EPA Water Disinfection

Project # P07401

Solar Pasteurizer with Integral Heat Exchanger
(SPIHX)

Rochester Institute of Technology
Multidisciplinary Engineering at RIT
Preliminary Design Packet
February 16, 2007

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I. Introduction

1. Background

The World Health Organization stated in a report entitled, “Water for Life”, that diarrhoeal diseases claim the lives of 5,000 young children throughout the world everyday. The lack of clean drinking water throughout the world can also cause social instability if not death. The United Nations has also expressed concern through the Millennium Development Goals which are eight goals that address global problems and are aimed to be achieved by 2015. Some of these goals are eradicating hunger and poverty, achieving universal primary education, and reducing child mortality.

2. Sponsorship

In accordance with this global concern, a grant awarded by the Environmental Protection Agency will provide funding for the research and development of a solar water pasteurizer. The grant is part of their P3 competition in which students devise various methods and products to address the well being of *people, prosperity,* and *planet*.

3. Customers

People of third world regions who lack access to clean, safe drinking water are the customers whose needs are to be met. Because there was no effective way to communicate between the customers and the design team on a global scale, Venezuela was targeted as a primary customer. Venezuela was chosen because the team had faculty members who had established points of contact with local Venezuelan non-governmental organizations and churches who worked closely with poorer sections of the country.

4. Mission Statement

The project mission is to design, construct, and test a working prototype of water pasteurizer that utilizes solar energy.

II. Customer Needs and Specifications

1. Customer Needs

Table II.1.1 below provides a summary of customer needs that were devised by the team members, team guide, and other faculty advisors. There was no direct communication with people of Venezuela or other third world regions but question and answer sessions were held with faculty members and an RIT graduate who has helped install UV light water disinfection units in Haiti.

The needs were ranked by the team members using a 1-3-9 matrix in which 1 indicated a low importance and 9 indicated high importance.

The list of needs divided themselves well into categories which are indicated in bold headings in table II.1.1. From the needs assessment exercises and after numerous discussion the team focused on a design that can be easily manufactured, easily operated, safely operated, inexpensively fabricated, and easily purchased by the end user low financial standing.

Need #	Need	Importance*
1	**SOLAR PASTEURIZER SHOULD BE ECONOMICAL**	**X**
1.1	Use resources readily available in the developing world	9
1.1a	Will not use specialized imported system components	3
1.2	Use fabrication techniques readily available in the developing world	9
1.3	Should be functional without electrical power	9
1.4	Should not require scarce fuel wood	3
1.5	Should not require a source of chlorine	3
1.6	Should be affordable	9
1.6a	Cheap to produce	3
1.6b	Cheap to purchase	9
1.6c	Cheap to own (little or no maintenance)	9
1.7	Should be durable	9
2	**SOLAR PASTEURIZER SHOULD BE SAFE**	**X**
2.1	Will disinfect the water source available to that area	9
2.2	Will thermally kill pathogenic protozoan, bacteria, and viruses below the boiling point	9
2.3	Will be able to handle sediment in the water	3
2.4	Will be failsafe (tamper proof)	9
2.5	Will entail a treated water testing system to ensure a quality end product	3
3	**SOLAR PASTEURIZER SHOULD BE VERSATILE**	**X**
3.1	Will be effective on different sources of water	9
3.2	Will work for either home, school, or small clinic applications	3
3.3	Can be used in different countries (language, climate, etc.)	3
3.4	Will be easily integrated into existing water system	3
4	**SOLAR PASTEURIZER SHOULD BE EASY TO OPERATE**	**X**
4.1	Will be low maintenance	3
4.2	Will be operable by a person with little education	9

Table II.1.1 – Summary of needs assessment.
X = n/a, 1 = low importance, 3 = medium importance, 9 = high importance.

The design was approached with the understanding that this was a first in an attempt to prototype a working solar water pasteurizer. The team was advised by the team guide, Dr. Robert Stevens, that a prototype may have greater incurred costs. Also, the product was designed with the idea that mass production and government subsidies may help drive costs down.

2. Specifications

Target specifications are quantifiable metrics that the team can use to measure how well they have achieved the goals in order to meet the customer needs. Table II.2.1 provides a summary of metrics that correspond to specific needs of table II.1.1 along with the importance of the metric. Again the importance was weighted using a 1-3-9 measure.

Metric No.	Need Nos.	Metric	Imp.	Units	Marginal Value	Ideal Value
1	1.6, 1.6a, 1.6b, 1.6c	Cost per unit to manufacture	9	$	60	25
2	1.1, 1.1a	# of parts imported	9	#	5	0
3	1.1, 1.1a	% of total cost for imported parts	9	%	30	0
4	1.2, 1.1, 1.1a	Local fabrication possible	9	% of component type	80	100
5	1.3, 1.4, 1.5	Use of chlorine, wood, electricity	3	y/n	n	n
6	2.1, 2.2, 2.5, 3.1	Reduction of *Entamoeba histolytic*	9	log	4	5
7	2.1, 2.2, 2.5, 3.1	Reduction of *Cryptosporidium parvum*	9	log	4	5
8	2.1, 2.2, 2.5, 3.1	Reduction of *Cyclospora cayetanensis*	9	log	4	5
9	2.1, 2.2, 2.5, 3.1	Reduction of *Giardia lamblia*	9	log	4	5
10	2.1, 2.2, 2.5, 3.1	Reduction of *Schistosoma*	9	log	4	5
11	2.1, 2.2, 2.5, 3.1	Reduction of *E. Coli*	9	log	4	5
12	2.1, 2.2, 2.5, 3.1	Reduction of *Salmonella typhi*	9	log	4	5
13	2.1, 2.2, 2.5, 3.1	Reduction of *Shigella*	9	log	4	5
14	2.1, 2.2, 2.5, 3.1	Reduction of *Hepatitis A*	9	log	4	5
15	2.1, 2.2, 2.5, 3.1	Delta T between ambient & fluid in pasteurization section	9	delta °C	40	40+
16	2.1, 2.2, 2.5, 3.1	Reached equivalent Safety Zone*	9	y/n	y	y
17	1.7, 2.1, 2.3, 3.1	Handle sediments	3	y/n	n	y
18	1.7, 4.1, 4.2	Output before unexpected failure**	9	L	7300	36500
19	1.7, 4.1, 4.2	Average time for scheduled maintenance	1	min	2	1
20	2.4	Leak proof	1	y/n	y	y
21	1.7	Thermal cycling until failure**	3	# cycles	1000	2000
22	3.1, 3.2, 3.3, 3.4	Average daily potable output for typical Venezuelan climate	3	L / day	20	40
23	4.2	Usability	9	1-10 rating	6	8+
24	1.7, 4.1	# of moving parts	3	#	2	0

*Equivalent safety zone is a reference safety zone curve shifted by an applicable delta °C that fits test conditions

**Due to required completion date of April 6th, testing may not get done.

Table II.2.1 – Summary of specifications the team can quantitatively measure the success of the project. The 1-3-9 metric was used once again where 1 indicated low importance and 9 indicated high importance.

Two values, marginal and ideal, were devised for each specification by the team through several discussions along with guidance from Dr. Stevens. The two values can be simply thought of as “values that the team *should* achieve” and “values that the team would *like* to achieve” for marginal and ideal values respectively.

III. Design of the Solar Pasteurizer

Detailed drawings of the design can be found in the appendix at the end of the Preliminary Design Packet.

1. Pasteurization of Water

Pasteurization is a function of temperature and time. This is best defined by figure III.1.1 in which the curve indicates the time required to pasteurize for a given curve. Hence, the region above curve is called the safety zone.

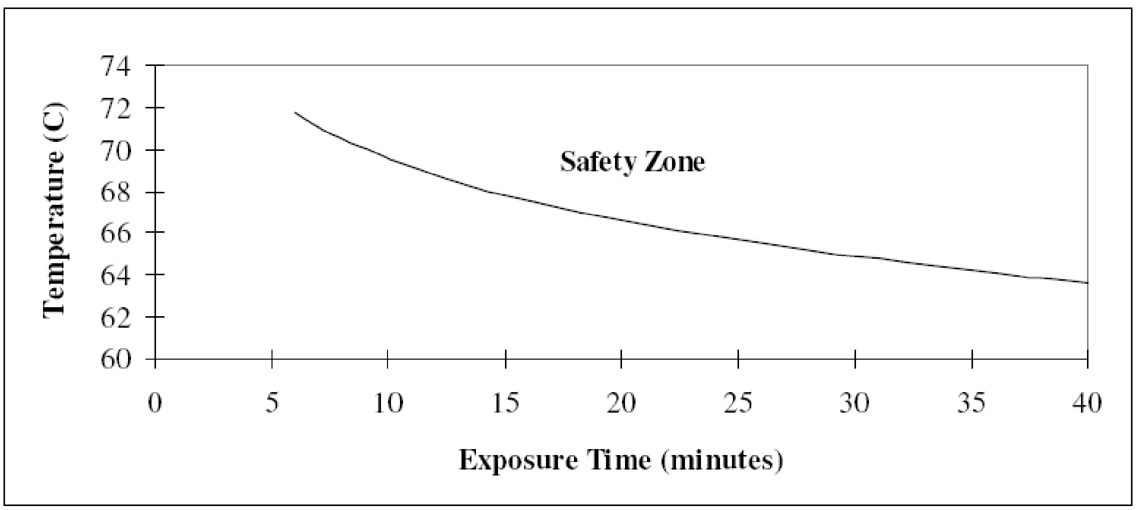


Figure III.1.1 – Safety Curve.
A pasteurization process only has to cross into the safety zone at one point to be effective.
(Reproduced from “An Investigation of a Solar Pasteurizer with Integral Heat Exchanger” by Robert Stevens)

2. Solar Water Pasteurizer with Integral Heat Exchanger (SPIHX)

The ultimate objective of the SPIHX is to capture heat energy from solar energy, bring water up to pasteurization temperatures, and then have the heated water flow in a counter flow direction to that of the cooler, incoming water. This integral heat exchanger design allows for heat recovery and greater outputs.

An integral heat exchanger design was called out for in the scope of the project and in the proposal for the EPA grant. The integral heat exchanger is one in which the heat exchange mechanism is enclosed within the pasteurizer assembly whereas an external design would have the heat exchanger located outside of the pasteurizer enclosure.

The team's design of the solar water pasteurizer can be best viewed as long, rectangular, and having many layers.

