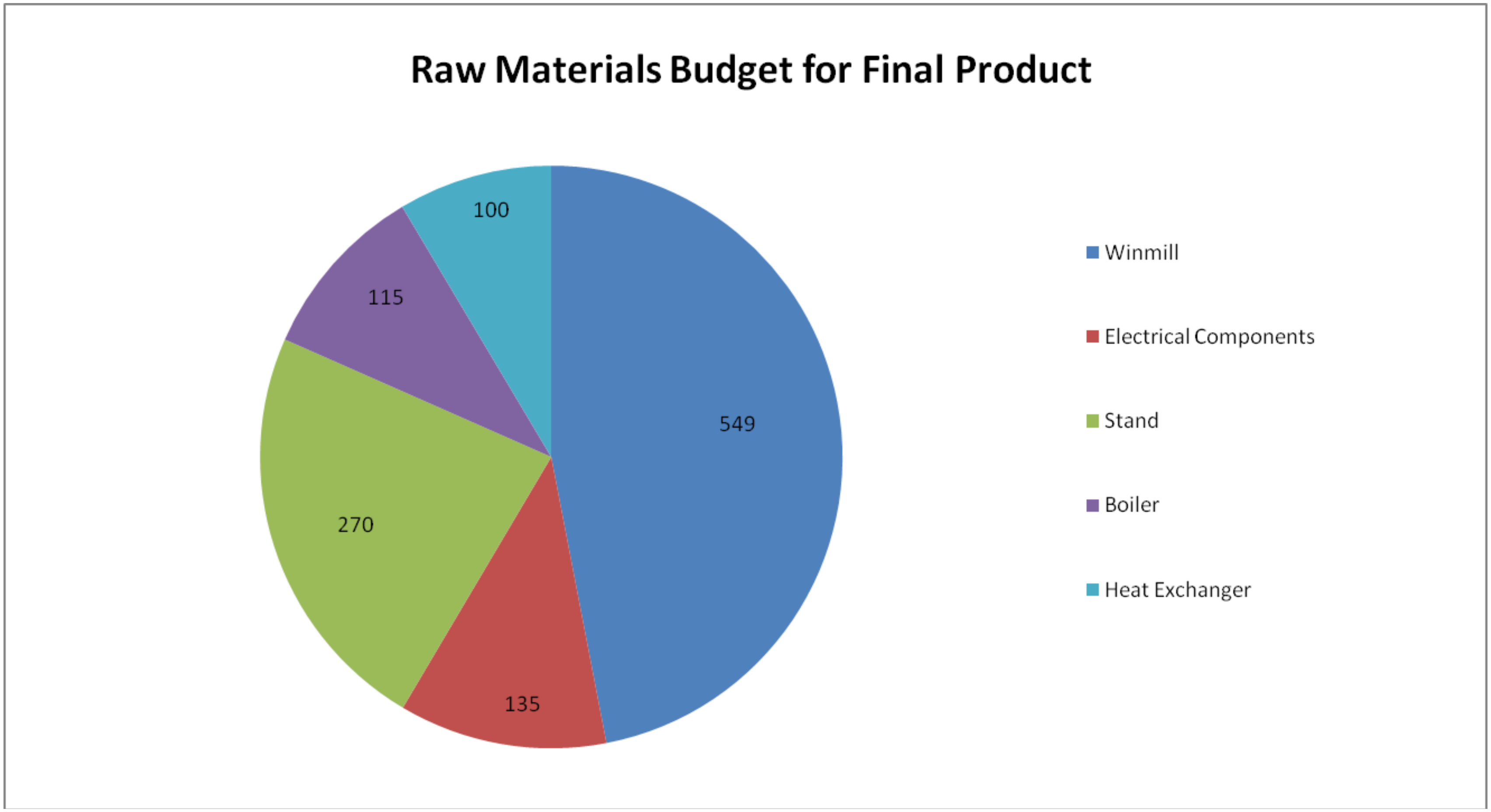
Water purity tests should be performed in conjuncture with the Universities Chemistry department to determine the cleanliness of the resultant water. pH tests which measure the acidity or alkalinity of a solution should be performed. Solutions at 25 °C with a pH less than seven are considered acidic, while those with a pH greater than seven are considered basic (alkaline). Another common water purity test is a nitrate test, which determines the presence of a nitrate ion in a solution. While nitrate is much less toxic than ammonia or nitrite, levels over 30 ppm of nitrate can inhibit growth, impair the immune system, and cause stress. Finally a microscope analysis must be performed to determine the presence of impurities before and after water purification.

Budget



This budget displays the overall expenses of the COOL Water Purification team, but does not include departmental expenses to make the windmill installation permanent. The overall budget was planned to include the design expenses for the ASME design competition as well as adapting the purification system to a renewable energy source, wind power. The ASME expenses include the costs of the prototype and competition fees. The rest of the sections display purchases made this summer including the Air-X Marine windmill and its components, as well as the new boiler components and rebuilt heat exchanger tubing. Several materials were reused during the summer to save money and time. All major wiring, steel, and paint for the windmill are being purchased by the engineering department of San Diego, in order to make the installation permanent and aesthetically pleasing.

Raw Materials Budget



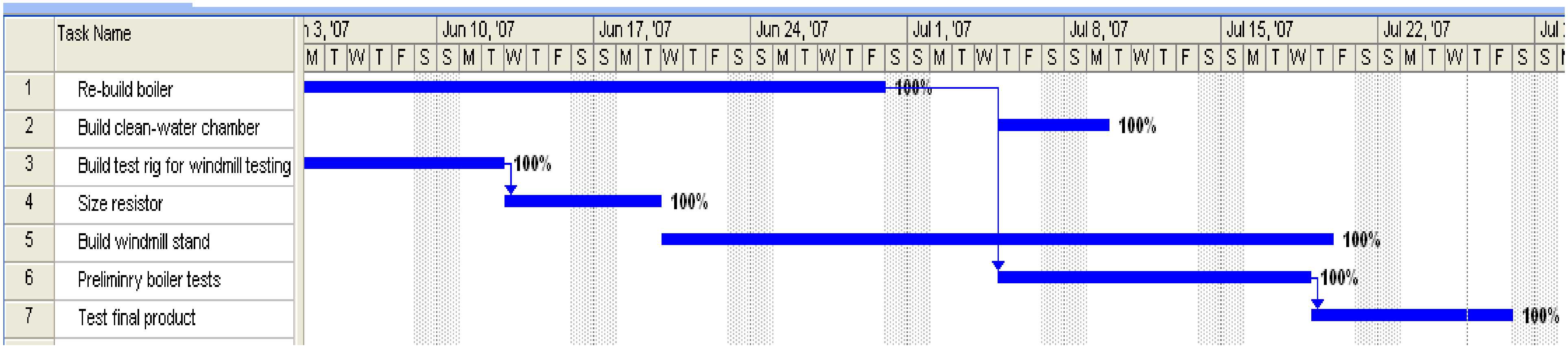
This budget displays the expenses of the raw materials used in the final product, but does not include cost of labor. The overall costs include the purchase of the windmill as well as the costs from each group member's specific task. The total cost of the raw materials is $1169. When these materials are purchased in bulk for a larger scale production the cost of raw materials per product is predicted to decrease significantly.

Economic Analysis

Material	Cost reporting rate	Total ($)
Mild Steel	$0.70 / lb	110.44
Copper	$1.06 / inch	4.24
Brass	$4.00 / lb	.02
Spa Tubing	$.13 / inch	31.20
PVC	$.04 / inch	.20
PVC fittings	$.30 / fitting	3.00
Plastic Barb fittings	$1.00 / fitting	2.00
1/8" thick Polycarbonate	$.08 / in^2	44.70
1/2" thick Polycarbonate	$.16 / in^2	49.28
	Material Total	245.08
Operation		
Labor (all activity, including assembly)	$35.00 / hr	36,400.00
CNC Machine (time)	$70.00 / hr	70.00
Computer aided operations	$70.00 / hr	350.00
Welds, per linear inch	$0.35/ inch	21.70
Saw or tubing cuts, per inch diameter	$0.40/ inch	7.60
Tube bends	$0.75 / bend	2.25
Non-metallic cutting, per linear inch	$0.20 / inch	9.24
Tube end preparation for welding	$0.75 / end	3.00
Drilled holes less than 1" diameter, any depth	$0.35 / hole	22.05
Drilled holes greater than 1" diameter	$0.35 / inch / hole	2.10
Tapped holes	$0.35 / hole	6.30
Sheet metal shearing	$0.20 / cut	.80
Sheet metal bends	$0.05 / bend	.05
	Labor Total	$36,895.09
	TOTAL	$37,140.17

The economic analysis calculated how much it would cost to mass produce our product. The price of the materials is based on the material being bought in bulk. All materials include the windmill stand, heat exchanger stand, heat exchanger, boiler and all of its components. Labor cost was calculated for four people over the building time period. Consequently, the total cost of the project comes out to $37,140.17.

Schedule



As of August 1, 2007, the COOL water purification project has accomplished all of its scheduled goals. The summer started off with the group re-building the boiler and building a test structure for the windmill. Both of these sub-projects were done simultaneously for faster product completion. Extensive time was spent building the flow control mechanism, as construction proved to be quite difficult. Once the windmill test-rig was completed, resistor size analysis was performed given typical power output at San Diego wind speeds. Preliminary boiler test coincided with windmill stand construction. Time dedicated to construction of the windmill stand hand to be increased as the windmill specification changed. It was decided that the windmill would be placed on the roof of Loma, added additional design criteria. Final stand construction and wiring was not completed until mid July, at which time the final product test began.

