Solar Autoclave for Rural Areas

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Team 6

Midpoint Report

Document

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Executive Summary (Kyle Godwin)

Developing areas around the world do not possess the technology to efficiently sterilize medical equipment. As a result, nurses and doctors at remote health clinics in these rural areas are continually challenged with the decision to operate with unsanitary equipment, risking the spread of infection, or to not operate at all. A solar autoclave provides an alternative solution to this problem. Using only solar radiation, a solar autoclave can provide remote health clinics with an inexpensive, efficient way to sterilize medical equipment.

Our objective is to create a solar autoclave for use in rural areas that can be operated by any relatively inexperienced client and in a safe manner. To begin, a parabolic trough was constructed to harness the irradiation from the sun and heat up a boiler located at the focal point of the trough. The water inside the boiler becomes pressurized, creating steam at 121°C. A spring-release valve allows the steam to travel through a hose to a pressure vessel containing the unclean medical equipment. After a designated amount of time, the pressure is released and the sterile medical equipment can safely be removed from the pressure vessel.

The autoclave as a whole must be built in a safe manner such that the autoclave will fail before user injury is possible. Interchangeable parts allow for various modifications and easy repairs depending on the materials native to the area. This allows for the autoclave to remain functioning without the need of outside assistance.

Introduction (Kyle Godwin)

At the midpoint of our solar autoclave prototype construction, the final design has been concluded that will be fully built and working no later than Tuesday, March 12th, 2013. Since the previous progress report, no conceptual aspects of the final design have changed. However, all necessary materials have all been collected and the construction of the solar autoclave prototype is well underway. As requested by our client, the autoclave must not surpass a budget of $300, which the team was able to do with ease. A bill of materials, presented in Appendix A (Table 1), shows that the overall budget is a far less than $300. The final design as shown in Figure 1 below still remains unchanged. The team has delegated construction of the trough, the boiler and the pressure vessel to three sub-teams, which will be explained in explicit detail throughout the rest of the report.