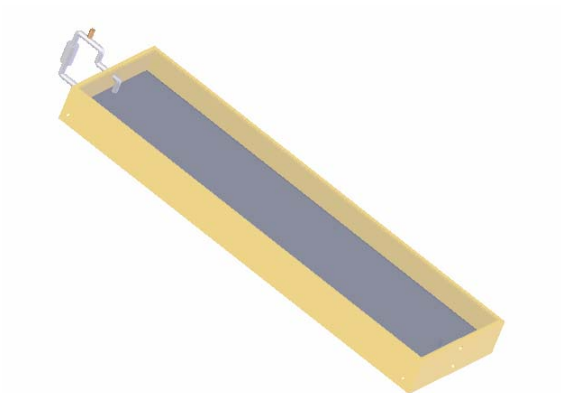


Figure III.2.1 – Solar Water Pasteurizer with Integral Heat Exchanger (SPIHX)

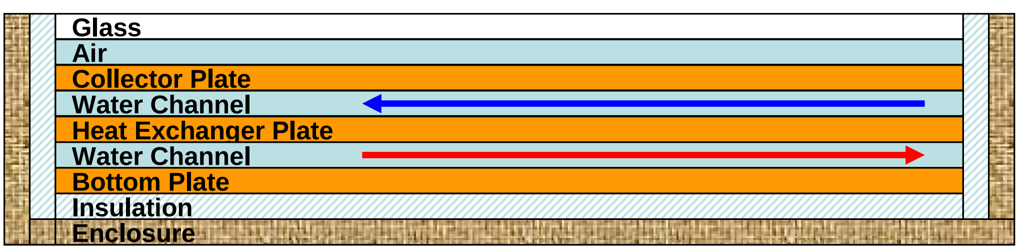


Figure III.2.2 – SPIHX sectional view.
The colder, unpasteurized water is pasteurized due to heat transfer through the collector plate. Upon pasteurization, it is routed in a counter flow direction for heat recovery.

The top layer consists of a thin glass that allows sunlight to penetrate while trapping in heat along with the layer of air. The collector, heat exchanger, and bottom plates are all made of the same metal material. The collector plate is coated on the top with a chemical that is specially designed to provide high values of adsorptivity and low emissivity of sunlight thus, adding to the heat transfer rate. The heat exchanger plate acts as the dividing wall and heat exchange medium between incoming, cooler water and outgoing, warmer water. Insulation on the bottom and around the sides minimizes heat loss and the enclosure acts as the structural casing as well as providing protection from ambient conditions.

It is important to grasp the scale of dimensions of the various layers of the pasteurizer. The glass is 1/16" thick followed by an 8 cm gap of air. The collector, heat exchanger, and bottom plates are on the order of 0.016 mm to 1 mm. And the water channels are 5 mm in height. Heat transfer is maximized with decreasing thicknesses of the plate material and decreasing heights of the channels.

Copper, aluminum, steel, and polymers with good heat transfer properties were looked at by the team. Due to surging costs of copper and corrosive attributes of steel, the team selected aluminum as the material of choice. Polymers are usually the economical solution when compared to metals for most applications. However, the cost to fabricate very thin thickness and channel heights was determined to be too expensive. Fiber glass and plywood were selected as the material for the insulation and enclosure, respectively, to minimize cost.

3. SPIHX and External Components - Assembly Overview

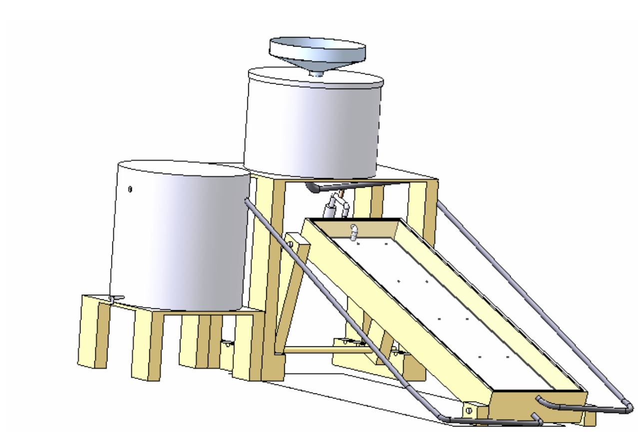


Figure III.3.1 – Front view of the pasteurizer assembly

The overall assembly, shown in figure III.3.1, consists of two 5-gallon buckets. The inlet storage bucket, placed at a higher elevation, provides the pressure to drive unpasteurized water through the entire system. A funnel with a metal mesh at the end is fitted to the lid of the bucket as a means to filter out sediments that may collect in the pasteurizer over time. At the outlet, another bucket is placed at a slightly lower elevation to account for pressure losses and receive pasteurized water.

UV resistant PVC tubing (shown in black) routes water into and out of the pasteurizer.

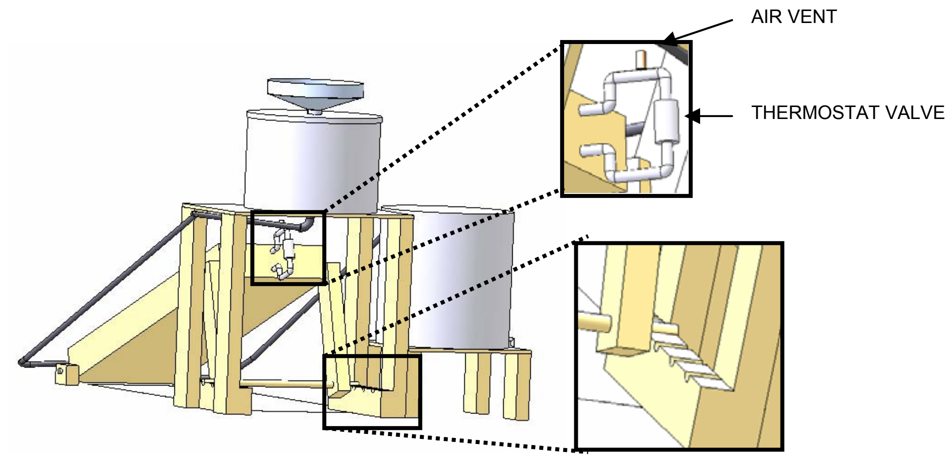


Figure III.3.2 – Back view of the pasteurizer assembly.
The tubing making U-bend and shown in white contains the thermostat valve housing and an air vent to address the release of air within the collector plate.

A thermostat valve ensures that water has reached the required pasteurization temperatures before it can continue its path down into the next channel in a counter flow direction. The thermostat valve was acquired from an auto parts store. It is the same wax-filled radiator thermostat valve for a car.

Bendable aluminum tubing will allow for a U-turn bend without the need for elbows which can increase costs. At the top most point of the U-bend is an air vent. Because water releases oxygen as it gets heated, the air vent will address the need to remove any air bubbles that may block flow. The air vent and thermostat valve housing are highlighted in figure III.3.2.

Solar energy is best harnessed when a large surface area is angled such that sunlight reaches the area perpendicularly. Hence, a test stand was devised that allowed the angle of the pasteurizer to be adjusted by utilizing a series of notches grooved into the base of the inlet storage bucket support as shown in figure III.3.2.

4. Special Subcomponents

In order to make local fabrication possible in Venezuela or any other third world region, the team tried to keep specially made parts to a minimum in fear of not having them available in developing regions. However, the following items had to be ordered directly from the manufacturer.

4.1 Air Vent

Since it is anticipated that air buildup will occur within the system, which would lead to flow blockage, an air release valve has been incorporated into the design. Due to the small operating pressures, it has proven laborious to design and manufacture a reliable air release valve for a low cost. Instead a commercially available low cost air release valve was selected to be used on the system. The Honeywell GoldTop Air Vent, commercially used for heating and cooling systems was selected.

Honeywell Gold Top Air Vent
Connection Type: 1/8" NPT
Material: Brass
Operating Pressure: 1-150 psi
Weight: 0.18 kg; 0.4 lb
Dimensions: 1 27/32" high, 3 ¼" long; 24 mm high, 83 mm long
Vent rate (@1psi): ~ 0.2 scfm
Manufacturer Info: Honeywell USA (www.honeywell.com)

The valve may be purchased at any of the Honeywell authorized dealers as well as many other HVAC supply retailers. The test valve was purchased at PlumbingSupply.com for a retail price of **$11.01**.

4.2 Thermostat Valve

To control the flow within the pasteurizer and allow only pasteurized water to pass through, an automobile thermostat valve was chosen as the most cost effective, reliable option. The automobile thermostat valve is virtually present in all modern water cooled vehicles and is readily available in any auto parts store. This alone was the main reason why it was chosen to be a part of the design. The valve is factory set to open at a specific temperature, depending on the valve. For initial testing purposes a 71°C valve was chosen, however the design can accommodate valves rated at different temperatures. The valve housing is represented in the accompanied drawings. The test valve was purchased at the local parts store Advance Auto Parts. Information on the valve is shown below.

Stant Manufacturing Thermostat 13006 (160°F/71°C):

Dimensions: 1.6" high when closed, 1.85" high when fully open,
2.1" wide, including seal ring
Price: $3.97 retail (Advance Auto Parts, Rochester NY)

Manufacturer Info: Stant Manufacturing, Inc
A Thomkins Company
Connersville, Indiana 47331 USA
www.stant.com

IV. Engineering Analysis & Modeling

1. Excel Spreadsheet

In order to model the flow of the water through our heat exchanger, we set up an Excel spreadsheet in order to calculate the flow rate of the water. This flow is changing throughout everyday, based on the solar radiation available to heat the water, so the flow rate was calculated for every hour for an entire year. Hourly weather data was not available for Venezuela, but we were able to find hourly data for San Juan, Puerto Rico that closely resembled the weather in Venezuela. The equation for the steady-state flow rate was modeled in *An Investigation of a Solar Pasteurizer with an Integral Heat Exchanger* by Dr. Robert Stevens and is

$$\boxed{m = \frac{C_3}{\ln\left(C_4\left(C_5 - C_6 e^{\frac{C_7}{m}}\right)\right)}}$$

These constants are calculated through a large series of equations based on many different parameters that account for losses from the system, different forms of radiation coming into the system, and the effects of material properties and sizes on heat transfer. The spreadsheet was set-up so that these parameters could be changed in order to maximize our flow rate while keeping the cost of the final system down. So with this spreadsheet, we were able to decide on materials and sizes for our final design. The main parameters that affected the output and the values chosen for them are shown in Table IV.1.1

Width Collector	0.25	m
Length Collector	1	m
Area Collector	0.25	m^2
Thickness of Channel	0.0047625	m
collector efficiency factor, F'	0.95	
valve open temperature, T_{past}	75	°C
thickness of collector	0.001	m
thickness of glass	0.0015875	m
thickness of air between plate and glass	0.08	m
thickness of heat exchanger	0.001	m
thickness of bottom plate	0.001	m
thickness of insulation	0.03	m
thickness of plywood	0.0127	m
thermal conductivity of insulation, k_{ins}	0.046	W/m-K
conductivity of plywood, k_{ply}	0.13	W/m-K
emissitivity of collector plate, ε_p	0.49	
emissitivity of glass, ε_{g1}	0.88	
tilt angle of collector, s	10	°
Latitude	10	°N
solar absorptance value of collector, α	0.88	
ρ of plates	7854	kg/m^3
C_p of plates	434	J/kg-K

Table IV.1.1 – Parameters that affect output flow.

An example of the effect of the size of the collector plate on the average daily output per month is shown below in Figure IV.1.1. This shows that as the collector area is increased, the output of potable water is increased, but when we go to collector areas as high as 0.5 m^2, the cost of the collector plates and heat exchanger become too expensive for our design. This model of our flow led us to decide on a collector area of 0.25 m^2.