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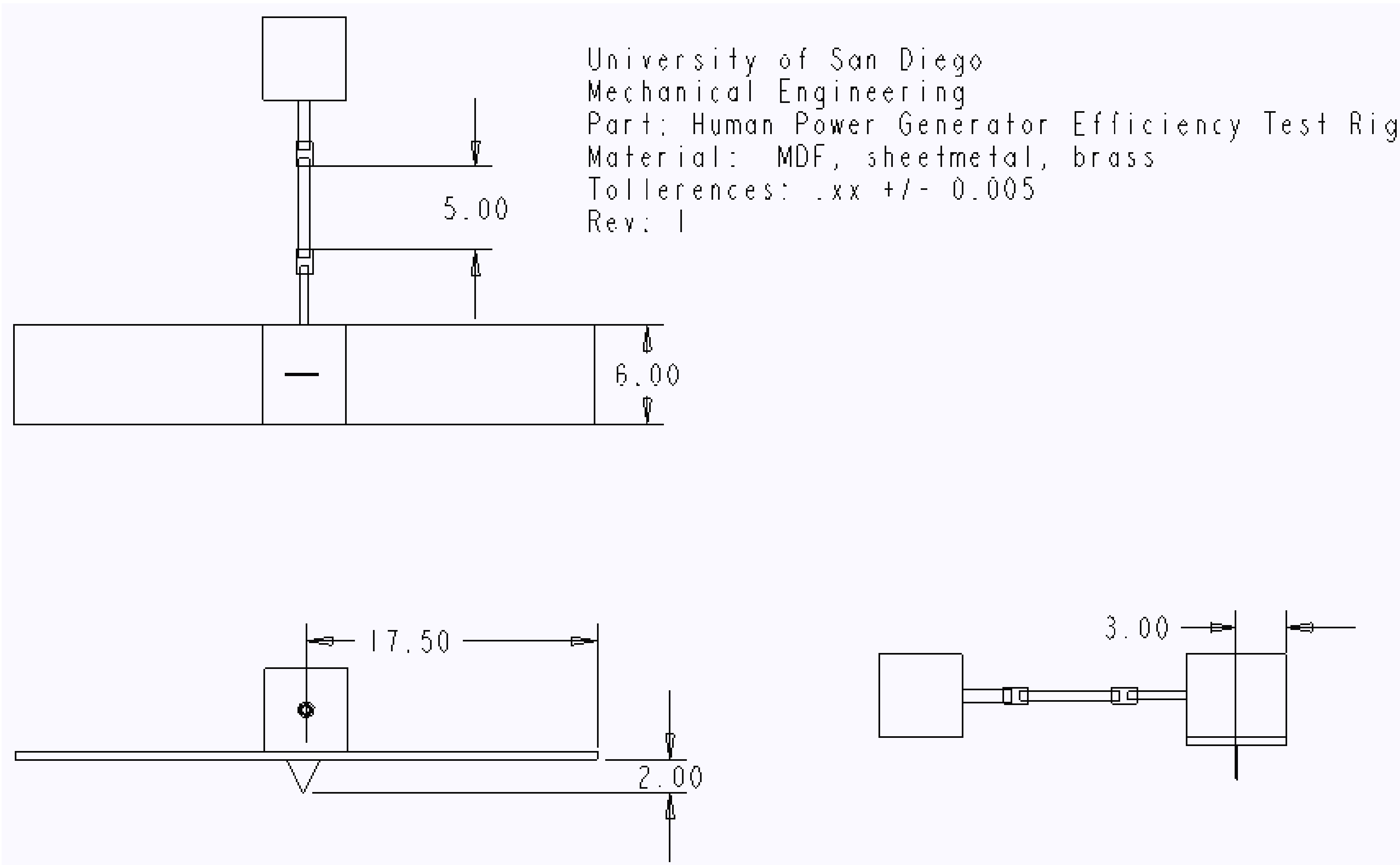
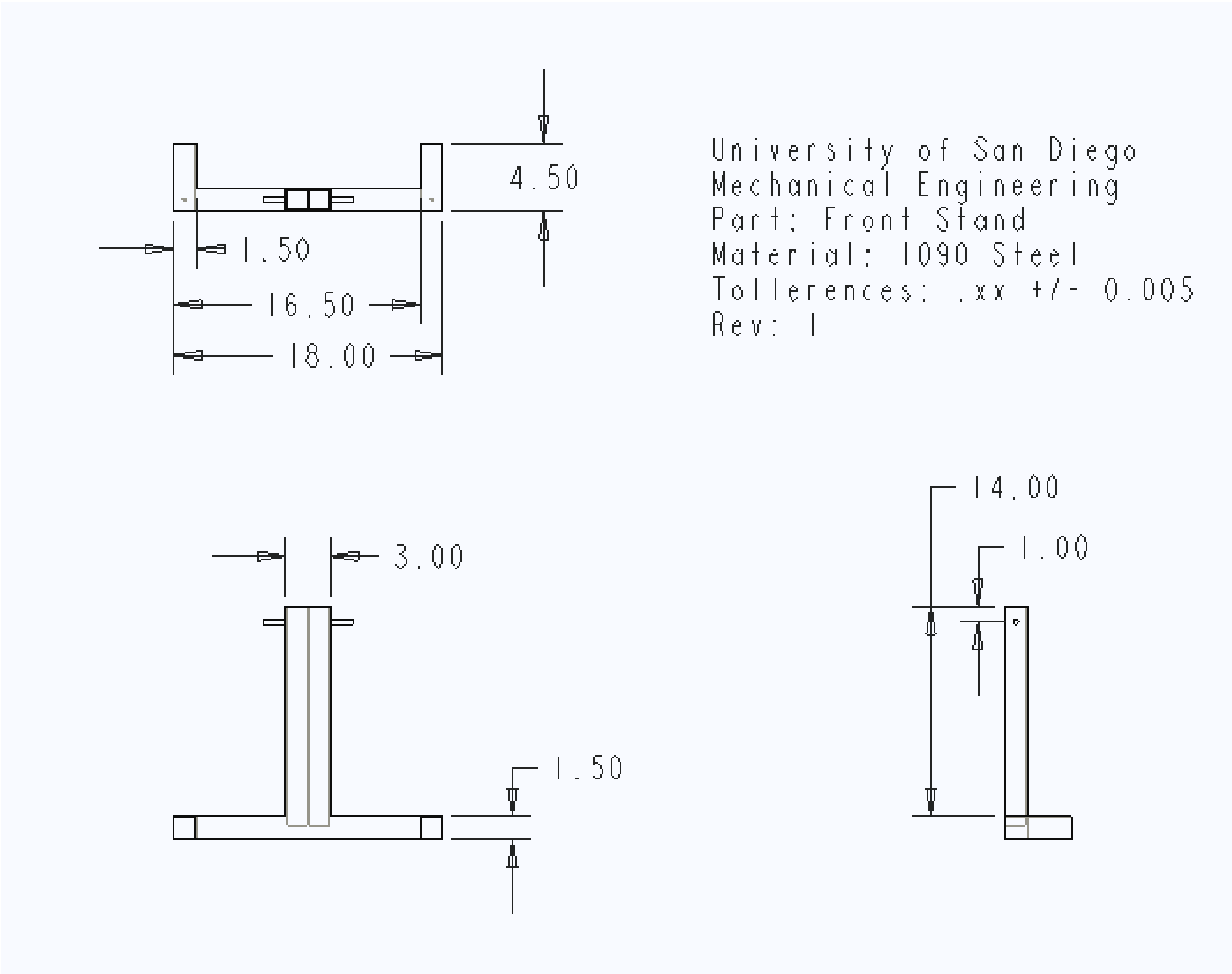
Appendices