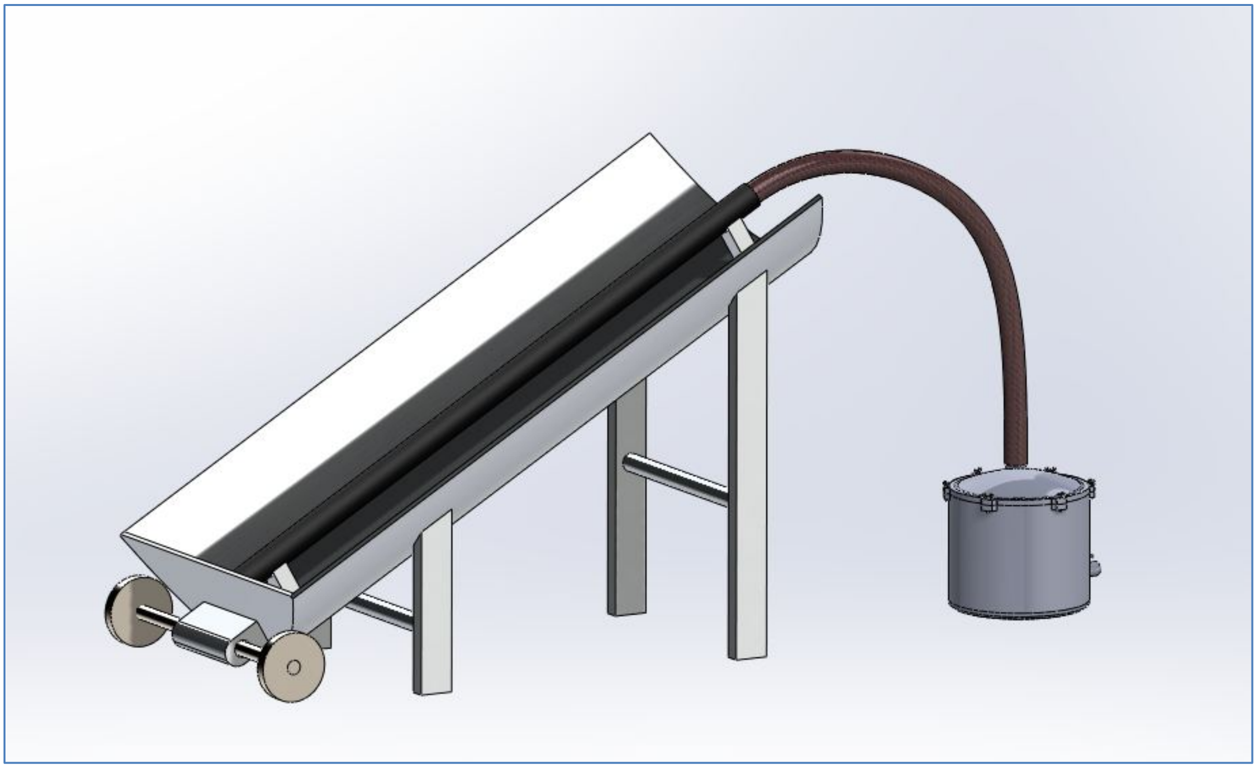

Figure 1 – Final Design

Trough Design (Adam Compton)

The key element to our solar autoclave is irradiation capture. After much consideration, our team has decided to use a trough design to capture solar irradiance. This design uses a parabolic curve in one plane, the X and Y, and then this shape is extended out in the Z plane. The X and Y plane is demonstrated in Figure 2.

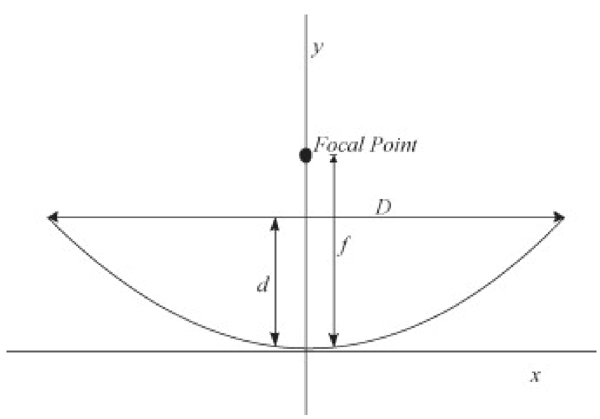

Figure 2 – X and Y Plane of Trough

The X and Y plane are then extended in the Z direction to create the parabolic trough. This trough is shown in Figure 3.

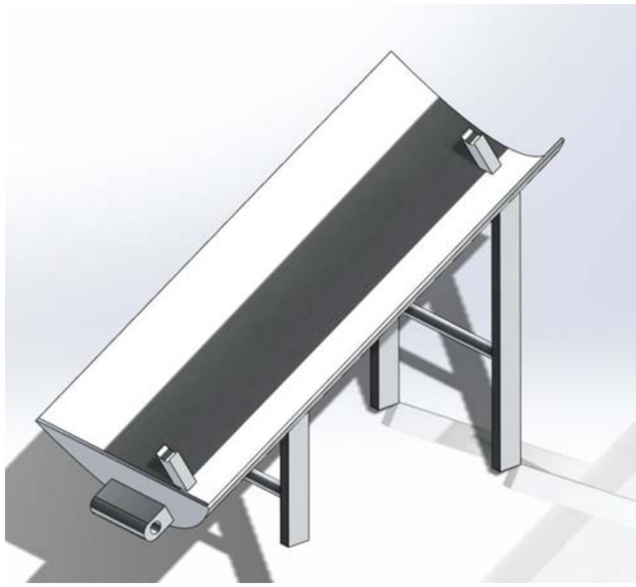

Figure 3 – X and Y Plane Extended by Z

Using this design, solar irradiance is reflected off of a reflective material and it concentrated on the boiler in the focal point of the trough. This focal point it displayed in Figure 2 above.

Design Dimensions

Using the assumption that the irradiation from the sun will be approximately $850\ \frac{W}{m^2}$, the team was able to calculate a projected area of $0.528\ m^2$ to be necessary. This allowed us to make design measurements as shown in Figure 4, below.