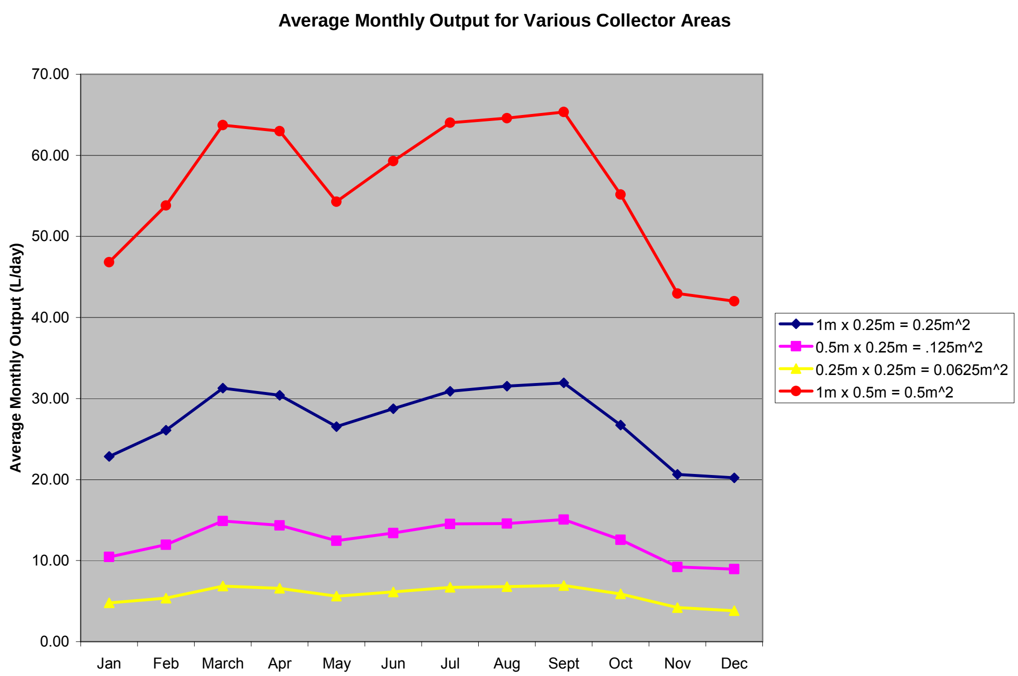


Figure IV.1.1 – Average daily outputs for each month for various collection areas.

The flow rates found above do not take into account the transient period at the beginning and end of each day. There will be a period of time after the solar radiation begins before the water reaches pasteurization temperature and starts flowing. The warm-up time that is required each day was found, and this gave us a better expectation of how much water could actually be pasteurized each day. The model of the transient process is

$$\boxed{Q'' = M_{thermal}\left(T_{final} - T_{initial}\right) + U_L \Delta t\left(\frac{T_{init} + T_{final}}{2} - T_a\right)}$$

$$\boxed{T_{final} = \frac{Q'' + M_{therm}T_{init} - \dfrac{U_L \Delta t T_{init}}{2} + U_L \Delta t T_a}{\left(M_{therm} + \dfrac{U_L \Delta t}{2}\right)}}$$

Where the thermal mass is defined as

$$\boxed{M_{thermal} = \left(\rho d C_p\right)_{metal} + \left(\rho d C_p\right)_{water}}$$

Four days were chosen throughout the year, one in each season, to illustrate the pattern of the water temperature throughout the day starting at midnight. This is shown in Figure IV.1.2.

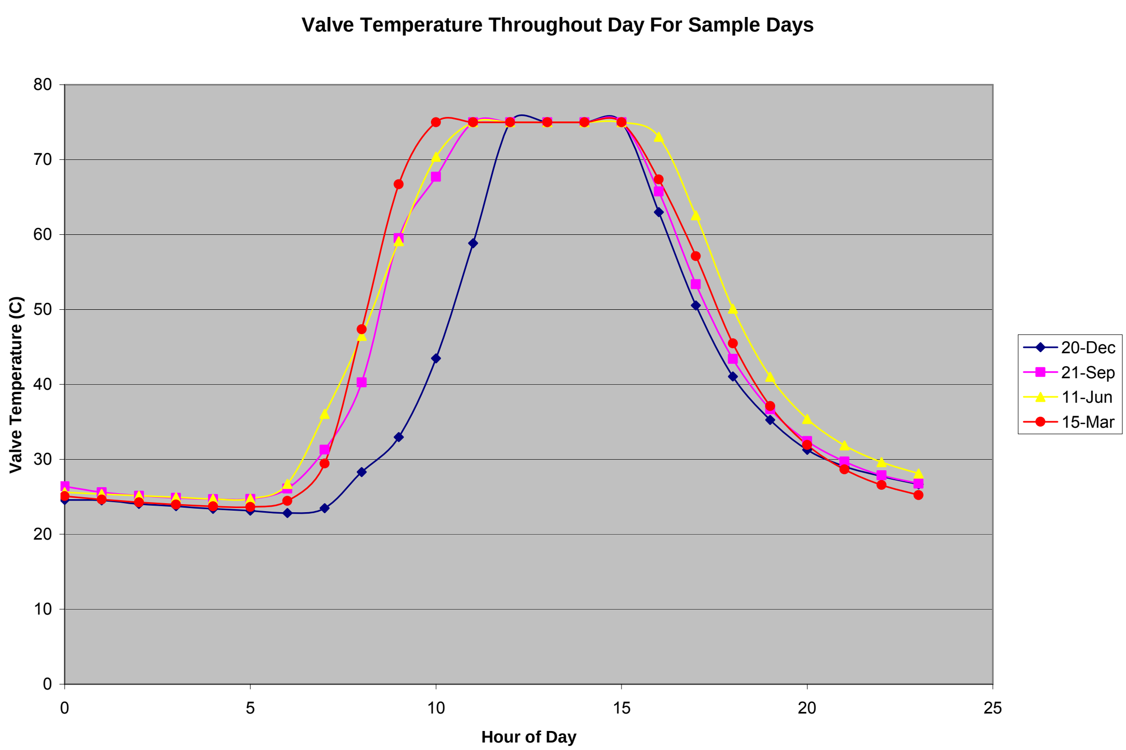


Figure IV.1.2 – Valve temperature for each hour of the day for 4 sample days.

The warm-up time for the system is affected by the thickness of the channel that the water is flowing through. A thinner channel would allow for a faster warm-up and therefore allow for a larger output for the day. Once these channels become too thin, it gets harder to manufacture the system. The effect of the channel thickness is illustrated in Figure IV.1.3, and with this we decided on a channel thickness of 0.5 cm. When analyzing our manufacturing for the system, the mold that will be used to form the plates will actually allow for a channel thickness of 0.47625 cm.

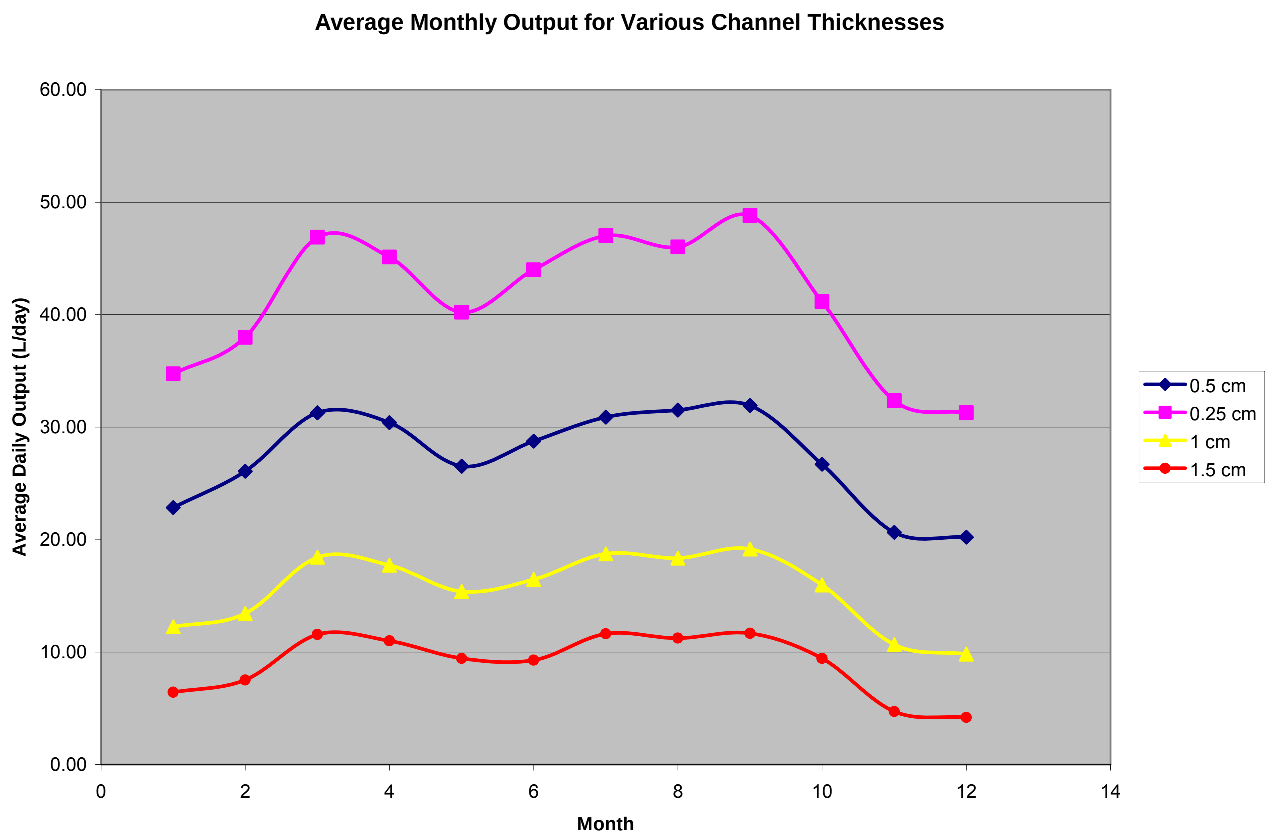


Figure IV.1.3 – Average daily outputs for various channel thicknesses.

With the collector area and channel thickness decided, along with all of the material properties and sizes, the average daily output for each month was found. This table gives the average daily output for each month and ensures that the output is always above 20 L/day which is our target value.

Jan	***Feb***	***March***	***Apr***	***May***	***Jun***
23.73	27.33	32.65	32.29	28.00	31.24

Jul	***Aug***	***Sept***	***Oct***	***Nov***	***Dec***
33.06	33.36	33.56	28.12	21.75	21.23

Table IV.1.2 – Average daily outputs for each month with the set parameters.

2. Thermal Expansion

The plates were analyzed to see how much they would expand with the temperature change in order to assure that there is enough room in the slots for them to expand. An example of how the plate will expand is shown in Figure IV.2.1.