A – Technical Drawings

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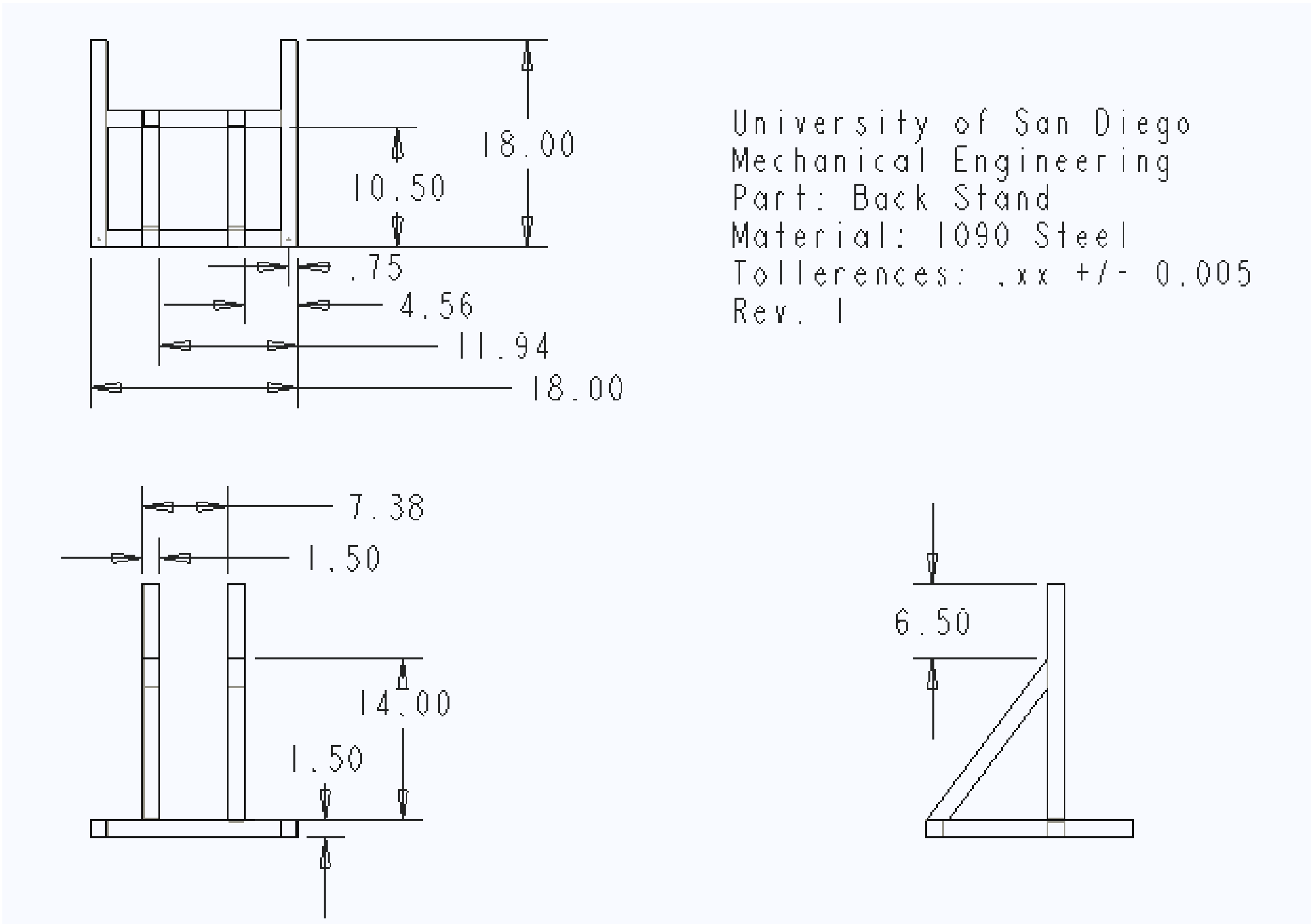
1.50
14.00
1.00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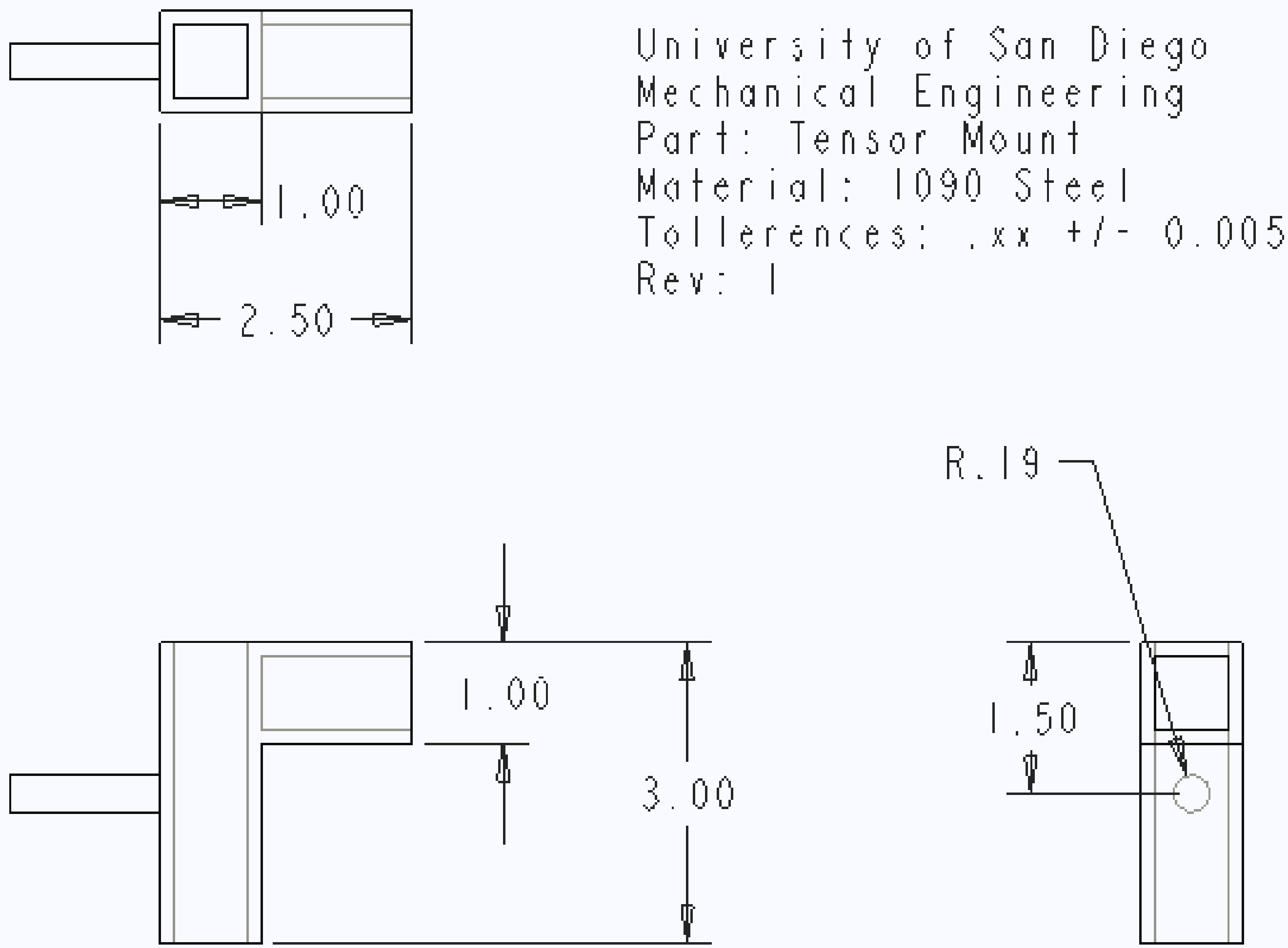
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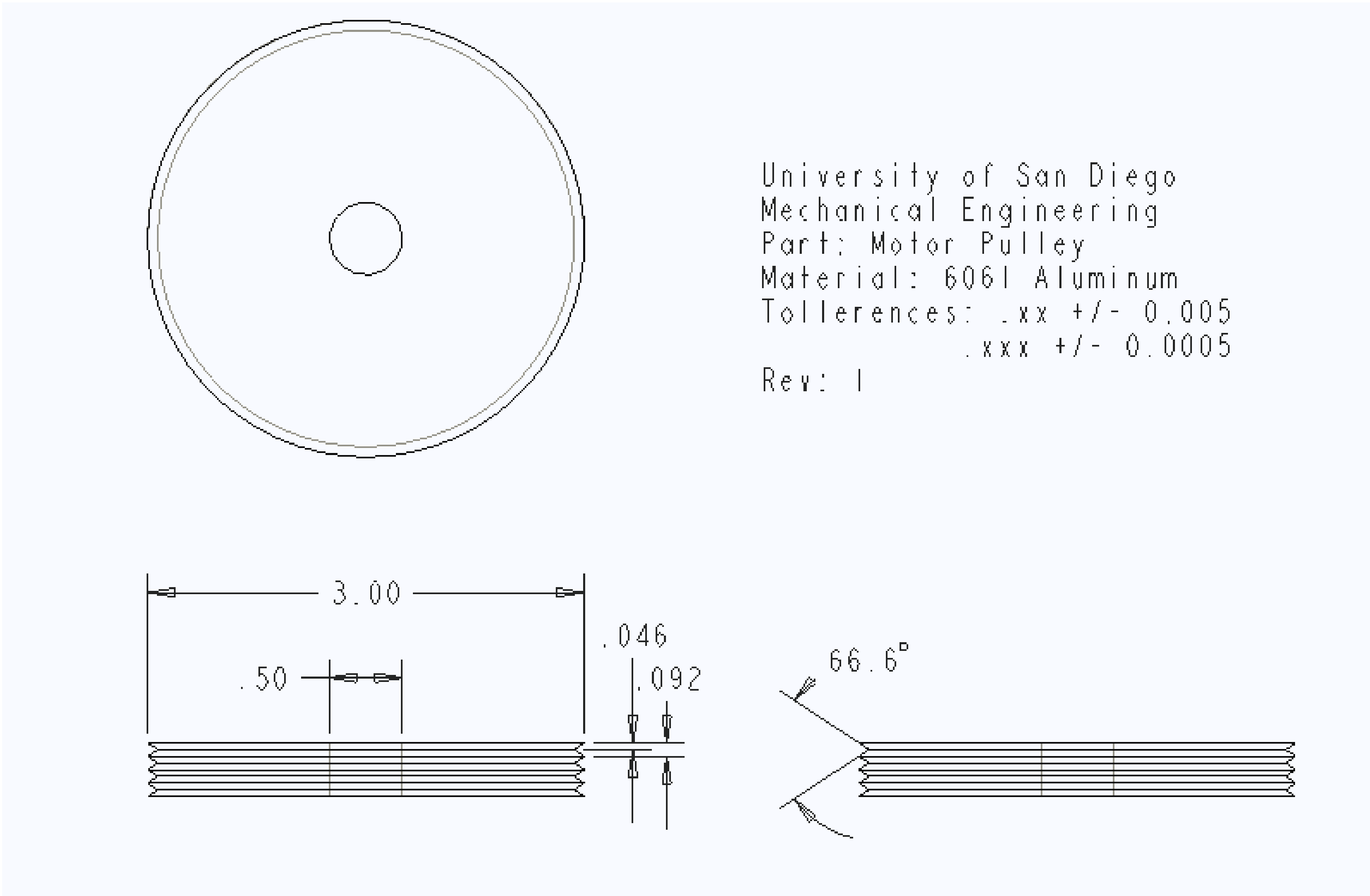
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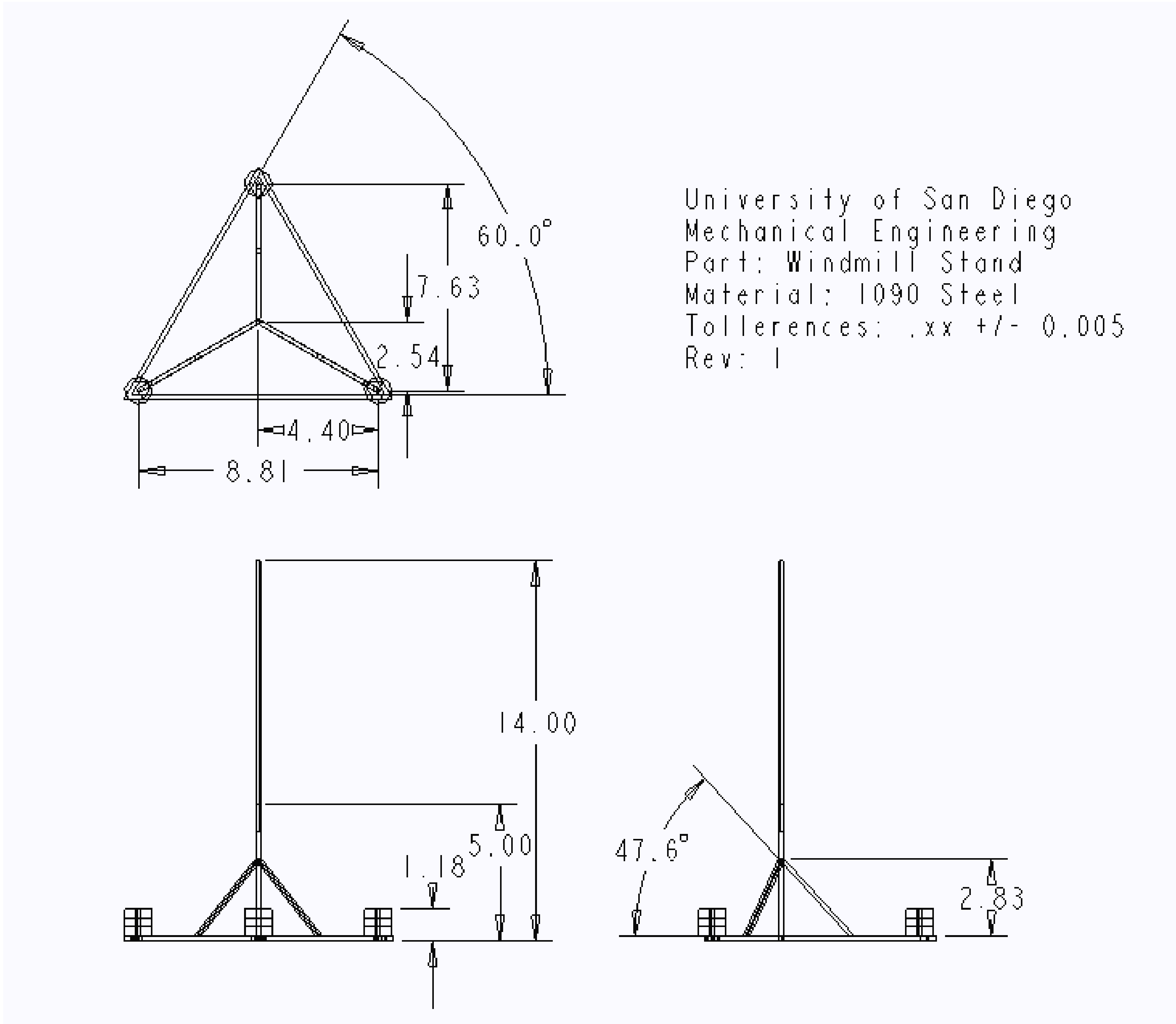