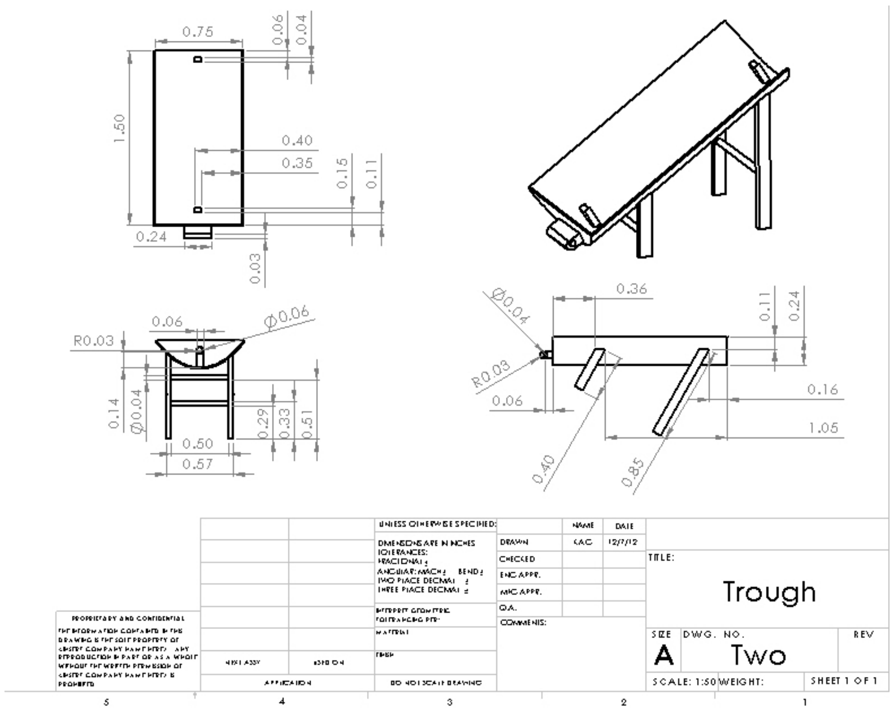

Figure 4 – Trough Dimensions

Theses dimensions did not consider a factor of safety that is necessary as all solar irradiation may not be reflected and captured onto the boiler. As seen from the figure, the overall dimensions of the trough were to be 1.5 meters long and 0.75 meters wide, however this has been changed. The actual dimensions with the factor of safety will be 2 meters long and 0.75 meters wide. The boiler rests at the focal point, which has not changed, at 0.14 meters above the lowest point on the trough. This was calculated using the equation of $y = \frac{x^2}{4f}$ and the depth of the trough being 0.234 meters.

Trough Materials

The trough will be composed of several different materials. There materials create the trough itself, the wood to mold the trough and the reflective materials to concentrate the solar irradiance. These materials are as follows:

1. Sheet Metal: Zinc 24 gage (8ft by 4ft)
2. Particle Board: 5/8" (8ft by 4ft)
3. Screws: 2-1/2 inch Zinc Plated (100 count)

4. Spray Adhesive: “3M Super 77 16.75 f. oz. multi-purpose spray adhesive”
5. Mylar: “Viagrow 25ft Mylar 2mil reflective film”

Manufacturing of the Trough

The manufacturing of the trough will happen in several easy steps. These steps include actual trough construction and application of the reflective material on to the trough. These steps are as follows:

1. Cut particle board into three identical sections, with the help of the machine shop. Each of these sections will be cut into a parabolic trough shape that the sheet metal will eventually be mounted to in order to create the trough.
2. Cut the sheet metal into the required dimensions using the machine shop.
3. Drill holes into the metal at identical locations at both ends and middle of the sheet metal for the screws to pass through into the particle board.
4. Screw in screws using either drills or screwdrivers through the machined holes in metal into particle board to form trough

A note needs to be made here as design for the boiler holder is still uncertain. The boiler holder will be built into the trough and will affect the placement of the Mylar. The design being considered is the design shown in Figure 5 and is highlighted by the red arrows.