$L_o \approx$ 1mm
α = 24x10^{-6}/°C (for aluminum)
$\Delta T \approx$ 75°C-25°C

Figure IV.2.1 – Thermal expansion of plate where the black area represents the plate and the gray area represents the expansion area.

$$\alpha = \frac{\Delta L / L_o}{\Delta T} \Rightarrow \qquad \Delta L = \alpha L_o \Delta T \approx \left(\frac{24\times10^{-6}}{{}^\circ C}\right)(1\ mm)(75^\circ C - 25^\circ C) \approx 0.0012\ mm$$

This expansion is very minimal compared to our thickness of the plate. The slots in the case where the plates slide in only need to be manufactured about 0.002mm thicker than the plate.

3. Temperature of Outside Surface

The heat loss through the bottom of the collector was found in our original calculations using the equation

$$U_{bottom} = \frac{1}{A_{collector}\left(R_{cond} + R_{conv}\right)}$$

The losses from convection on the bottom surface are negligible compared to the losses from conduction through the insulation and the casing. The resulting equation takes into account l_{ins} and l_{case} which are the thickness of the insulation (.03m) and the case (.0127m) respectively. It also takes into account k_{ins} and k_{case} which are the thermal conductivity of the insulation (.046 W/m-K) and the case (.13 W/m-K) respectively. Therefore the equation becomes

$$U_{bottom} = \frac{1}{A_{collector}\left(\dfrac{l_{ins}}{k_{ins}A_{collector}} + \dfrac{l_{case}}{k_{case}A_{collector}}\right)} = \frac{1}{\left(\dfrac{l_{ins}}{k_{ins}} + \dfrac{l_{case}}{k_{case}}\right)} = \frac{1}{\left(\dfrac{.03\ m}{.046\ \dfrac{W}{m\cdot K}} + \dfrac{.0127m}{.13\ \dfrac{W}{m\cdot K}}\right)}$$

$$U_{bottom} = 1.334\ W / m^2 \cdot K$$

This heat transfer coefficient through the bottom can then be used to find the heat transfer rate between the water in the bottom channel, which is a maximum of 75°C (348 K), and the ambient air, which never goes above 306 K. The equation for this heat transfer rate through a composite wall is

$$\frac{\Delta T}{q} = \frac{1}{UA} \Rightarrow \qquad q = UA\Delta T = \left(1.334W/m^2 \cdot K\right)\left(0.25m^2\right)\left(348K - 306K\right) = 14.01\,W$$

Now backing up to find the surface temperature, this equation can be applied from the water in the bottom channel to the surface with the same heat transfer rate. For the surface temperature, $\Delta T = (348K - T_s)$

$$\frac{\left(348K - T_s\right)}{q} = \frac{1}{UA} \Rightarrow \quad T_s = 348K - \frac{q}{UA} = 348K - \frac{14.01\,W}{\left(1.334W/m^2 \cdot K\right)\left(0.25m^2\right)} = 306K$$

The bottom surface of our system is about 33°C ≈ 91.4°F at the highest ambient temperature and highest water temperature.

4. Stress Analysis

Stress and deflection analysis was done on the top plate of the heat exchanger. There were multiple analysis tests to find a factor of safety above 1 with minimal amount of deflection and stress. Different plate thickness, aluminum alloys and the amount of dimples were all varied to find an optimal top plate for the heat exchanger.

The dimples are used to strengthen the heat exchanger throughout the top and bottom plates, both will be designed and fabricated in the same way. The figures are all shown with a scale used to help clearly show where deflections and stresses occur since both are often minuscule when compared to the rest of the part.

The first test was conducted with no dimples and was fixed along its outer edges and with a uniform pressure of 13.8 kPa applied to the underside. Figure IV.4.1 shows how the plate reacts to the pressure without support from the dimples.

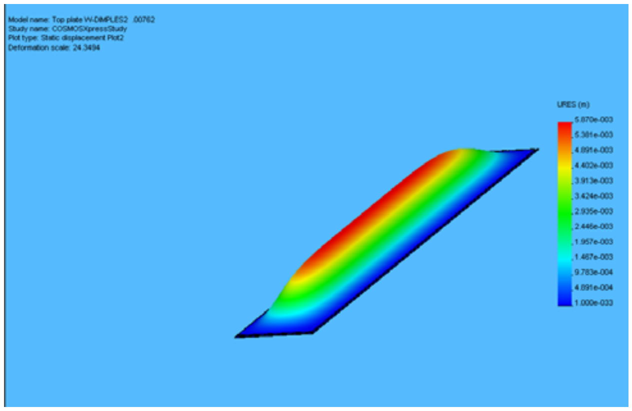


Figure IV.4.1 – No dimples - shown
on a scale of 24.34 max deflection of 5.87e-3

Fifteen dimples were then drawn into the model. Another analysis was done by fixing the sides of the plate as well as the bottom of the fifteen dimples, this will replicate the dimples being welded to the middle plate of the heat exchanger. Again a 13.8kPa pressure was applied to the underside. Figure IV.4.2 shows the improvement of deflection from the first analysis, from 5.87mm to 2.28mm. Even with such improvement in deflection the stress analysis produced a max stress above the yield strength, hence failing. This is shown in Figure VI.4.3.

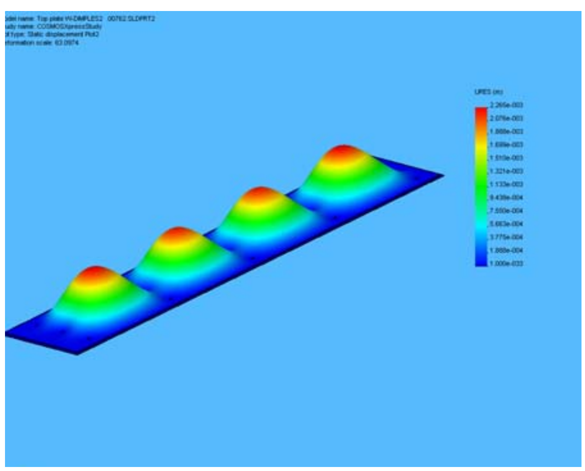


Figure IV.2.2 – 15 Dimples – Shown on a scale 63.09
max deflection 2.285e-3m

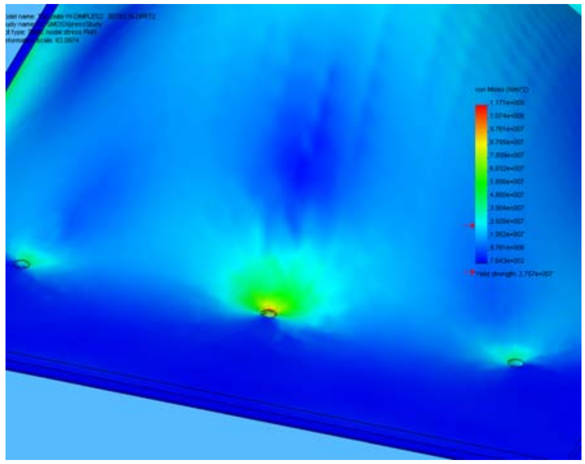


Figure IV.4.3 – 15 Dimples – Shown on a 63.09 scale max Von Mises stress 1.17e8N/m^2

After varying the above specifications it was found that 85 dimples produced a satisfactory factor of safety of n=1.53 with all the stress below the yield strength by an order of magnitude. Figure VI.4.4 and figure VI.4.5 show both the deflection and the stress analysis for the.

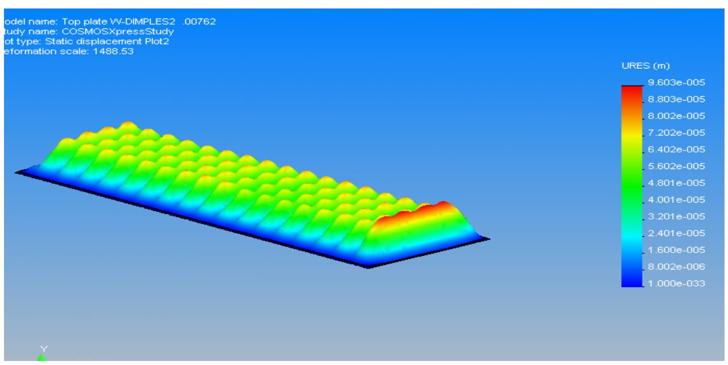


Figure IV.4.4 – 85 dimples - Shown on a scale of 1488.53 Max displacement 9.603e-5m

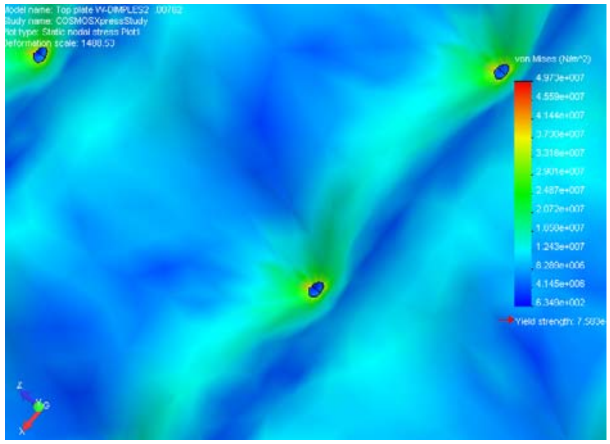


Figure IV.4.5 - Shown on a scale of 1488.53 max Von Mises stress 9.73e7N/m^2

It was determined that the addition of dimples creates a much stronger heat exchanger. There were assumptions used in the analysis. The dimples were all fixed in space, this will not be the case when built. The top plate will be attached to the middle plate, the middle plate is attached to the bottom plate. It will be possible for some fluctuation through the three plates. A constant uniform pressure was applied during the analysis, when filling and if emptied there will be a changing pressure. For simplicity of the analysis thermal expansion was not taken into account.

V. Test Plans

In order to investigate the performance of the prototype and verify that it is in accordance with the engineering analysis the following test procedure was written for review and improvement.

1. Pasteurizer Testing

Purpose: This protocol describes all the tests that will be performed on the solar water pasteurizer, in order to verify its operating characteristics and capabilities. The tests are separated by subfunction, however most of the tests will be performed simultaneously with other sub-function tests.

Scope: This protocol scope encompasses only the tests associated with the RIT built solar pasteurizer, P07041.

Location: The following tests will be performed outdoors at the Rochester Institute of Technology, Rochester, New York, during March-April 2007.

Test Stand: Please refer to the accompanied drawings of the test stand and adjoining sub components. The test stand will include an adjustable base, allowing the pasteurizer to be angled between 10° to 50° from the horizontal, a feed water tank supplying untreated water, and a treated water tank. The system will also include all the adjoining connections and hoses that go along with the system.

I. Heat Exchanger

Summary: The heat exchanger consists of the two parallel plates between which the water will be traveling. In order to verify the heat exchanger efficiency and design capabilities, the following tests will be performed and the results compared to the theoretical model.

Test 1: *Temperature Distribution Test*

Description: The temperature of the water between the channels will be measured as a function of the distance along the channels during normal operation.