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Mechanical Engineering
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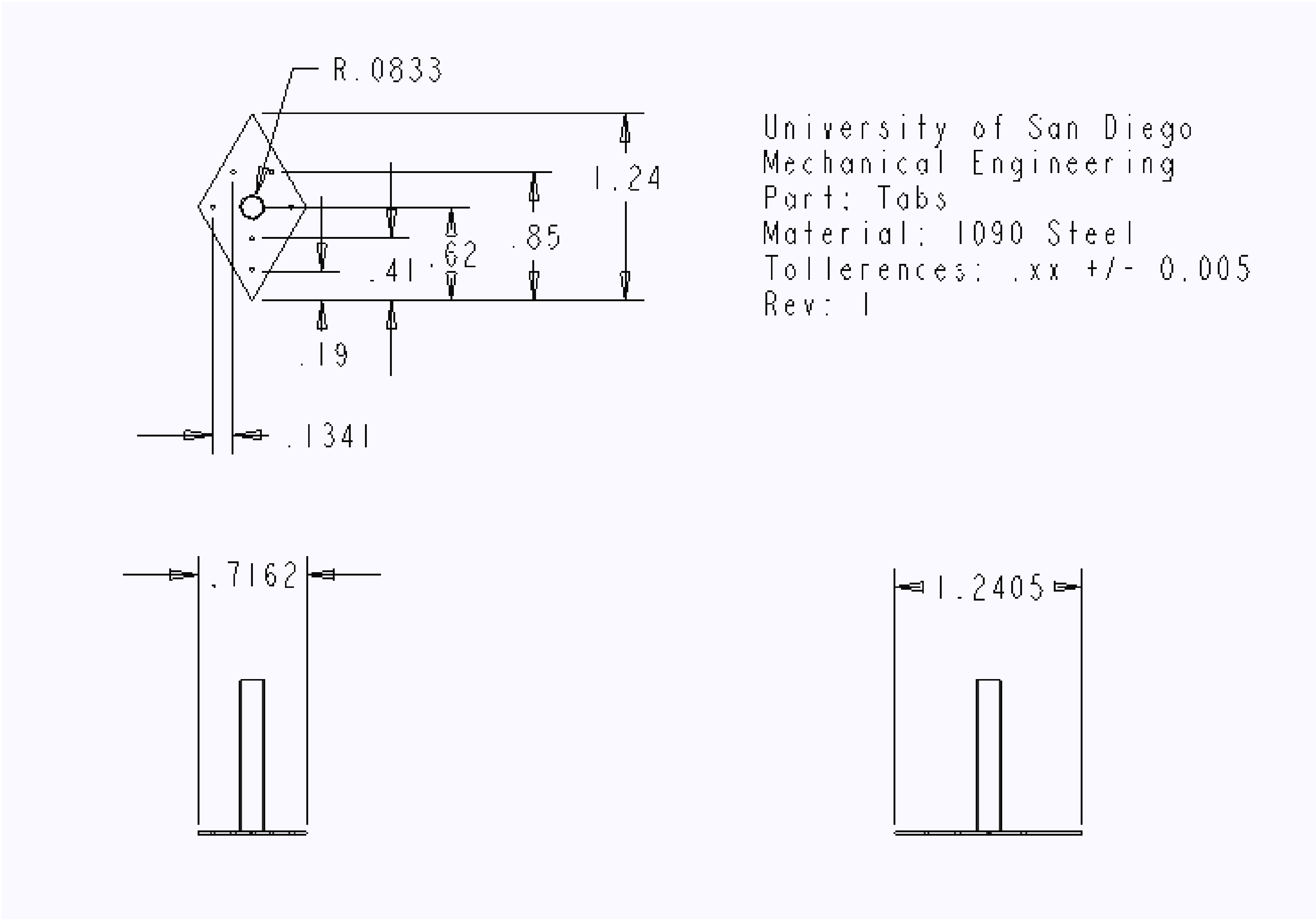
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University of San Diego
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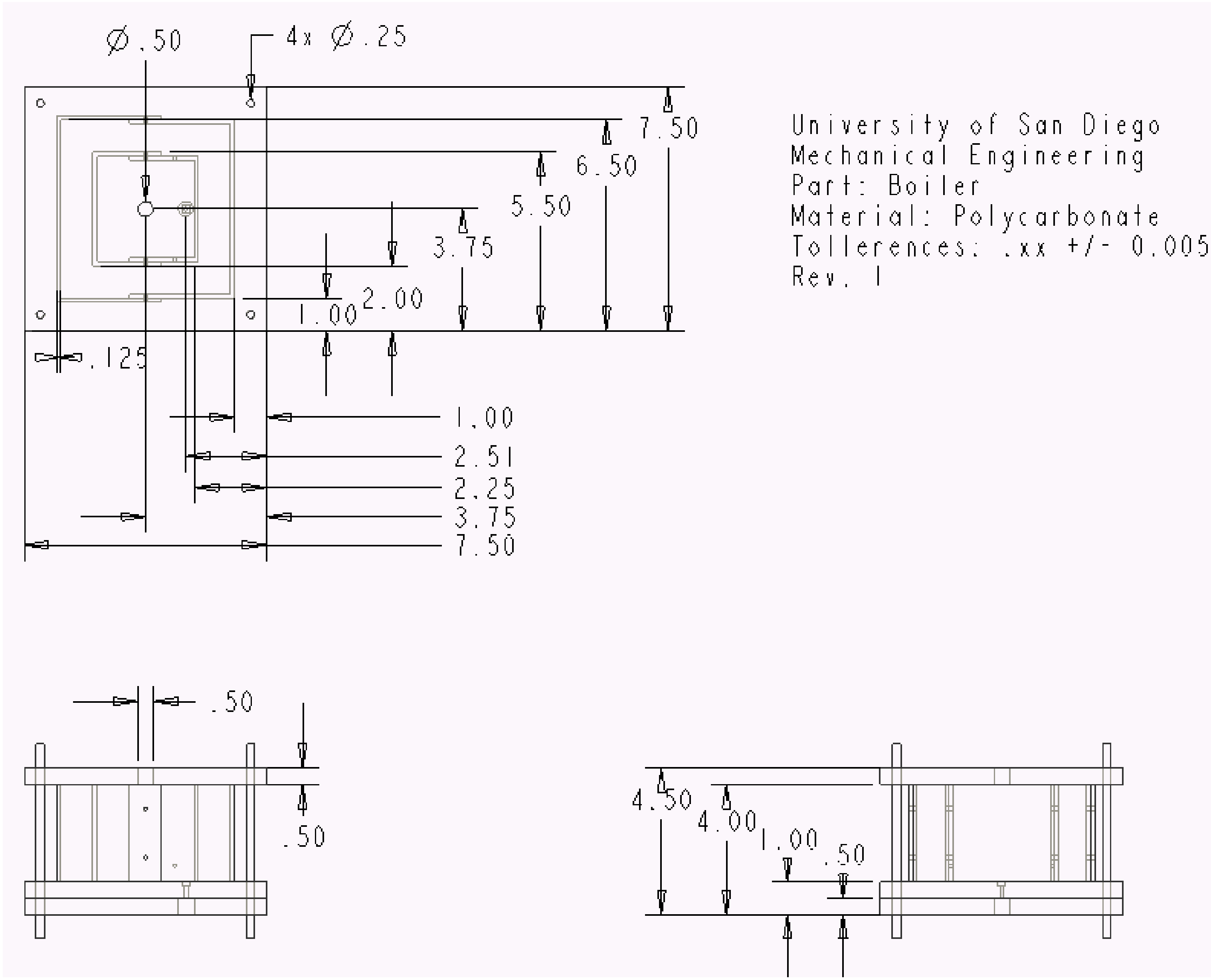
Material: 1090 Steel
Tollerences: .xx +/- 0.005
Rev: 1