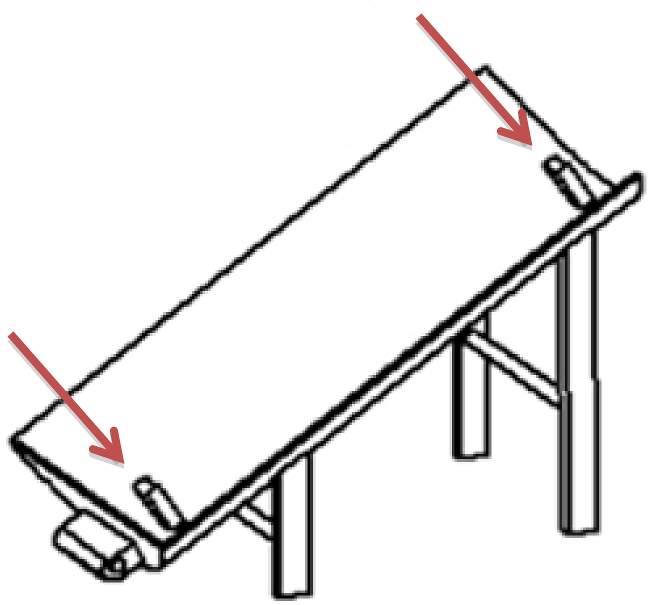

Figure 5 – Trough with Boiler Holder.

After the design for the boiler holder is finalized the last steps for the trough construction can be completed. These steps will pick up from the list given earlier. This continued list is as follows:

5. Apply adhesive spray evenly across trough avoiding screw heads and boiler holding mechanism.
6. Carefully apply Mylar evenly and without ripple across the trough creating an even amount of Mylar across the whole surface.
7. Using a razorblade cut any additional Mylar from edges and around protruding screw headings.

Following this procedure should create an effective solar trough. Using this system in conjunction with the boiler system will produce the heat necessary to sanitize the medical equipment. Additional considerations to be had after the completion of the trough include the design for the frame. This design will be built around the particle board that holds the troughs shape and potentially the design for the boiler holder, although not likely. One consideration for the frame is in Figure 5, which is located below the actual trough in the figure.

Boiler (Eric Brettner)

Since the last report the boiler has been modified. The main function still remains the same – to collect the sun's rays to sterilize the medical equipment. However, instead of pressurizing the water before traveling to the pressure vessel, the boiler and pressure vessel will be an open system. The way this will be achieved is with a petcock located on the pressure vessel. It will allow us to cheaply and efficiently maintain pressure, and therefore temperature. This will be explained further in the pressure vessel section. The boiler will be made from various components; these are listed as follows from the bottom working the way to the top (picture proceeds description.

1. Galvanized 1-1/4" NPT Female cap – this cap will seal the bottom end with a factor of safety of 20 and an upper temperature range of 176°C.

Figure 6 – Female Galvanized Cap.

2. Galvanized 1-1/14” X 10' NPT Male pipe – the pipe is the main body of the boiler that will be collecting the energy and transferring the energy to the water to create the steam needed. This component also has a factor of safety of 20 and an upper temperature range of 176˚C.

Figure 7 – Galvanized Pipe.

3. Galvanized 1-1/4” X 1-1/4” X 3/4" Reducing Tee Fitting – with this fitting attached to the top of the pipe it will allow two points of entry. The perpendicular, or top fitting will allow water to be added to the system when beginning. The parallel fitting will allow the steam to travel down to the pressure vessel. This component also has a factor of safety of 20 and an upper temperature range of 176˚C.

Figure 8 – Female Galvanized Tee Fitting.

4. Galvanized 1-1/4" Plug – this plug will allow the addition of water to the system with then safely sealing the perpendicular section of the tee fitting. This component also has a factor of safety of 20 and an upper temperature range of 176˚C.

Figure 9 – Galvanized Plug.

5. Brass NPT Ball Valve (Male to Female) 3/4" – attached to the parallel end of the tee fitting this will allow (once the boiler is taken out of the sun) a shut off valve, so the sterilized medical equipment can be safely removed. This attachment has a factor of safety of 16 and upper temperature range of 185˚C.