Test Set-up:

1. Thermocouple holes will be drilled along the top and the bottom plates of the heat exchanger, every 10 centimeters in length. J-type thermocouples will be secured in these holes, ensuring complete sealing, with a silicone sealant. The thermocouples will measure mean fluid temperature at a particular location along the channels of the heat exchanger.
2. The incoming and outgoing fluid temperature, as well as the ambient temperature will be measured using thermocouples as well.
3. LiCor LI-200 Pyronometer will be used to collect solar radiation data during the period.
4. The thermocouple measurements will be automatically taken every 10 seconds, using Data Acquisition (DAQ) hardware and LabVIEW software, during the normal pasteurizer operation.
5. The temperature profile will be graphed as a function of heat exchanger distance, for both the bottom and top plates, and analyzed against expected results.

Test 2: *Maximum Operating Temperature*

Description: In order to ensure that there are no material failures within the system, a test will be performed to capture the maximum temperature of the system.

Test Set-up:

1. The pasteurizer will be set up under normal conditions. All of the water within the system will be drained, leaving the pasteurizer and all of the components completely dry.
2. Bare tipped J-type thermocouples will be mounted directly on the surfaces of the heat exchanger plates, as well as along the thermostat valve. The thermocouples will be bonded using thermally conductive epoxy. Thermocouples will also be mounted inside the enclosure, in the same manner as Test 1 of this section.
3. The temperature readings of the thermocouples will be monitored using DAQ hardware and LabVIEW software, throughout the entire day.
4. The maximum achieved temperature will be compared against the operating temperatures of the various components in the bill of materials, ensuring that it did not exceed the operating temperatures of any of the components within the system.

Test 3: *Output Flow Rate*

Description: The output flow rate of the clean water is one of the most important parameters in the evaluation of the design of the solar pasteurizer. The flow rate must be sufficient enough in various operating conditions to satisfy the output specifications.

Test Set-up:
1. A pressure transducer (Omega PX137) will be mounted on the bottom of the supplied water collection tank. The pressure transducer will be able to measure the change in the gage pressure at the bottom of the tank during operation. The pressure reading will be logged using LabVIEW software.
2. Using the pressure differential obtained, the mass flow rate of the system will be calculated.
3. The experimental flow rate will be compared against the theoretical calculated flow rate, in order to verify theoretical assumptions.

Test 4: *Total System Output per Day*

Description: The system output describes the average number of liters of pasteurized water that the device can produce in a given day. This output must be verified to match the target specification of 20 L/day for an average day. This test will be performed to capture the actual output that the system can achieve.

Test Set-up:
1. This test will be done simultaneously with all of the other tests which involve normal operation of the pasteurizer (i.e. the system is flooded with water).

2. Solar flux readings will be taken and averaged for ever hour using a LiCor 200Sa pyranometer, along with ambient temperature readings for every hour of the day.
3. The output water will be collected during each day of testing in a graduated container, from which the total output volume can be read.
4. At the end of the day, when pasteurization has completely stopped, the total output will be compared to the theoretical data of the model, for particular solar radiation and ambient temperature readings.
5. The model will be verified against the test results and if needed adjusted to more closely represent actual outputs for the entire year.

II. Water Quality

<u>Summary</u>: In order to test the effectiveness of the pasteurizer in terms of pathogen reduction in output water, water quality testing will be performed on the treated water. Contaminated water from the local supplies will be used during testing, and tests will be performed before and after the water is treated.

Test 1: Pathogen Reduction

<u>Description:</u> The Standard Total Coliform Fermentation Technique, Test 9221B, as described by the Standard Methods for the Examination of Water and Wastewater will be used to measure the total coliform reduction.

<u>Test Set-up:</u>

1. Contaminated water will be collected from local sources such as small streams, rivers and lakes, which are known to contain certain contaminations such as e-coli and other pathogens. The incoming water will be tested to be able to gauge the reduction of pathogens using the procedure described below.
2. 100 ml Samples will be taken three times per test day, at specific intervals. The intervals will be at the beginning of pasteurization and one 100 ml sample for every 2 liters of pasteurized water thereafter.
3. Samples will be distributed among 10 sterile test tubes and combined with lauryl tryptose broth, which will be made according to the technique 9221 B in the Standard Methods for the Examination of Water and Wastewater.
4. Samples will be incubated for a period of 24 hours at 35°C and examined for positive reaction by counting the tubes.
5. Results of the outgoing water will be compared with the incoming water, in order to determine the coliforml reduction obtained from the pasteurizer.

Test 2: Safety Zone Exposure

Description: In order to verify that the output water has reached the described Safety Zone, at which all of the harmful pathogens will be neutralized (Feachem, et al 1983), an exposure curve will be fitted against the Safety Zone boundary and verified that it meets the needs.

Test Set-up

1. The flow rate will be obtained from the previous pressure measurements from section I, from which the mean velocity of the water can be calculated. Since the maximum velocity for flow between parallel plates is 50% greater than the mean velocity, the maximum velocity can be calculated as well.
2. Using the temperature profile obtained from the temperature distribution test, the minimum time above a desired temperature can be fitted against the Safety Zone curve and compared to ensure that the water reaches the safety zone for a desired amount of time.

III. Thermostat Valve Assembly

Summary: The thermostat valve will be set to open automatically at a desired temperature above the minimum pasteurization temperature of 65 °C. The tests below will be performed in order to verify the design capabilities of the thermostat valve and its assembly.

Test 1: Pressure Test

Descriptions: The thermostat valve and its housing will be pressure tested in order to verify that they can safely withstand higher than operating pressures without opening.

Test Set-up:

1. The valve housing assembly will be removed from the pasteurizer and tested separately.
2. In its vertical position, with the valve closed, the valve housing will be fitted with clear tubes on both the inlet and outlet sides. The inlet side will be filled with water only.
3. The outlet side will be fitted on an air compressor supplying a maximum of 40 psi of pressure.
4. The inlet side will be observed for the presence of air bubbles with would indicate that the valve is leaking.

Test 2: Leak Tests

Description: Leakage between the incoming water and the outgoing water through the thermostat will be tested to ensure that no untreated water passes through the valve when it is closed.

Test Set-up:

1. After solar testing is complete, the pressure of the treated water tank will be recorded over an 8hr time period, during which time the thermostat valve will be known to be closed.
2. The pressure differential of the treated water tank will be monitored, in order to determine any leakage in the valve assembly.

Test Equipment List:

Item	Test #	Product Name	Product Description	Vendor	Model Number	Cost	Unit	Qty	Total Cost ($)	Lead Time
1	I-1,2,4 II-2	Thermocouples	J-type, Temperature measuring device	RIT-Wellin	N/A	$0 (in house)	N/A	30	0	In House
2	I-3,4 III-2	Pressure transducer	Temperature compensated pressure measurement	Omega	PX137	$55	per transducer	1	$55	In Stock
3	II. 1	Incubator	Water quality test equipment	Dr. Lodge	N/A	$0	N/A	1	$0	In House
4	II-1	Lauryl-tryptose	Broth mixture for pathogen testing	Dr. Lodge	N/A	$0	20ml broth/100ml of water	400ml	$0	On campus
5	II. 1	Test tubes and other equipment	Necessary equipment for testing	Dr. Lodge	N/A	$0	N/A	10+	$0	On campus
6	All	Pyranometer	Sensor to measure solar flux	LI-COR	LI-200SA BNC connector LI-200SZ bare leads	$195	per pyranometer	1	$195	In Stock
8	All	DAQ Card	Data Acquisition Card for Test Sensors	LabVIEW		$0 (in house)	per card	1	$0	In House
9	III. 1	Air Compressor	Air Compressor (at least 40psi)	RIT	N/A	N/A	N/A	1	$0	In House
								Total test equipment cost	$250	

2. Usability Testing

Executive Summary

The goal of a successful design is to make the product appealing to the user from various different aspects such as performance, safety, ease of use etc. All of the specific human factor methods and techniques carry out the methodological principle in the field of human factors to center the design process on the user, this making it a user-centered design (Wickens). This means that the ultimate goal is to find a system design that supports the user's needs rather than making a system to which the user must adapt.

Task analysis is a way of describing human interaction with a system to understand how to match the demands of the system to human capabilities. In this case, Task analysis will be used as the initial method of evaluation and will be followed by Usability Testing.

Usability is the degree, to which the system is easy to use, or user-friendly (Kantowitz and Sorkin). This translates into a cluster of factors, including the variables Learnability, Efficiency, Effectiveness, Memorability, Errors and Satisfaction. Learnability is measured by the effort needed from the user to acquire proficiency in operating the system. Efficiency is related to time to complete certain tasks, frequency of help or documentation use, time spent on errors, number of repetition or failures. The effectiveness of the system is determined by percent of tasks completed and/or ratio of successes vs. failures. Memorability on the other hand, is defined as how much information the user needs to retain in his/her memory in order to ease the operation of the system. Errors could be counted or represented as percentages of user failure throughout the test. Ultimately, the User Satisfaction will be provided by the user in terms of a rating of functions/features, expressing perception of the directions, causes of frustrations.

Usability Testing is the process of having users interact with the system to identify the design flaws based on the categories mentioned. It can be carried out using different methods, such as Heuristic Evaluation and through user surveys. Heuristic evaluation involves experts analyzing the system at hand from a usability stand-point and reporting the results in order to improve the existing design. On the contrary, user surveys include a sample population of potential customers, asked to perform tasks and report on the criteria given, their thoughts and feelings of the product. Ideally, utilizing both approaches is beneficial to the analysis.

Eventually, the evaluation studies are intended to provide feedback for making necessary modifications to the design.

Methodology

The system at hand is a Solar Water Pasteurizer. It will utilize a feedwater component to collect water which is the portion that requires the most user input; the collector will accumulate the water that will get heated using the solar energy. The heat exchanger acts as a major component in heating and cooling of the input/output water as it gets pasteurized. Once the pasteurization is completed, the output water is returned to the initial feedwater system that also incorporates output water storage. The user will remove the output water to serve their needs.

This product is intended to accommodate communities who do not have access to clean water in rural areas in the third-world countries. The target population has multiple characteristics including cultural background, language, race, age, education level, and mechanical aptitude that need to be considered while selecting the survey population. Even though, the prototype will be manufactured and tested in a technologically developed setting, attention will be paid to stay true to the target population and conditions such as cultural stereotypes.

Initially, the system will be tested using the Heuristics Evaluation by experts in the field who also have experience with the conditions and characteristics of the target population. Improvements on the system will be made according to the outcome of the Heuristics Evaluation. In order to optimize the usability of the system as much as possible, User Survey method will further be incorporated as well. The users will be provided surveys with tasks they need to carry out and will be timed accordingly for future statistical analysis. The sample size will be 5-6 people, in order to identify the problem without much complication. Therefore, multiple cycles of small number of participants rather than a larger group of people testing the same product will be the method followed in this case. The survey populations will be selected randomly, providing a diverse variety of cultural background, language, race, age, education level and mechanical aptitude characteristics.