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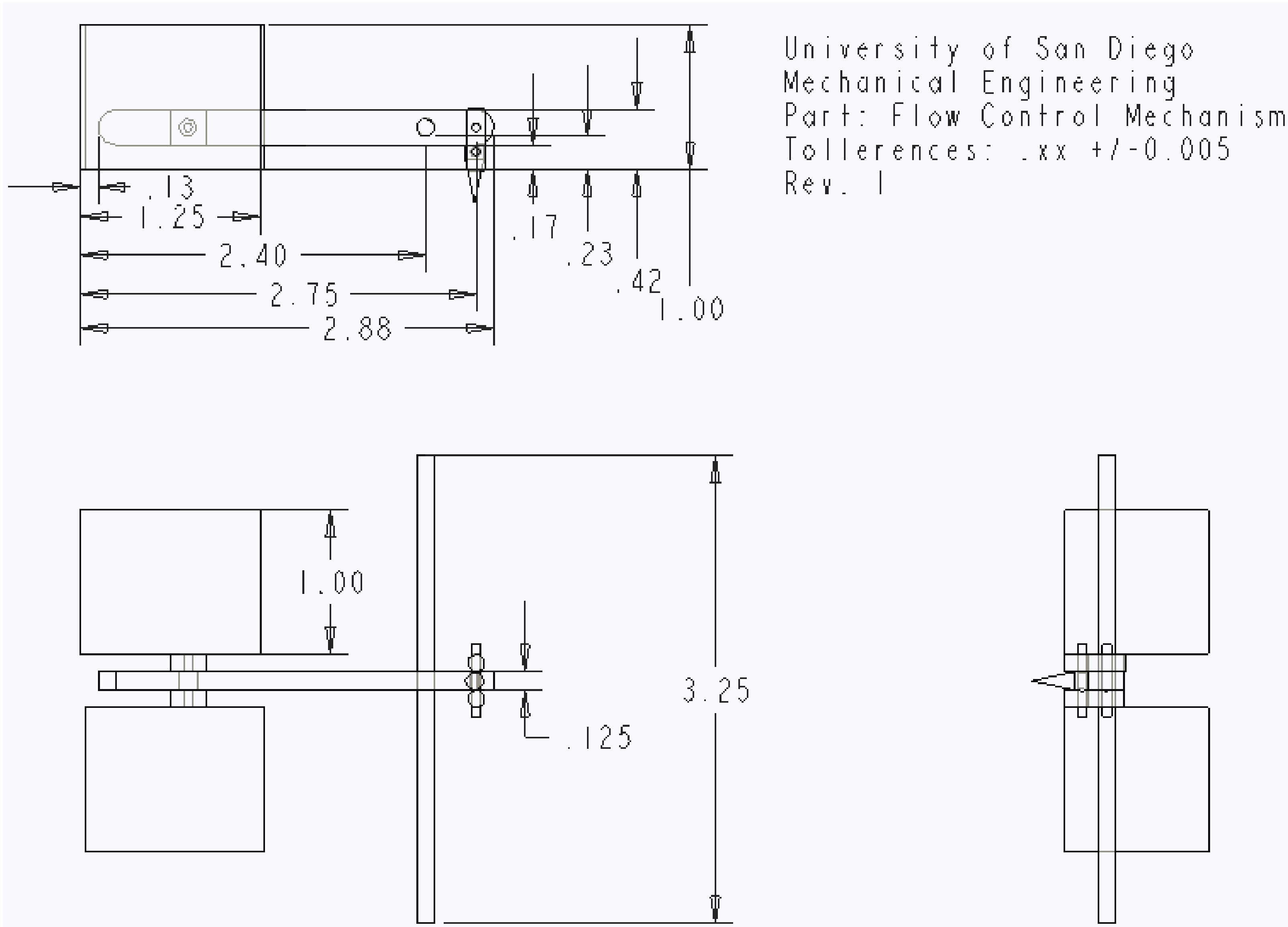
Rev. 1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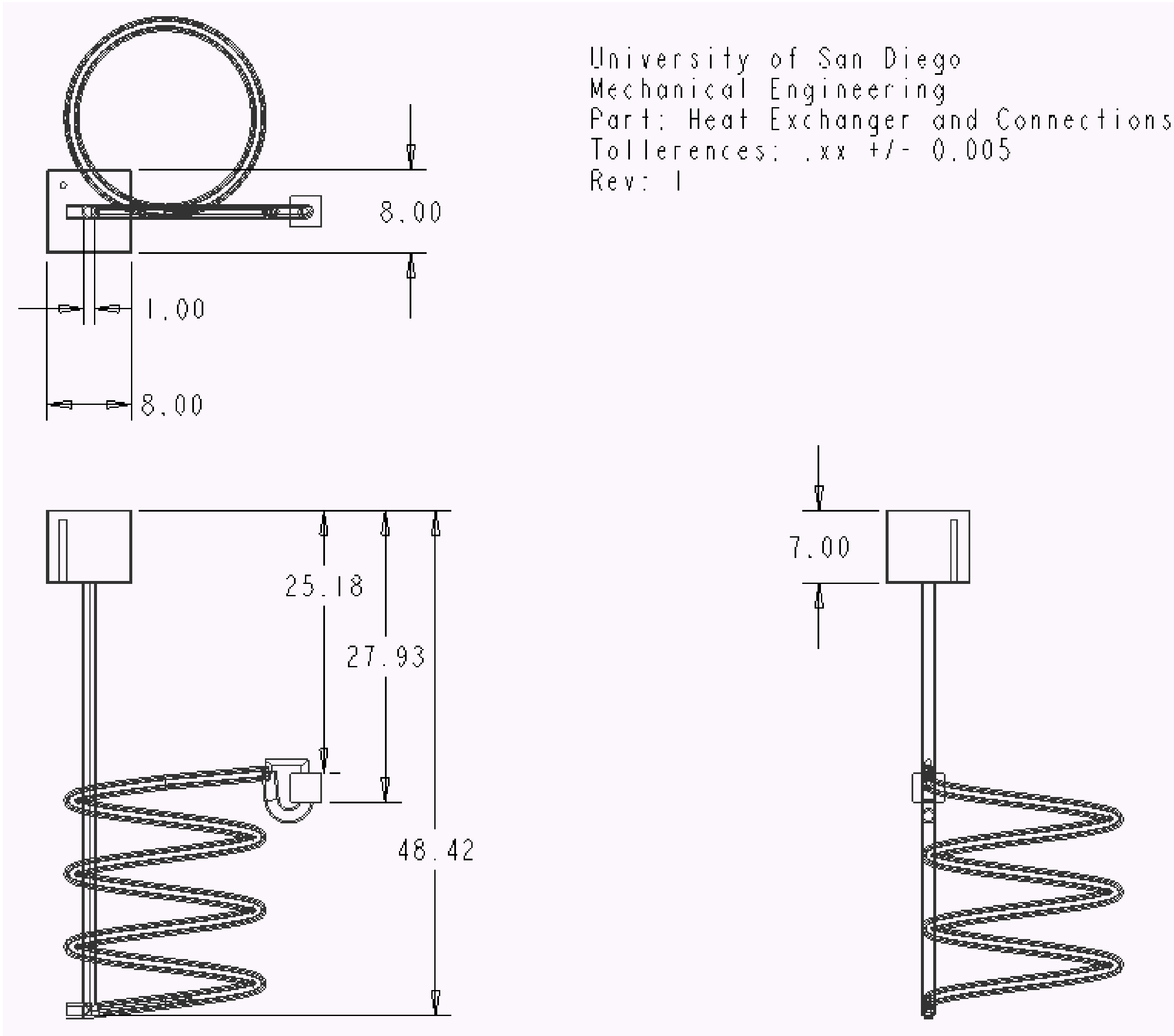
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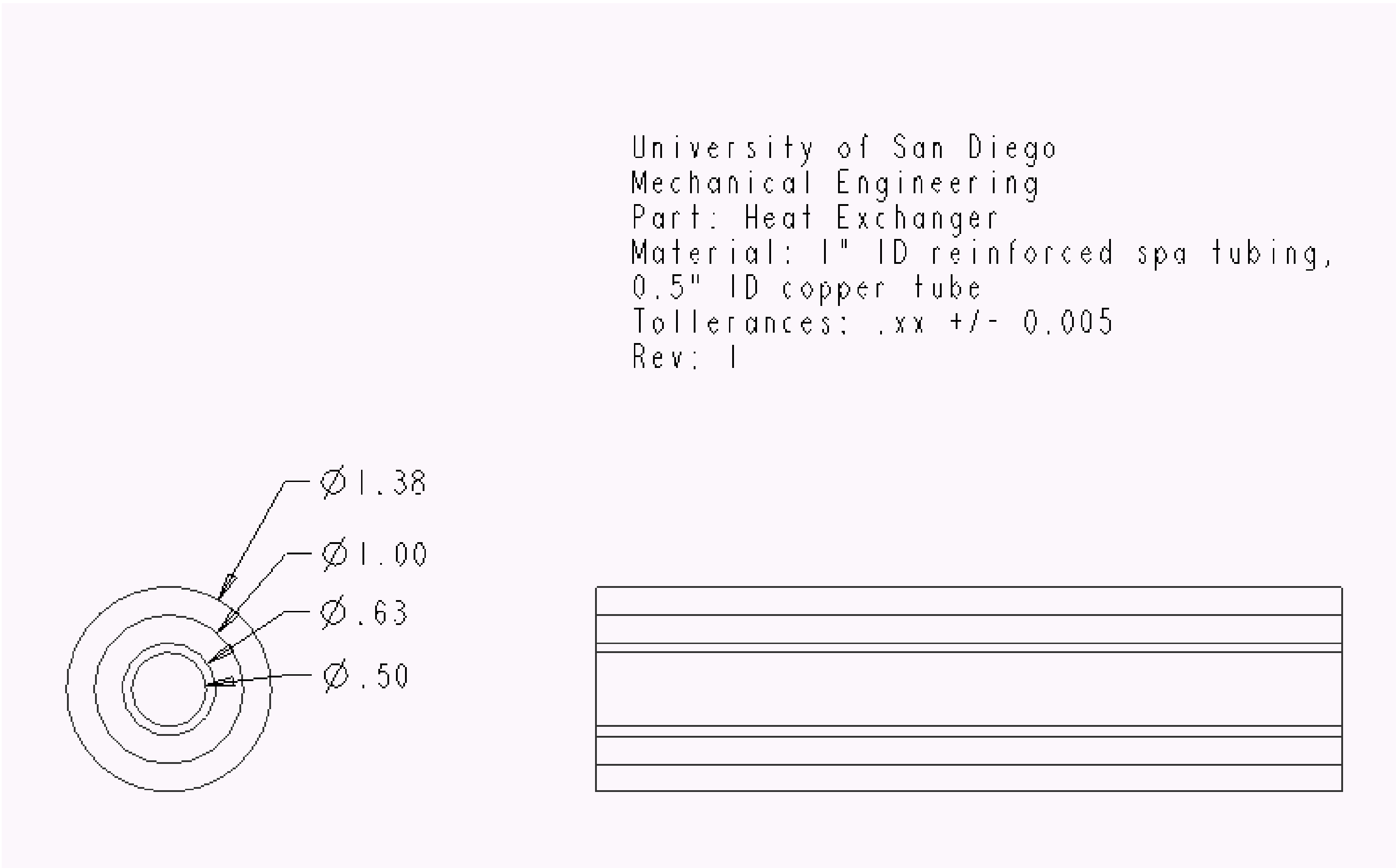
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Mechanical Engineering
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Ø1.00
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Ø.50

B – ASME Design Competition Rules

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 returned water. If less than 90% of the water given to a team is present at the end of the run the score the team receives will be adjusted as follows:

   Adjusted Score = Raw Score * [(1.1 * wt of water returned)/(wt of water issued)]

SCORING

At the end of the one-hour test period, the winner will be the team which maximizes the score according to:

SCORE = (Weight of distilled water, gm) * 10,000
+ (Wt of test water in device, gm, at end) * (Tend – Tstart, C)
- (Dry weight of the device, gm.) / 100
– (Volume of box in which device can be packed, cm^3) / 1000

Notes:

1. All scoring values and calculations will be rounded to the nearest integer value.
2. If the water in the test device is contained in more than one reservoir then the weights of water in each reservoir at the start will be multiplied by the difference between temperatures in that reservoir at the start and at the end of the test to determine the second scoring factor.

COMMITTEE COMMENTS

The SDC Committee has received periodic requests for a "head-to-head" type of contest. Logistical and seeding problems have generally not made this practical. But this year we have come up with a contest where everyone will run at the same time, and spectators will be able to watch and compare the results in nearly real time. We think this will provide an exciting and interesting contest.