Figure 10 – Brass NPT Ball Valve.

6. Dixon Stainless Steel 316 3/4" NPT Male 3/4" Hose Barb – attached to the female end of the ball valve this will allow a safe connection to the hose that travels to the pressure vessel. Attached over the hose will be a hose clamp to ensure the hose does not come free during use.

Figure 11 – Hose Barb.

7. Gates Durion Silicon Heater Hose inside Diameter 3/4" – the hose will travel from the boiler to the pressure vessel providing steam. The hose has a working pressure of 3.5 bar and an upper temperature range of 204˚C.

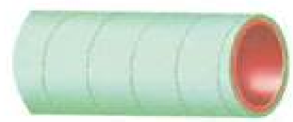

Figure 12 – Gates Durion Silicon Heater Hose.

Pressure Vessel (Blake Lawrence)

Following the boiler, a high temperature and pressure silicone hose will transfer the steam into the pressure vessel that holds the medical equipment. The pressure vessel that will be used for testing will be a modified Mirro Matic 394M 4 Qt. Pressure Cooker. This pressure cooker was determined to act as the base of the pressure vessel unit when it was located at a local Goodwill. This is convenient for testing, and even shows how common one of these devices is, meaning it is possible to obtain in a developing country. The reason this pressure cooker will only be used for testing is because we still intend to prove that this entire design can be made with normal materials. In other words, we want to show that a pressure vessel can be designed without using something "pre-made"; with only using common pots and pans. The design for that pressure vessel will be more detailed in a later section.

Figure 13 - Mirro-Matic 394M 4 Quart Pressure Cooker

A few modifications will be required to create a suitable pressure vessel. The modifications and parts include:

- Adding a pressure regulator
  - Mirro 9898 Pressure Regulator
- Drill ¼" NPT for Tridicator
  - Honeywell TD-165 Temperature & Pressure gauge
- Remove burst disk and replace with proper hose fitting
  - Dixon Stainless Steel 316 1/2" NPT Male 3/4" Hose Barb
- Drill and install a valve on the bottom of the vessel
  - Apollo ½" Brass Ball Valve NPT Full-Port
  - ½" Conduit Nipple
  - ½" Hexagonal Locknut
  - Doublers

The first step will be to drill a ¼" hole symmetrical to the location of the burst disk in the lid of the vessel. This hole will be threaded using NPT standards and will serve as the location of the temperature and pressure gauge, or tridicator. This gauge is important, as it can measure up to 160ºC and 75 psi. It also has a ¼" NPT connector, so it will be able to thread directly into the lid of the pressure vessel. Teflon tape will surround this, as well as any other threaded connection, to create a better seal. This will allow the user to monitor the pressure vessel and become aware if temperatures or pressures are dangerously high. Figure 14 below shows the Honeywell TD-165 Tridicator.

Figure 14 - Honeywell TD-165 Tridicator

Next, the burst disk will be removed, and replaced with a Dixon 1/2" NPT Male to 3/4" Hose Barb. This is where the Gates Durion Silicone Heater Hose will attach, reinforced with a hose clamp and Teflon tape to create an airtight seal. This hose barb is made of stainless steel, and will be able to withstand the high temperatures and pressures the pressure vessel experiences. This attachment can be seen in Figure 15.

Figure 15 - Dixon Stainless Steel 316 1/2" NPT Male 3/4" Hose Barb

Now that the burst disk is removed, a pressure regulator is needed. We will be using the Mirro 9898 Pressure Regulator, which can be set to 5-10-15 psig. For our application, we will use it at 15 psig. This will allow the steam inside the pressure vessel to be created at 121ºC, which is required to completely sterilize the medical equipment. In fact, additional weight will be added to the pressure regulator in order to increase the temperature in which the phase change from water to steam occurs. This will ensure that the steam being created is above the correct temperature. A view of the pressure regulator can be seen below.