What is more, the survey populations will be provided pictorial directions as to how to use the solar pasteurizer. By doing Task Analysis, we will be able to measure their responses to the system from different perspectives.

(see attached task analysis chart)
(see attached usability survey)

Usability Test
Objective and Subjective Assessment Interview
Solar Pasteurizer Senior Design Team

Subj.#: Native Language:
Age : Latest Educational Inst.:

The Solar Pasteurizer Senior Design team would like to test the functionality and ease of use of the solar pasteurizer. Simple instructions will be provided to you to carry out certain tasks. For any instruction set you are asked to perform, observations of your interaction with the product will be recorded, including time. Please perform the tasks at a normal pace, and do NOT try to hurry because of the stopwatch. Questions are encouraged if the directions are unclear.

"Using the bucket and the water from the faucet, please follow the pictorial instructions to load the system."

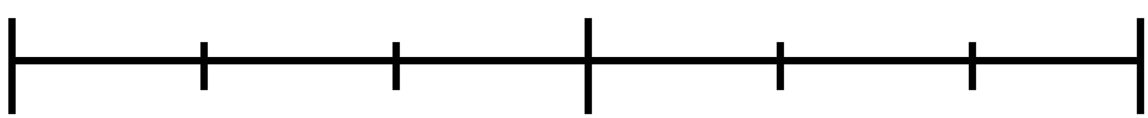
Record the time it takes to load the system. Count the number of visible errors the user makes and the number of questions he/she has to ask for more clarification. State which aspect that they have more difficulty in.

Time to load the system: ______________________

Total Questions/Errors: ______________________

Additional Comments: ______________________

"On a scale from 1 to 7, with 1 being very difficult, 7 being very easy and 4 being neutral, how easy was it to load the feedwater system?



1 Very Difficult | 4 Neutral | 7 Very Easy

Q. "How clear are the pictorial directions for use of the product?"

A. ____

____

Q. "How easy is it to keep the feedwater system to a usable level?"

A. ____

____

Q. "How easy is it to clean and check the filtering system?"

A. ____

____

Q. "Are there any problems with the heat coming off of the collector?"

A. ____

____

Q. "What did you find most challenging?"

A. ____

____

Additional Comments

____

____

____

____

TASK ANALYSIS

Solar Pasteurizer

	Task Description	Attention	Senses	Perception	Memory	Decision	Control	Feedback	Posture	Other	Observations
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											

Attention: requires more attention than user can apply for that task.
Senses: user can't sense all they are supposed to.
Decision: user is unable to effectively decide between options.
Memory: requires more memory than the user's capacity.
Control: user can't maintain control of items in task.
Feedback: user is unsure if task is completed or not.
Posture: positioning of body and/or appendages could lead to erosion of vital tissue in the long run

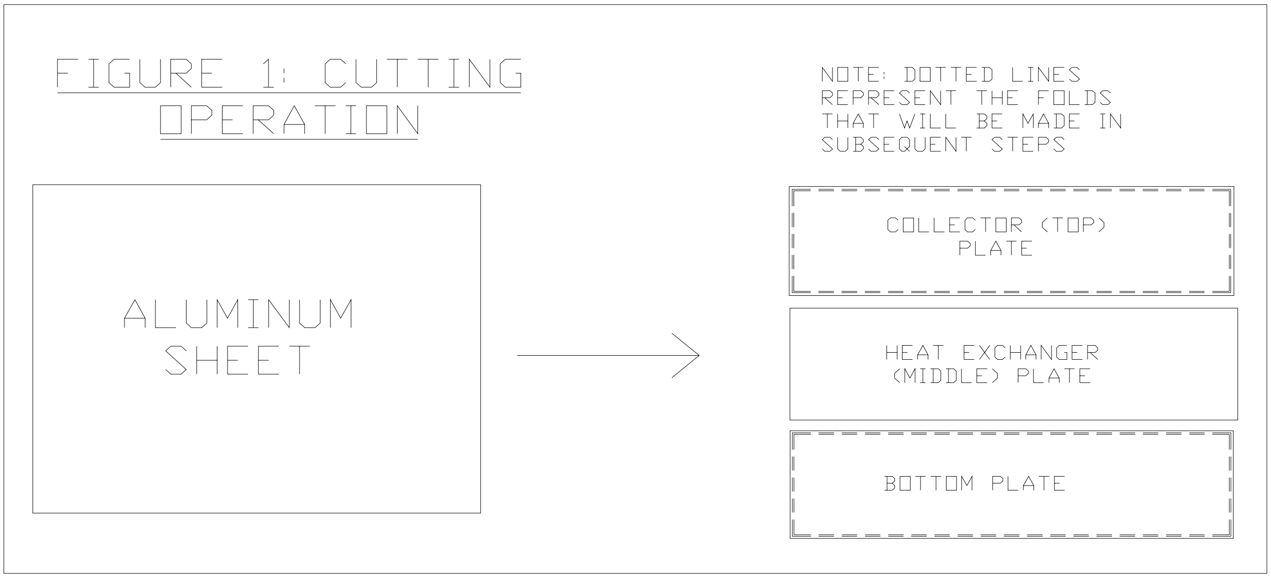
VI. Fabrication Plans

Another challenge with the design of the pasteurizer would be minimizing the amount of fabrication steps and resources necessary without compromising the quality of the heat exchanger. Considering the amount of materials necessary to make the heat exchanger, the enclosure, the housing for the thermostatic valve, and the piping necessary to form the overall assembly, many steps would be necessary to form the initial pasteurizer.

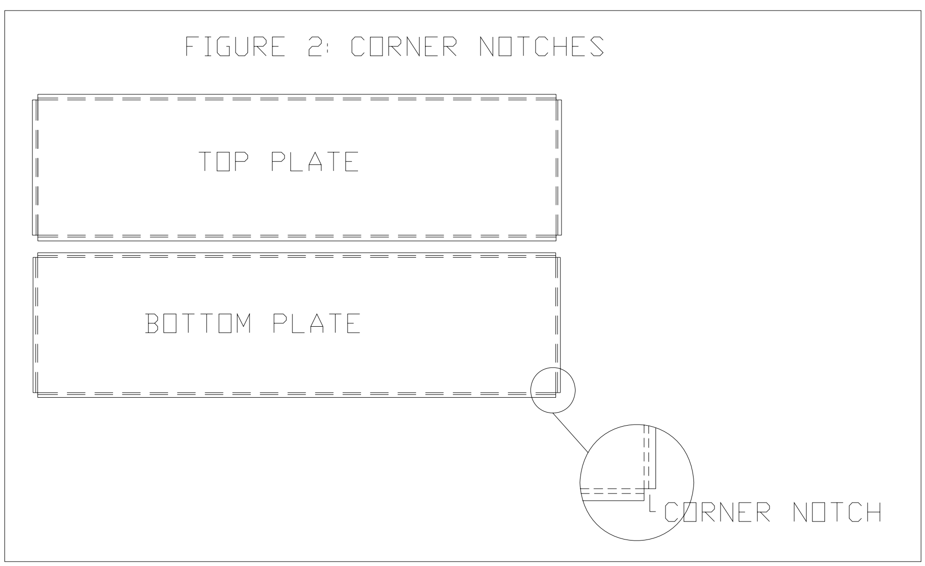
1. Heat Exchanger Assembly

The heat exchanger is going to be made using three separate channels that will be mechanically formed and sealed without requiring special equipment.

1. The aluminum sheet used for each of the plates (collector, heat exchanger, and back plate) will be cut on a band saw to the dimensions necessary for channels, plus some extra room in order to fold it over to form weld joints on the side in Step 6. Of these, the heat exchanger plate will not need to be touched until Step 5. See **Figure 1.**



2. A notch must be cut in each corner of the collector and back plate as shown in **Figure 2**.



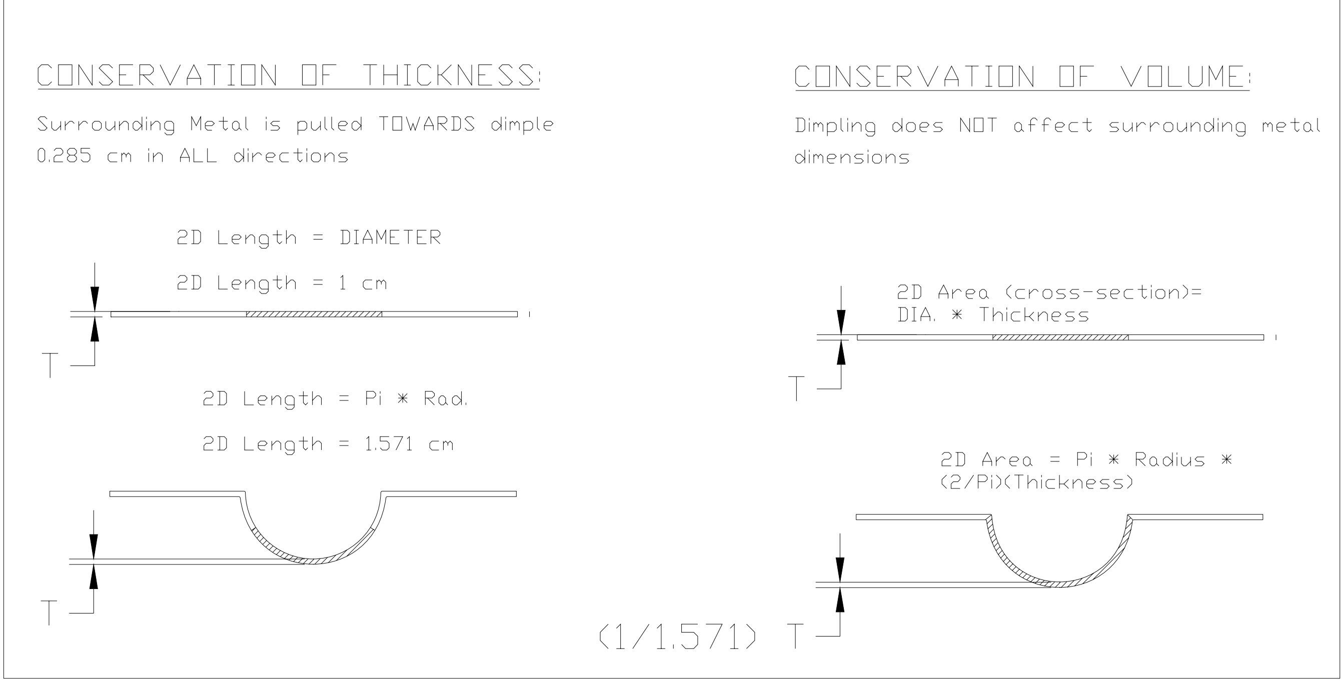
3. The notched sheets must then be dimpled by using the following procedure (do this for both the collector sheet and the back plate sheet):
   3.1 Place in between a top and bottom dimpling template sheet such that the corners of the notches made in Step 2 are as close to the corners of the dimple templates as possible. To find out how to manufacture the template sheets, see the **Tooling Assembly** section**.**

3.2 Clamp down on the four corners of the top dimple template.

3.3 Taking the ball punch (to learn how to manufacture the ball punch, see **Tooling Assembly** section) place the punch in each of the holes on the Top dimpling template sheet and press down using an Arbor press or by lightly tapping a hammer.