This contest differs from previous years' contests in one other important aspect. This time the power input to the device must come from work input by the team members. Thus it is clearly advantageous for a team to include at least one person who is in good physical shape at the time the contest is run. This should be kept in mind as project teams are formed to compete in this contest. Note, however, that bringing on board a person whose only contribution to the project is physical work input violates both the spirit and the letter of the rules. Please review the requirements set down for team members who will be operating the machine and make sure that the information asked for is available to the judges at the contest.

The SDC Committee does not believe that this contest will be won or lost primarily on the physical strength and endurance of team members. There are too many other factors which enter into the design and competition processes. These include the design of an effective human interface, the quality and effectiveness of the thermal insulation, the thermal mass of the device inside the insulation envelope, the effectiveness of the heat rejection/condensation process equipment, any thermodynamic energy conservation measures implemented, and effective use of team members in the competition.

C – Syringe and Valve Calculations

Equations

Mass of clean water in one cycle:

$$m = \frac{V}{v_g} = \left(\frac{.02L}{57.791 m^3/kg} \right) \left| \frac{1m^3}{1000L} \right| = 3.460746E - 7kg \qquad \text{(per cycle)}$$

To exhaust all 200g of dirty water:

$$.2kg \left| \frac{1cycle}{3.460746E - 7kg} \right| = 577917 cycles$$

If it takes the average person takes 7seconds per cycle then the amount of cycles per hour is:

$$\left(\frac{3600s}{1hr} \right) \left(\frac{1cycle}{7s} \right) = 514.28 \, cycles/hr$$

At this pace the amount of water purified is:

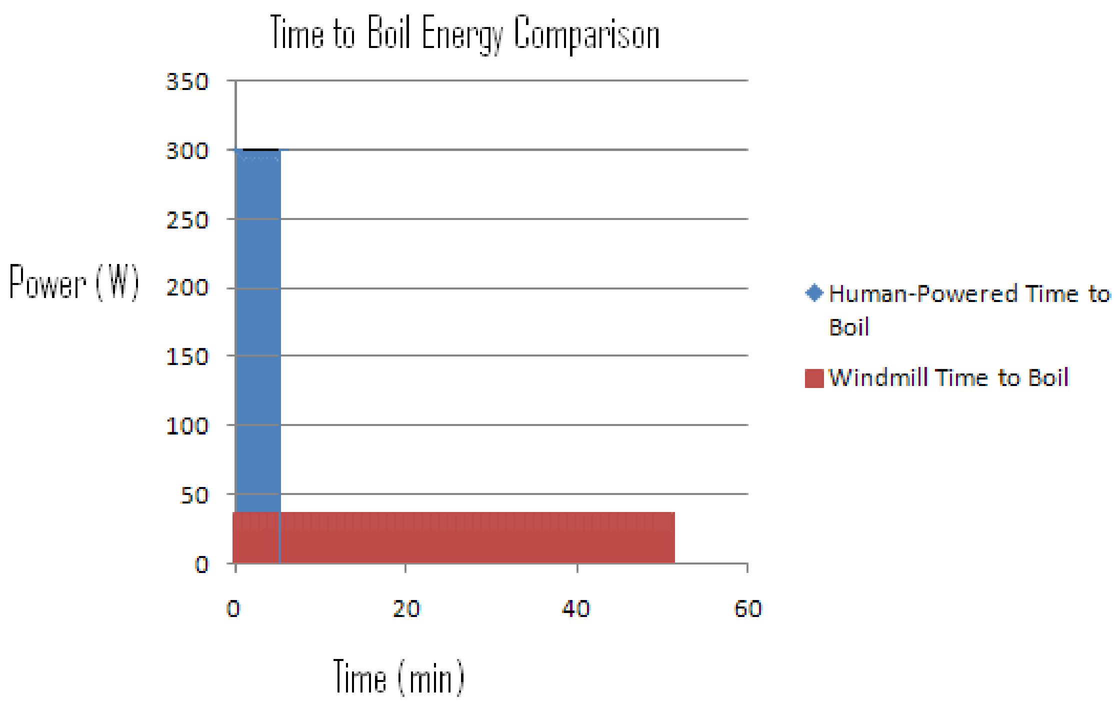
$$\left(\frac{3.460746E - 7kg}{1cycle} \right) \left(\frac{514.28cycle}{1hr} \right) = 1.779812E - 4kg \left| \frac{1000g}{1kg} \right| = 0.1779812g$$

To purify all the dirty water at the average persons pace it would take:

$$.2kg \left(\frac{1hr}{1.779812E - 4kg} \right) = 1123.71419hrs \left| \frac{1day}{24hrs} \right| = 46.8days$$

D – Human Power vs. Wind Power "Time to Boil"

The windmill generator is compared to the prototype, human-powered system. The human-powered system produced a larger instantaneous power, but could only be sustained for 1 hour. This comparison can estimate the "time to boil" of the purification system by comparing the energy in the system. From this comparison the approximate time to boil for the windmill is 50 minutes, but can be sustained for long periods of time. It is acknowledged that the wind may not be consistent over 50 min. However, if the boiler is adequately insulated the heat loss should be minimal and at a net time of 50 min with a power input of 30W the water should begin to boil. If the losses in the boiler turn out to be more than expected, the net time to boil will increase.



Water Production

Energy required to boil 1 liter of water:

$$Q = mC_p\Delta T$$

Constants

m = 1kg

C_p = 4184 J/K*kg

ΔT = 75 K

Q = 314,000 J

Results:

Windmill Power = 30 kwh / month

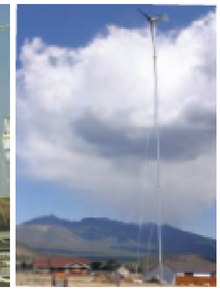
Water produced = 91 gallons / month

E – Windmill Specifications Sheet

Air-X Land / Air-X Marine

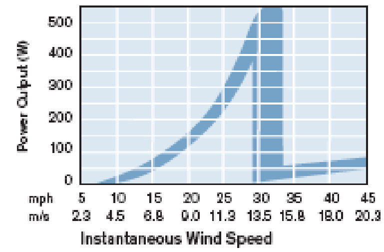
Technical Specifications

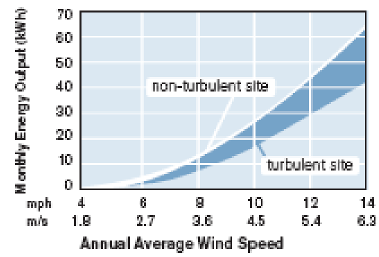
Rotor Diameter	46 inches (1.15 m)
Weight	13 lbs (5.85 kg)
Shipping Dimensions	27 x 15 x 9" (686 x 38 x 229 mm) 17 lbs. (7.7 kg)
Mount	1.5" schedule 40 pipe (1.9" OD, 48 mm)
Start-Up Wind Speed	8 mph (3.58 m/s)
Voltage	12, 24 and 48 VDC
Rated Power	400 watts at 28 mph (12.5 m/s)
Turbine Controller	Microprocessor-based smart internal regulator with peak power tracking
Body	Cast aluminum (AirX Marine is powder coated for corrosion protection)
Blades	(3) Carbon fiber composite
Overspeed Protection	Electronic torque control
Kilowatt Hours Per Month	38 kWh/mo @12 mph (5.4 m/s)
Survival Wind Speed	110 mph (49.2 m/s)
Warranty	3 Year Limited Warranty