Figure 16 - Mirro 9898 Pressure Regulator

Figure 17 - Apollo 1/2" Brass Ball Valve NPT Full-Port

Figure 17 shows the valve that will be placed on the bottom of the pressure vessel. This Apollo 1/2" Brass Ball Valve will be open initially when steam inside the boiler is being created. Once still fills the entire pressure vessel, evacuating any remaining air inside, the valve will be closed. This will cause the steam to condense back into liquid phase, pressurize, and become steam again when the pressure is above 15 psig. The result will be steam at a temperature above 121ºC. Once the pressure regulator starts rapidly releasing steam, we know the temperature and pressure requirements have been met. The medical equipment must then stay in contact with the steam for at least 15 minutes to fully eliminate all prions associated with bacteria.

This valve will be attached by drilling a 1/2" hole in the direct center of the bottom of the pressure vessel. It has a maximum pressure of 600 psi and can withstand 400ºF temperatures, which is much higher than we will create. Doublers will be used to reinforce the connection between the 1/2" Galvanized Conduit Nipple, the locknut, and the Apollo valve. Companies such as Boeing use doublers to attach antennas to airplanes. They will help evenly spread the pressure when the steam pushes down on the valve from inside. Additional analysis will be done to ensure the pressure vessel remains safe after attaching these modifications. Each of these parts was specifically chosen because they can withstand the temperatures and pressures during the autoclave process.

Homemade Pressure Vessel Design (Yuchen Liu)

For now, we already have a pressure vessel to modify and use for testing. However, in order to prove that the pressure vessel can be built from readily available materials as our client asked, we are going to design a modified homemade pressure vessel.

The modified pressure vessel mainly consists of 6 parts:

1. Lid
2. Pot
3. Gasket
4. Valve
5. Hose fitting
6. Temperature and pressure gauge

The lid and pot options are still being considered, and can be found online or in person. As for the valve, hose fitting and temperature/pressure gauge, these materials can use the one we are going to apply on the pressure vessel as mentioned on the previous section detailing the modified

Mirro Matic pressure cooker. The gasket will need to purchased from online. Before that, it is necessary to determine which one is suited for the modified pot.

There are several gasket materials available. After research, it is found that the metal jacketed gasket is the proper one to use for the autoclave. Following are the summaries for different gasket materials:

Cork:

- Suited for confined application
- Can be easily shaped
- Tend to crumble
- Recommended for use <275°F (=135°C)
- Low pressure duties

Figure 18 – Cork Gasket

Leather:

- Tough, pliable, relatively resistant to abrasion
- Porous (absorb lubricating fluids)
- Must be tanned and treated
- Recommended for use <220°F (=104°C)
- Never used with steam pressure of any type

Figure 19 – Leather Gasket

Silicone:

- Recommended for use <450°F (=232°C)
- Useful in outdoor settings
- Not oil or steam

Figure 20 – Silicone Gasket

Metal jacketed:

- Specially designed and widely used for autoclaves, pressure vessels
- Economical
- Recommended for use <900°F (=482°C)