It will be assumed that the formation of the dimples will force the overall length and width of the sheet to shrink, based on the amount of extra surface volume needed for each dimple. This calculation has two extremes shown in the next figure.

FIGURE 3: EXTREME EFFECTS FROM DIMPLING



3.4 Form the sides of the sheet one at a time using a hammer and a crimping tool. The finished sides will all eventually be made to look as close to how the drawing appears.

3.5 Unclamp the assembly and pull out the sandwiched plate

3.6 Arc-weld each corner of the plate until there are no visible cracks in the plate

4. Form the holes for piping needed in the top and bottom dimple plates BEFORE they get welded to the heat exchanger plate.
5. Center the dimpled plate on the heat exchanger plate and apply a cold-welding solution to the tips of the dimple. This will eventually form a joint against the heat exchanger plate. J.B. Welding products are an example of a good cold-welding

solution. It may be possible to cold weld both the collector and the back plate to the heat exchanger at the SAME time, which may cut assembly time.

NOTE: It is important that while the welding solution is hardening, enough pressure is being made between each dimple and the heat exchanger plate to ensure a constant joint.

6. At this point a flange weld must be made around the entire perimeter of the three plates. Because of the improbability of correctly arc-welding the entire perimeter using the thickness of aluminum, the joints will be held together using the same cold weld sealant used in Step 4.

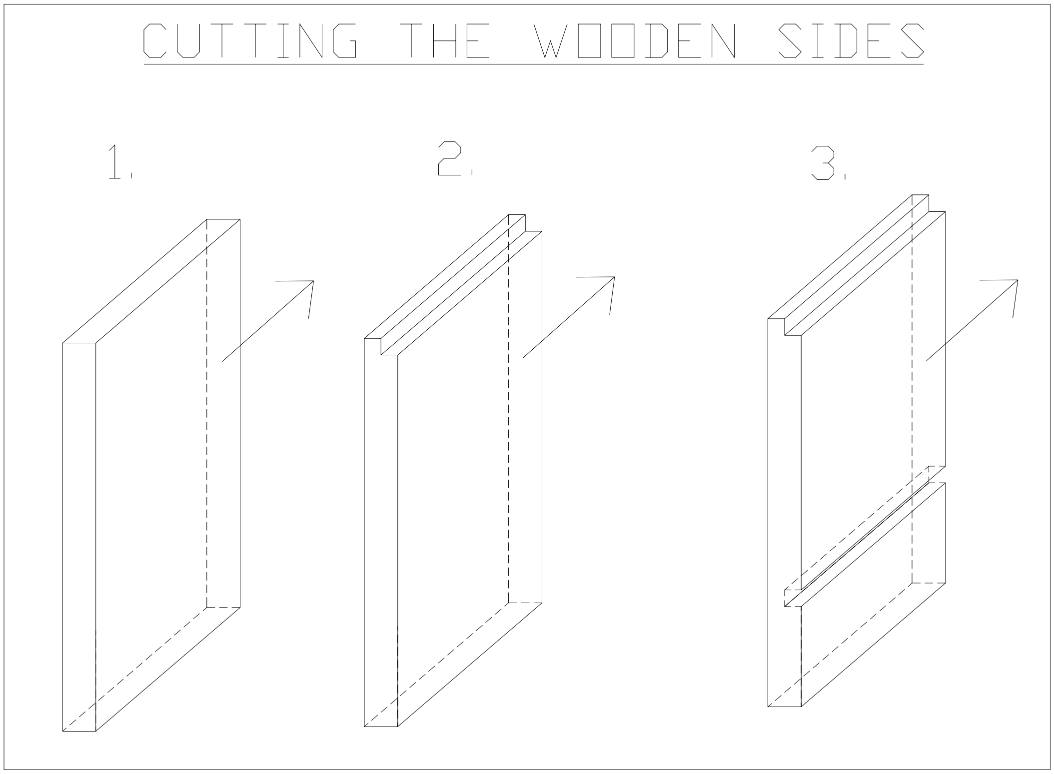
2. Enclosure Assembly

The heat exchanger/collector assembly is truly the most integral part of this project. However, there needs to be some consideration as to how the enclosure and insulation, that will hold the glass plating and collector assembly, is going to be made.

1. Using a large piece of plywood, four wooden panels are to be cut for the front, back, and sides of the enclosure, which will hold the insulation and the heat exchanger, as well as another panel to form the BOTTOM of the enclosure.

   On the front and back panel there should also be an entrance and an exit hole for the piping to go into and out of. When piping has been placed through it, it will need to be sealed using Silicone Sealant caulk.

2. Form a notch on the top of each side panel. This is where the glass plate will eventually rest.
3. Form a lengthwise notch in the middle of each panel above the bottom. The specific location of this notch above the bottom is going to be approximately at the point to which the side of the heat exchanger will fit. **See Figure below.**



4. Fasten the two side panels and front panel to the bottom panel, using nails and a hammer**.**
5. Apply Silicone sealant to all the inside edges present in the assembled unit. This will ensure that no water will leak into the enclosure.
6. Place the precut fiberglass sheet at the bottom of the enclosure and make sure that it rests snugly.
7. When the Heat Exchanger Assembly has been finished, slide it through the notches formed in Step 3 until it is fully inside the enclosure.
8. At this point, the back wall should be fastened to the bottom of the enclosure and the sides so that the structure is fully enclosed. BEFORE nailing it together, however, make sure to pre-place Silicone sealant at the corners.
9. **MAKE sure that all piping has been routed in and out of the pasteurizer before moving on to Step 10.**

10. Place the window so that all four sides are resting within the notches formed in Step Two. If the dimensions are OK and the window rests comfortably on top of the wooden siding, then apply the Silicone Sealant caulk where the wooden notches meet the glass.

3. Storage Tank Assembly

The scope of this project is to make a cost effective pasteurizing machine. The presence of a feedwater and finished water storage tank is needed in this project to make sure the water has receptacles for priming and receiving water. It is NOT one of the primary focuses of the design.

The storage tank used to hold feed water will be a purchased 5-gallon bucket constructed out of plastic. There will be a coarse sediment filter at the top of the bucket that will be held in place by a plastic lid. The filter would be very easy to empty when it is full of sediments. All water has to pass through the filter before it goes into the pasteurizer.

As water goes out of the bucket it will travel through a plastic, UV-resistance pipe that will connect to the pasteurizer through the enclosure. After treated water travels through the bottom channel it will travel through a pipe of the same material that is transferred to a 5-gallon bucket at a much lower height.

This design will require the manufacturing of two rectangular wooden tables, so that the pressure of the water coming from the feedwater is enough to force flow all the way through the entire machine. The taller table, holding the feedwater bucket, will be approximately half a meter high up, and will have a wooden brace with notches between the side legs. This is so that the angle of the pasteurizer can be adjusted. The table holding up the finished water bucket needs to be much smaller in height. It is assumed that the legs will be made of 2 x 4's or similar material, while the tabletops are made of plywood.

4. Valve Assembly

The channels of the pasteurizer are only half a centimeter wide, which is too small to house the automobile thermostatic valve we chose for regulating flow. Therefore, the thermostatic valve would be external to the pasteurizer using aluminum piping. It was decided as well that an air release valve would best be suited at the point where the piping bends flat, under the assumption that air will mostly likely collect at that bend anyway. This piping would connect to a couple that will be cold welded to the thermostatic valve housing.

The thermostatic valve housing will be made of two aluminum cylinders that are bolted together. All fabrication will take place on a lathe, outside of the formation of bolt holes. The inside of the housing must be made so that the thermostatic stroke does not come in contact with the top. The two cylindrical fabrications will be bolted together with a rubber O-ring in between providing a good seal. By not having the two joint aluminum pieces welded together, it is possible then to replace the thermostatic valve at its end of life without having to scrap the pasteurizer.