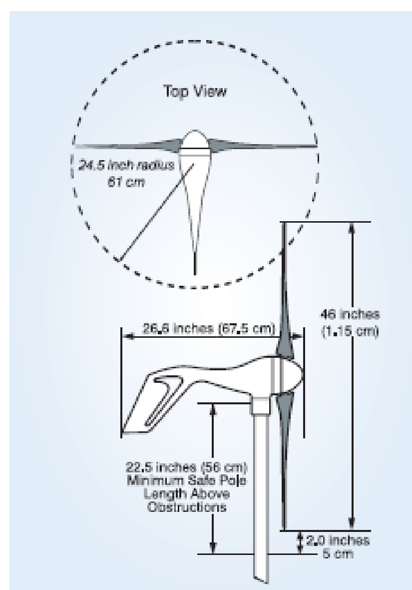
MADE IN THE USA

Performance Curves





Sphere of Operation



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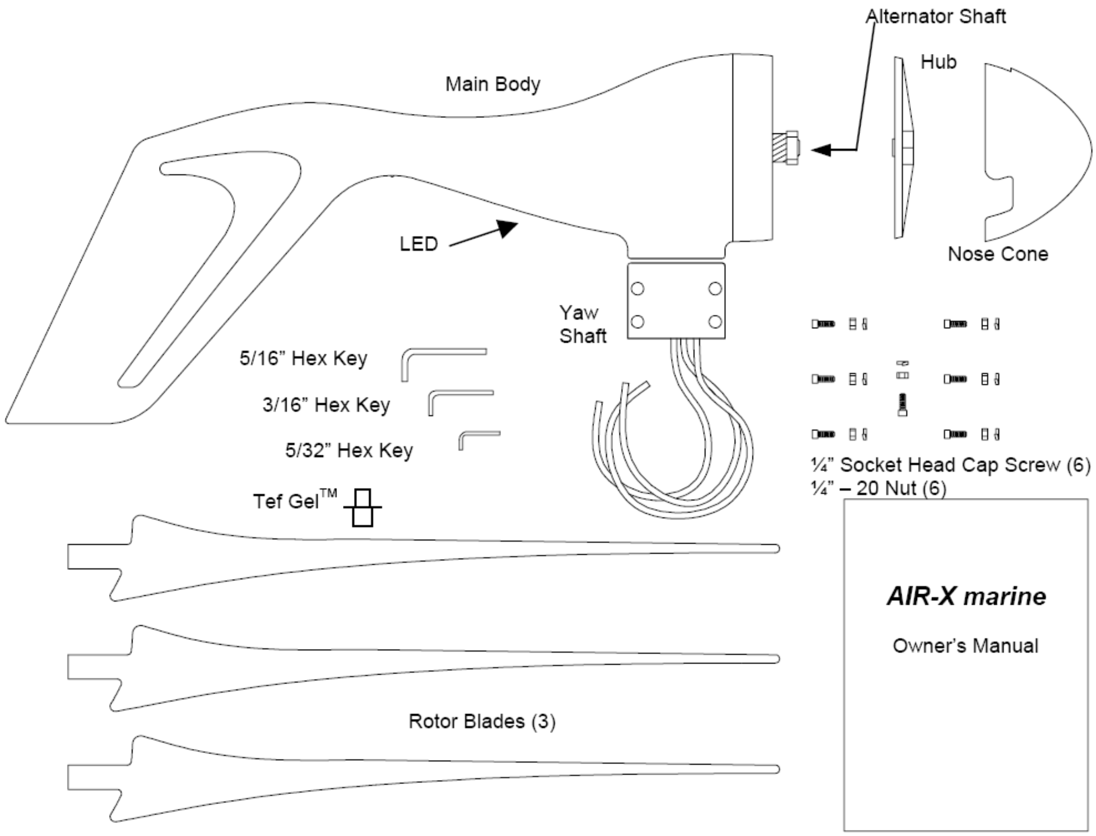
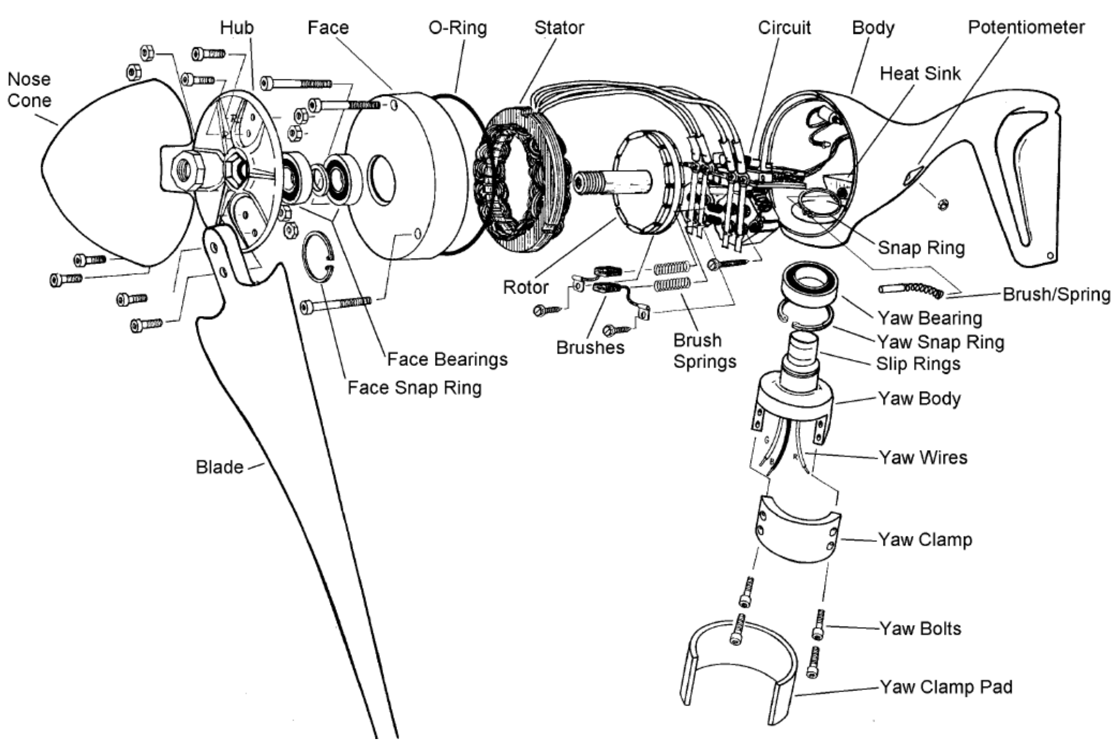
www.windenergy.com



7.4 Exploded View of *AIR-X marine*



F – Heat Exchanger Constants

Average Specific Heat (cp) for Mix of Water at 20 and 99 degrees Celsius:

$$cp = (.5)(cp_{water,\ 20°C}) + (.5)(cp_{waterr,\ 99°C}) = (.5)(4.181kJ/kg) + (.5)(4.241kJ/kg) =$$

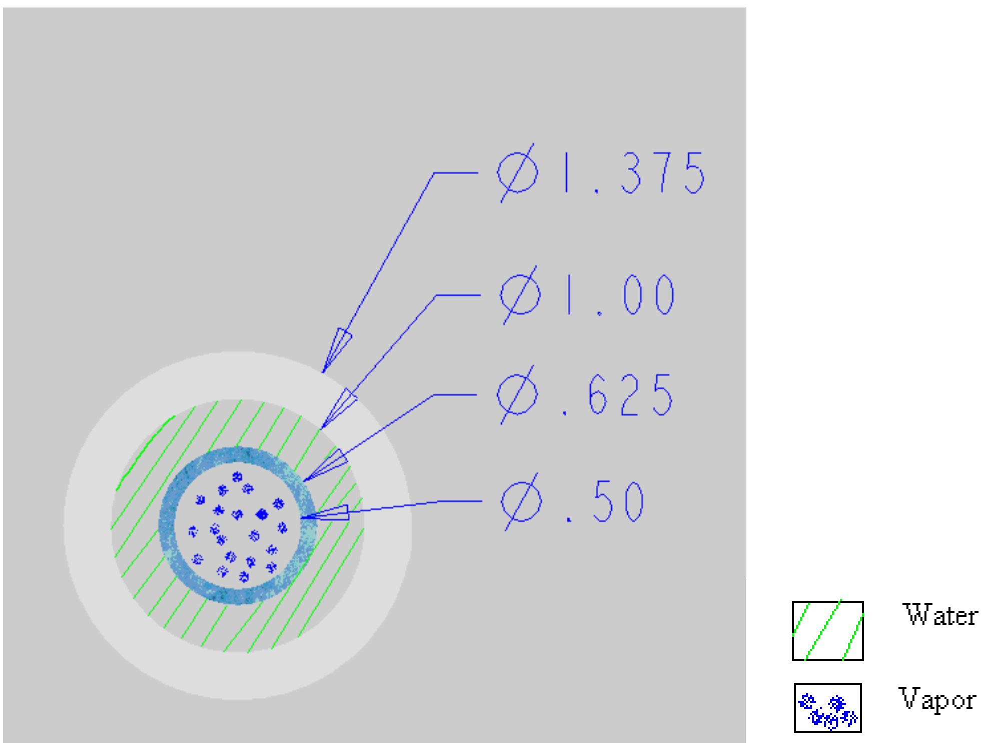
4.211kJ/kg

Average Thermal Conductivity (K) for Mix of Water and Water Vapor:

$$K = (.5)(K_{air,\ 100°C}) + (.5)(K_{water\ vapor,\ 100°C}) = (.5)(3.17E\text{-}2\ W/mK) + (.5)(2.36E\text{-}2\ W/mK) =$$

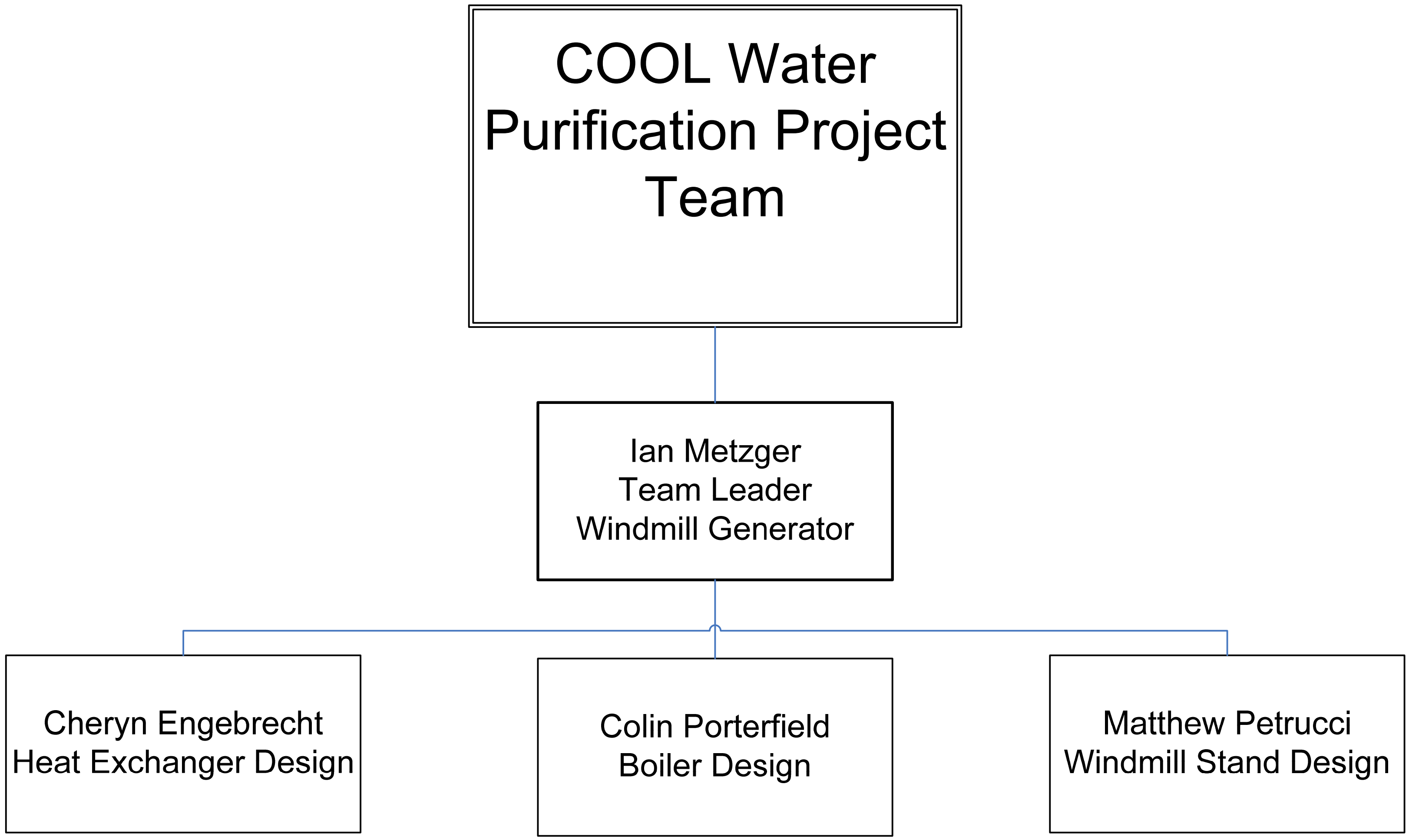
2.77E-2 W/mK

Equivalent diameter calculation (similar equation used for equivalent radius):



Equivalent diameter = 1-.625=.375 inches

G – Personnel / Organization Chart



Cheryn Engebrecht

2012 Coolidge Street #89, San Diego, CA 92111 (503) 708-1281 cheryn-07@sandiego.edu

Objective: An enthusiastic, hard-working Mechanical Engineer looking for a full-time position at Exact Packing Incorporated in the area of environmental design.