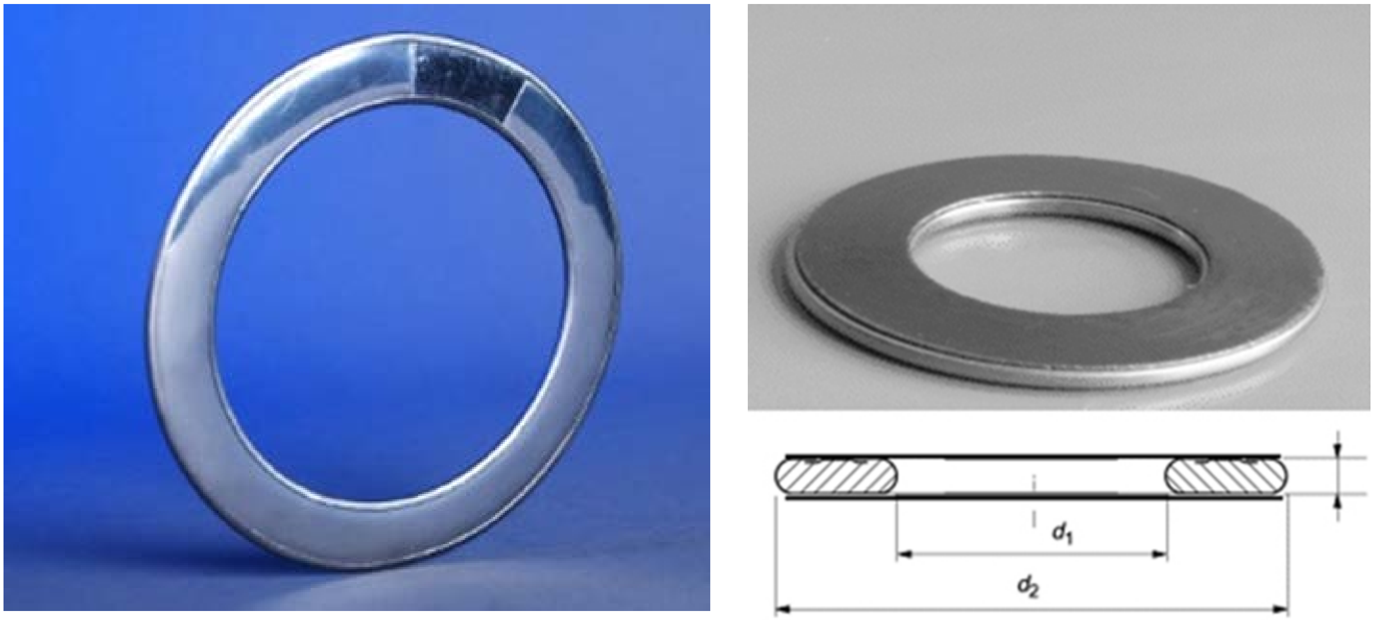

Figure 21 – Metal Jacketed Gasket

Conclusion (Yuchen Liu)

Our task for this project is to develop a solar autoclave for rural areas that uses the energy of the sun to satisfy the sterilization requirements. The design should be flexible from location to location, the materials used should be readily available, and the parts in the design should be able to repaired or replaced from local materials.

The final design mainly consists of three parts: a trough, a boiler, and a pressure vessel which acts as the autoclave. The materials that will be used in the final design have been chosen, and the bill of materials is summarizes the cost as shown in Appendix A (Table 2). The team will start ordering the materials so that construction may begin. The construction of the trough, as well as the pressure vessel modification will start right after the main components are in hand, following by the manufacturing of boiler. We are still on track and will follow the tentative timeline as shown in Figure 22 below. We expected to finish the manufacturing and collaboration by the first week in March 2013 in order to leave enough time on testing and evaluation.