Education

University of San Diego, San Diego, CA Expected Graduation Date: August 2007

Major: Mechanical Engineering, Minor: Spanish
Major Specific GPA: 3.95, Overall GPA: 3.78

Experience

NASSCO, San Diego, CA **Jun. 2006 – Aug. 2006**

Management Engineer:

- Analyzed current block lay-down for the building of Navy ships
- Produced a much more efficient "process lanes" lay-down for future ships
- Initiated various smaller projects ranging from safety engineering to environmental engineering

MAXIM INCORPORATED, Portland, OR **Jun. 2004 – Aug. 2004**

Industrial Engineer:

- Analyzed current plant layout and computer programs
- Obtained in-house experience on computer chip and wafer testing machines
- Configured a program using MySQL, PHP, HTML, and some JAVA which reorganized current system for better organization

ROCKWELL COLLINS FLIGHT DYNAMICS, Portland, OR **Jun. 2002 – Aug. 2002**

Optical Engineer:

- Constructed multiple tunnel integrators
- Built prototype for a digital projector used in airplanes around the world
- Gathered and analyzed quantitative data using high tech equipment

UNIVERSITY OF SAN DIEGO, San Diego, CA **Sept. 2003 – Present**

Math Grader:

- Grade, record and evaluate the homework and test grades of math students of all skill levels up to and including Calculus II

Math Tutor:

- Challenged to come up with alternative ways to assist the students in attacking the various types of problems from a different angle
- Aided struggling math students gain confidence in their ability to work efficiently and effectively

Skills and Abilities

- Computer Skills: MatLab, Pro-E, Pro Mechanica, Fluent, C++, Microsoft Office, Microsoft Access
- Machining Skills: Mill, lathe, NC programming, band saw, and belt sander
- Technical Writer

Related Courses:

- Computational Fluid Dynamics (CFD's)
- Machine Shop
- PRO-E / MatLab
- Systems Engineering
- Senior Design

Honors and Activities

- Dean's Merit Scholarship and USD Scholarship
- Junior and Sophomore Mechanical Engineer of the Year Award (chosen by professors)
- 2nd place in ASME's Regional Conference Website Competition 2006
- Summer Undergraduate Research Experience Grant received for research in summer 2006
- Vice President of Society of Women Engineers (special projects: 'Evening With Industry' Planner)
- Treasurer of American Society of Mechanical Engineers
- Associated Students Representative of Pride (gay/straight alliance club)

IAN METZGER

2852 Laning Rd.
San Diego, CA 92106
(619) 321-8975
imetzger-07@sandiego.edu

Education

University of San Diego, San Diego, CA *2003-2007*

- B/S & B/A Mechanical Engineering and Liberal Arts
- Major Specific GPA: 3.98, Overall GPA: 3.7 (Magna Cum Laude)
- American Society of Mechanical Engineers member since 2005, Student Chapter President (2006-2007)

Work Experience

Mechanical Engineer Intern, General Dynamics NASSCO, San Diego, CA *Summer 2006*

- Design, team projects, process improvements, material properties research, time studies, consultation
- Various certifications from environmental engineering and transportation departments

Engineering Technician, USD Engineering Department, San Diego, CA *2003-2007*

- Prepared labs for engineering classes, machine shop maintenance, operating machines, computer upgrades

Relevant Engineering Skills

Computer Skills:

- ProEngineer, AutoCAD, Fluent/Gambit, CNC (G&M), MathCAD, MS Office, Surfcam, ProMechanica, MatLab

Technical Skills:

- Technical Writing, wood shop, metal shop, laser cutter, sand blaster, machine shop tools

Relevant Coursework

- Engineering Design
- Senior Design (1 & 2)
- Machine Design (1 & 2)
- Mechanical Vibrations
- Mechanical Systems Lab (1 &2)
- Machine Shop
- Strength of Materials
- Material Science
- Computational Fluid Dynamics
- Electrical Power
- Applied Thermodynamics
- Applied Engineering Math

Special Projects

Wind Powered Water Still *2006-2007*

- Windmill mechanics, electrical circuits, thermodynamics of water and vapor flow, heat exchanger, heat transfer analysis, material research, ProEngineer, Fluent/Gambit, technical writing, manufacturing
- 2007 ASME Student Professional Development Conference, Design Competition (using human-power)
- University of San Diego Associated Students Academic Grant

Project Sidewinder Off-Road Vehicle *2005-2006*

- Design, manufacturing, vehicle dynamics, computer modeling, material strength analysis, rebuilding engine
- University of San Diego Associated Students Academic Grant

Research

Preservation of Muscle Fascia and Fluid Mechanics of Microcirculatory Networks *2005-2007*

- Design of preservation frame, microscope images, fluid mechanics and statistical study of microvasculature
- 2nd Place in ASME Regional Student Conference Poster Competition, 2006
- Summer Undergraduate Research Experience (SURE) Grant, 2006

Computer Modeling of Liquid Metal Heat Transfer *2007*

- Fluent/Gambit simulations, heat transfer analysis, statistical analysis, development of equation

RC Car and Robotics *2005*

Publications

Jacobitz, F.G., Engebrecht, C.P., Metzger, I.D., Porterfield, C.A.: Simulation of the Microciculation in Rat Spinotrapezius Muscle Fascia. ASME 2007 Summer Biengineering Conference, SBC2007-175809.

Engebrecht, C.P., Metzger, I.D., Porterfield, C.A.: Properties of the Microcirculation in Capillary Bundles of Rat Spinotrapezius Muscle Fascia. University of San Diego Creative Collaborations Conference, 2007.

Metzger, I.D., Engebrecht, C.P., Garreau, D., Porterfield, C.A.: Preservation of Muscle Fascia. University of San Diego Creative Collaborations Conference, 2006.

Honors

Rothermel Graduate Scholarship, American Society of Mechanical Engineers Auxiliary *2007*

- Outstanding scholastic achievement and excellent character, one of two recipients nationally

The William J. & Marijane E. Adams, Jr. Scholarship, ASME Center for Education *2007*

- Excellent academic record and potential contribution to the field of engineering, only recipient nationally

Therese Whitcomb '53 Alumni Scholarship, University of San Diego Alumni Association *2007-2008*

- Exceptional service to the university and community

Recipient of four year USD Trustee Scholarship, University of San Diego Admissions *2003-2007*

- Superior academic achievement, test scores, leadership, service, talent, and other personal qualities

USD "Balanced Man" Scholar, Sigma Phi Epsilon Fraternity *2004*

- Outstanding academics, extra curricular activities, campus involvement, and merit

Matthew Petrucci

petruccim2@asme.org 303-594-0570

5998 Alcala Park Unit #8226 San Diego, CA 92110

EDUCATION

University of San Diego, San Diego, CA *Expected graduation Aug 2007*
Bachelor of Science in Mechanical Engineering
Bachelor of Arts in Liberal Arts

- Overall GPA: 3.15, Major GPA: 3.23

COURSES TAKEN

Design of Experiments	CAD Design	Vibrations	Electrical Circuits
Manufacturing	Public Speaking	Thermodynamics	Heat Transfer
Machine Shop	Machine Design	Economics	Senior Design

EXPERIENCE

Mechanical Engineering Senior Design Project *Jan 2007-Aug 2007*
Product Design: Human Powered Purification Design

- Team head for the human interface of the design
- Used CAD to design human interface

Zimmer Dental Inc. Carlsbad, CA *Jun 2006—Aug 2006*
Manufacturing engineer

- Worked on design review and was an on-floor manufacturing engineer
- Created a tool life management system for the machinery
- Established communication between engineering and operators on floor

USD Athletic Department, San Diego, CA *Sep 2003—May 2004*
Maintenance Person

- Responsible for maintaining field, dugouts, and bleachers

Abercrombie and Fitch, Lone Tree, CO *Jun 2003—Aug 2003*
Materials Handler

- Organized and managed stock room
- Involved in stock room planning layout

SKILLS

Computer Skills

ProEngineer	Solid Works	Pro Mechanica	MS Office
AutoCAD	SurfCAM	MatLab	Fluent

Technical and Personal Skills

Proficient Technical Writer	Spanish language proficiency	Well Organized
Proficient Mill and Lathe Operator	Self Motivated	Positive Attitude

ACTIVITIES/HONORS

ASME Public Relations Officer *Spring 2006—Present*
University of San Diego, Men's Baseball Team *Fall 2005—Spring 2006*

- Left handed pitcher for a NCAA Division I Tournament Team

San Diego City College, Men's Baseball Team *Fall 2004—Spring 2005*

- Concurrent full time enrollment at USD and at San Diego City College in order to be eligible to play baseball at San Diego City College.

Founder's Chapel Liturgical Ministry *Fall 2004—Present*

Colin Porterfield

1341 Goshen St., San Diego, CA 92110
480-296-8753 colinp-07@sandiego.edu

Education

University of San Diego, San Diego, CA — GPA: 3.80
BS/BA in Mechanical Engineering/Liberal Arts with Honors — Expected: August 2007
Intercollege, Nicosia, Cyprus — June - July 2005

Experience

General Dynamics NASSCO — May - August 2006
Test Engineer

- Worked in the Test and Trials department on an Alaskan Oil Tanker
- Assisted and eventually oversaw the preparation and repair of ship systems for final use
- Focused on trouble shooting, diagnostics, and managerial skills
- Went out with the ship on final sea trials for preparation for the customer

University of San Diego Mechanical Engineering Department — August 2005 **-** Present
SURE Research Grant - Modeling the Shear Dependence of Blood Viscosity and its Impact on Microcirculation

- Constructed a theoretical model of realistic topology; measuring vessel properties and blood rheology
- Used previous research in the areas of blood shear rates and red blood cell concentrations to develop a mathematical model of blood viscosity as a factor of hematocrit, diameter, and shear rates.
- Used this model with Poiseuille's law to create predict blood flow rates
- Research currently being reviewed by the ASME Journal of Biomechanical Engineering for publication

COOL Water Purification System Senior Design Project — December 2006 - Present

- Engineered and manufactured a small scale water purification system
- System runs solely on renewable energy
- Designed a human powered generator-boiling system to purify water to a suitable drinking level
- System requires no external power sources or filters necessary for water purification

University of San Diego Information Technology Services Department — August 2006 - Present
Desktop Support Technician

- Assisted in a wide range of hardware/software technical issues with a strong basis in customer support
- Network troubleshooting and problem solving

Skills

- AutoCAD, Pro Engineer, Fluent, Pro Mechanica, , C++, SurfCam, MatLab, Manual / CNC machining (mills/lathes/etc.), MS Office, Technical Writing

Honors

- **First** Engineer Graduating from the University of San Diego **Honors** Program
- University of San Diego Trustee and Ernest W. Hahn Scholarships, August 2003 – May 2007
- American Society of Mechanical Engineers: Vice-President, USD Chapter, 2004 – 2006