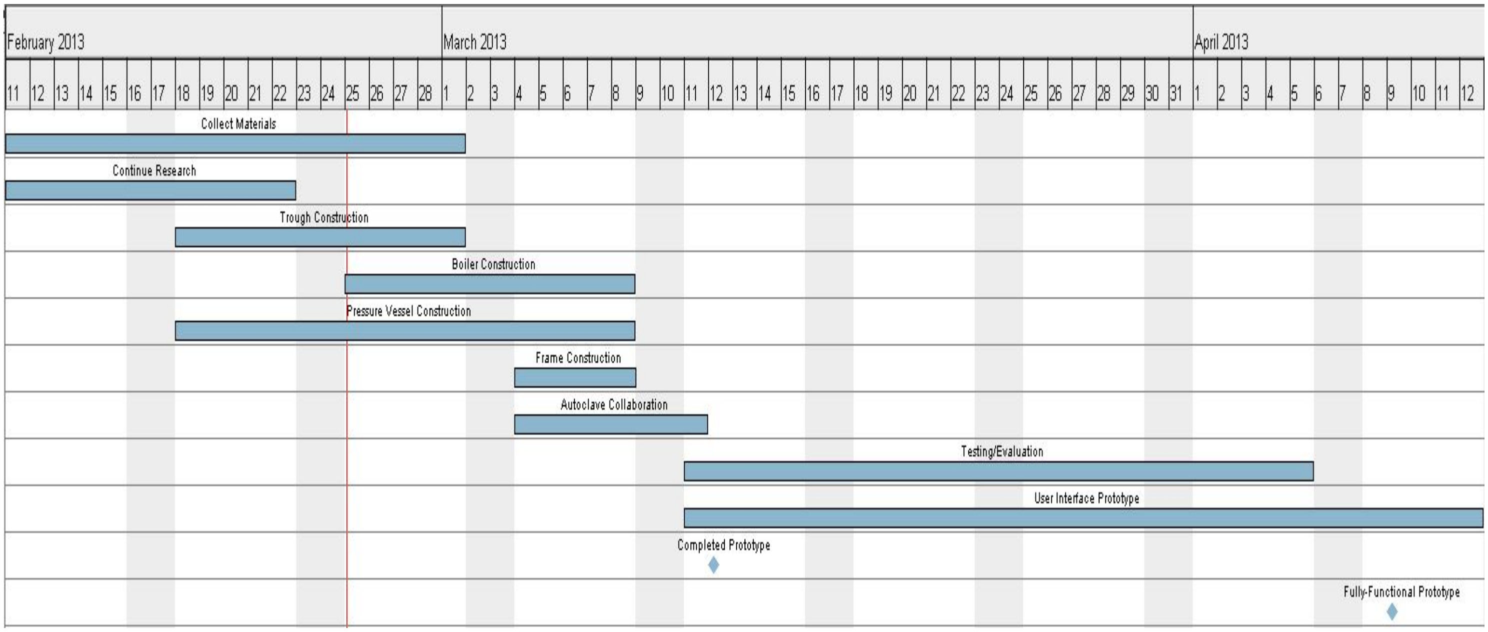

Figure 22 – Gantt Chart

Appendix A (Yuchen Liu)

Table 1: The Bill of Materials

		Material	Quantity	Unit Cost ($$)	Source	Details	Cost ($$)
Trough	1	Sheet Metal	1	20.00	Copper State	Zinc 24 gauge (8ft*4ft)	20.00
	2	Particle Board	1	17.32	Home Depot	5/8" (8ft*4ft)	17.32
	3	Screws	1	19.99	Home Depot	2-2inch Zinc Plated (100 count)	19.99
	4	Spray Adhesive	1	5.77	Home Depot	3m super 77 16.75 f.oz.	5.77
	5	Mylar	1	18.96	Home Depot	Viagrow 25ft mylar 2mil reflective film	18.96
Boiler	6	Schedule 40 Galvanized Pipe	1	36.75	Home Depot	1.25"*10' long cut to 2 meters	36.75
	7	Cap	1	6.64	Amazon	1-1/4”	6.64
	8	Reducing Tee	1	11.42	Amazon	1-1/4" x 1/2" x 1-1/4"	11.42
	9	Galvanized Plug	1	3.95	Amazon	1-1/4"	3.95
	10	Brass Ball Valve	1	14.96	Amazon	3/4" Male to Female Brass Ball Valve	14.96
	11	Tape	1	0.97	Home Depot	1/2" x 260 in. PTFE Tape	0.97
	12	Hose	6	8.20	O'Reilly	Gates Durion Silicone Heater Hose	49.20
Pressure Vessel	13	Hose fitting	1	25.50	Amazon	Dixon 3/4"X1/2"	25.50
	14	Hose fitting	1	25.50	Amazon	Dixon 3/4"X1/2"	25.50
	15	Valve	1	8.56	Home Depot	1/2" Brass Ball Valve	8.56
	16	Insulation	1	5.98	Home Depot	3" x 25' Foil-backed Fiberglass	5.98
	17	Pressure Regulator	1	17.95	Amazon	5-10-15 psig	17.95
	18	Pressure/ Temperature gauge	1	22.97	Honeywell	TD-165 1/4" NPT connection	22.97
	19	Miscellaneous	1	15.00	Home Depot	Locknuts, Conduit Nipple, Washers	15.00
	20	Total	24	**327.39**			**327.39**

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Boiler:

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