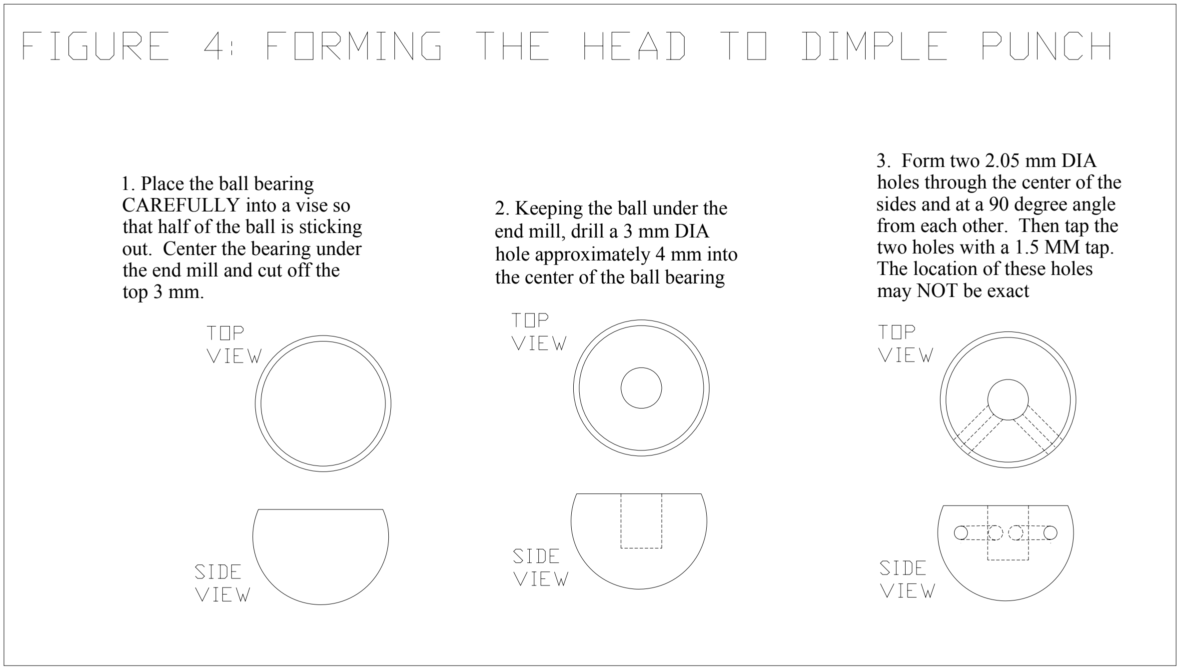
5. Tooling Assembly

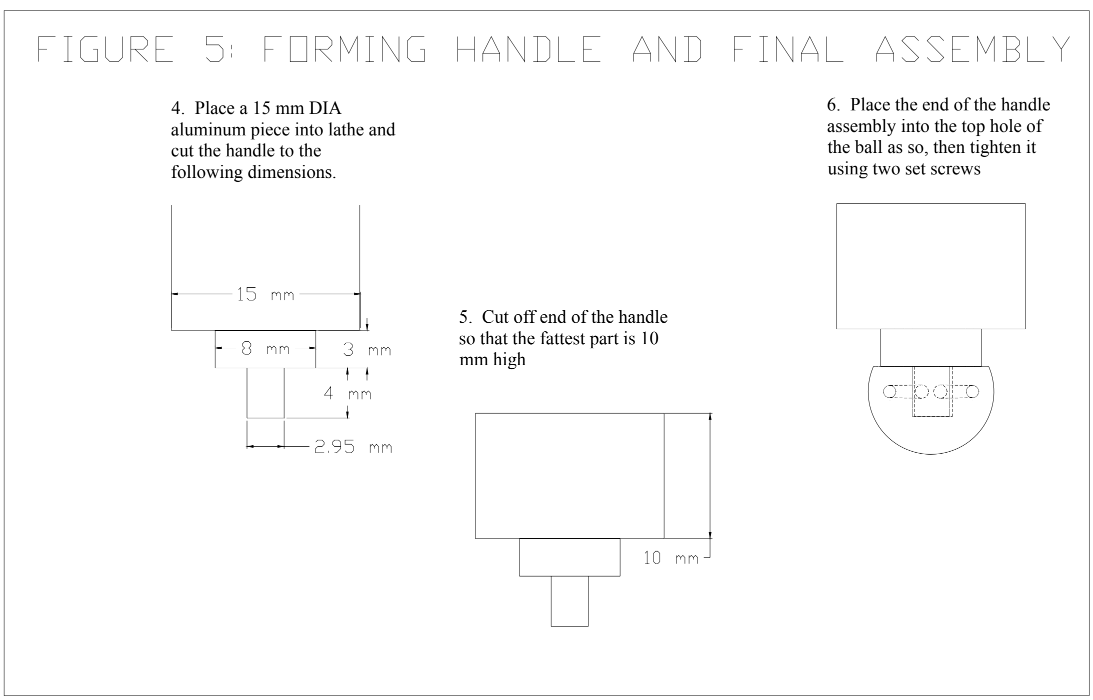
In order to form the dimples in the heat exchanger, two special tools would need to be made for the quickest and most simple way for forming them: a dimple punch and a dimpling template (made out of 5 millimeter steel) set. The manufacturing for each is important, but the hope is that they only need to be made once mass-producing top and bottom plates in the pasteurizer. All other tools that are used for manufacturing can be found or purchased in a machine shop.

Forming the Dimple Punch:

MATERIALS REQUIRED:
10 mm ball bearing, 15 mm DIA Aluminum Cylindrical Stock

PROCEDURE:





Forming the Top and Bottom Dimple Template Sheets:

1. Cut two pieces of 5 mm thick steel to the following dimensions: 1.41 M x 0.36 M.
2. Mark where the center of each dimple hole will go (this will be the same for both sheets).
3. Using a portable drill, drill holes into the locations you have marked in Step 2. **All holes drilled into the "top" template sheet should be made with the next highest drill bit above 10 mm wide, while the holes drilled in the "bottom" template sheet should be made using a 20 mm drill bit.**

5. Conclusions about Fabrication

It was understood that at the beginning of the design phase that importance was high on making sure the tooling and assembly operations would result in a high-quality, well-sealed product. At the same time, the limitations in what the team could produce using the facilities on campus was coupled with the idea that the team desired a project that could be made using simple tools, and could even be produced in Venezuela. The fabrication of the heat exchanger assembly was made so that simple mechanical processes and apparatuses could be used. Also, a single replicate of the custom fixtures and tools necessary for the manufacturing process could be used in mass production if the demand were to arise. It was important for the team to create a very rigid product (outside of being able to pop open the window and replace the thermostatic valve) that will stand the test of time. There is still a lot to learn about the details and control of the fabrication process. What is important now is there is a feasible idea of how to fabricate a prototype pasteurizer from start to finish.

VII. BOM

Use	Product Name	Product Description	Vendor	Part Number	Cost	Unit	Qty.	Total Cost	Lead Time
Feedwater System	Permanent Filter	Sediment Filter with strainer	Donated	N/A	$ -	Per filter	1	$ -	In House
	Bucket	5 Gallon Inlet/Outlet water storage	Amazon.com	50640	$ 5.69	Per bucket	2	$ 11.38	1 week
	PVC Tubing	UV Resistant Black PVC Tubing (1/4" ID, 7/16" OD)	McMaster Carr	5187KAC	$ 0.32	Per ft.	25	$ 8.00	1 week
	Millstead 4"x 4'x 8'	Pressure Teated Lumber	Home Depot	N/A	$ 6.97	per piece	4	$ 27.88	In Stock
	Millstead 1/2"x4'x8'	3 ply Sheating	Home Depot	N/A	$ 11.95	per piece	1	$ 11.95	In Stock
	5 1/2" long 1/4"-20	SS Bolts	McMaster	N/A	$ 9.06	10 pack	1	$ 9.06	In Stock
	Hose Clamps	5/16" Band Width (7/32-5/8"Adjust) Type 301 SS, Zinc Plat Screw	McMaster	5388K14	$ 4.68	10 pack	1	$ 4.68	In Stock
Heat Exchanger & Solar Collector	Plate	Aluminium (5052) Plate 18 ga.	Metal Supermarkets	N/A	$ 0.03	in^2	2324	$ 69.72	In Stock
	Glass	Solar Collector surface, 1/16" thick	Ray Sands Glass	N/A	$ 33.15	per m²	0.5	$ 16.58	In Stock
	Solkote	Selective Solar Coating	Solec	N/A	$ 0.92	per m²	0.5	$ 0.46	In Stock
	Silicone Sealant	GE Silicone Sealant	Home Depot	N/A	$ 5.39	Per tube (10.1 FL oz.)	1	$ 5.39	In Stock
Fabrication	Bearing	Steel Ball Bearing	McMaster-Carr	9292K47	$ 4.27	Per 20 pack	1 of 20	$ 0.21	In Stock
	Plate	Steel Plate 1.414m x 0.36cm	Metal Supermarkets	N/A	$ 65.00	Per plate	2	$ 130.00	In Stock
	Rod	Steel Rod 15mm Diam., 17mm Length	Found	N/A	$ -	Per rod	1	$ -	-
Valve Housing	Al 6061 Rod	For valve housing	McMaster Carr	8974K961	$ 67.62	12 in.	4	$ 19.72	1 week
	Al Screw	¼” x 20 x 1”	McMaster Carr	93306A542	$ 16.68	50 pack	4 of 50	$ 1.33	1 week
	Al Hex Hd Nut	¼” x 20 x 7/16” (7/32” tall)	MSC	67469684	$ 9.09	100 pack	4 of 50	$ 0.36	1 week
	Rubber Gasket	Rubber gasket	Donated	N/A	$ -	N/A	1	$ -	In house
	Thermo-stat vlv	160 deg. F	Stant Manufact.	13006	$ 3.97	ea.	1	$ 3.97	In house
	Al 6061 Tubing	6061 Al Alloy Tubing (.194" ID, 1/4"OD)	McMaster	9924K111	$ 11.08	3 Feet	1	$ 11.08	1 week
	J-B Weld	J-B weld	McMaster Carr	8265-S	$ 5.53	16 sq. in.	3	$ 16.59	1 week
	Hose Clamp	Stainless steel	Auto Zone	N/A	$ 1.59	2 pack	1	$ 1.59	In house
	Al Coupling	¼” NPT	McMaster Carr	44705K317	$ 1.44	ea.	2	$ 2.88	1 week
	Air vent	1/8” NPT	Honeywell	FV180	$ 11.01	ea.	1	$ 11.01	In house
	Elbow	90 Degree Elbow (1/4"ID)	McMaster	50915K143	$ 3.20	ea.	2	$ 6.40	In Stock
	Coupling	Compression Coupling (	McMaster	5220K23	$ 1.93	ea.	3	$ 5.79	In Stock
	Tees	Tube (1/4"OD), Male Pipe (1/8"), Tube (1/4'	McMaster	5220K158	$ 4.74	ea.	1	$ 4.74	In Stock
Enclosure	Millstead 3/4" x 4ft x 8ft	Plywood panel	Home Depot	166103	$ 18.99	per sheet	0.3	$ 5.70	In Stock
	Fiberglass- R-13 Kraft	Insulation material, 15" x 32ft x 35", 40 ft²	Home Depot	375004	$ 10.80	per roll	1	$ 10.80	In Stock
							Pasteurizer Only	$ 194.10	
							Total	$ 397.27	

VIII. Customer Needs & Target Specification Compliance

Customer Needs vs. Engineering Specifications

Customer Need Category 1: **Solar Pasteurizer should be economical**

A need of utmost importance is the cost-effectiveness of the Solar Pasteurizer. The criteria defined to live up to this need include using resources readily available in the developing world, with minimal or no specialized imported components to reduce cost associated with intermediate vendors as well as transportation. In the design, this goal is achieved by using standardized materials all throughout that do not require to be imported from other countries.
(Please refer to Bill of Materials for list of materials used in each subcomponent of the system).

The fabrication of the product can also be achieved in the developing world since it does not make use of any specialized materials or processing. (Please refer to fabrication materials). Therefore, 100% of the system can be locally fabricated. The pasteurizer operates solely by solar energy therefore does not require any additional fuel source such as electrical power or wood. Pasteurization process is achieved by changing the temperature of the incoming water to a level sufficient to kill the contaminating pathogens using the heat exchanger within the solar collector; therefore use of chlorine or similar disinfecting chemicals is not required.

The manufacturing cost is based on the Heat Exchanger, Solar Collector, Valve Housing and Enclosure.

Subsystem	Component	Price
Heat Exchanger & Solar Collector	Plate	$ 69.72
	Glass	$ 16.58
	Solkote	$ 0.46
	Silicone Sealant	$ 5.39
Valve Housing	Al 6061 Rod	$ 19.72
	Al Screw	$ 1.33
	Al Hex Hd Nut	$ 0.36
	Rubber Gasket	$ -
	Thermo-stat vlv	$ 3.97
	Al 6061 Tubing	$ 11.08
	J-B Weld	$ 16.59
	Hose Clamp	$ 1.59
	Al Coupling	$ 2.88
	Air vent	$ 11.01
	Elbow	$ 6.40
	Coupling	$ 5.79
	Tees	$ 4.74
Enclosure	Millstead 3/4" x 4ft x 8ft	$ 5.70
	Fiberglass- R-13 Kraft	$ 10.80
	Total Sum	$ 194.10

The cost turns out to be higher than both marginal and ideal values initially specified. However, it should be kept in mind that the cost of materials is based on a single prototype manufacturing. In mass production, the cost of raw materials is reduced due to aspects such as bulk purchase. Ultimately, the cost for commercial use would be driven down after mass production. The unit will be put through multiple usability/functionality examinations to validate little or no maintenance need. Plywood and Aluminum plates have tensile strengths 44 MPa and 360 MPa respectively where as Glass will be inserted and secured into notches within the enclosure to ensure durability. What is more, sealants and fasteners will be used in order to increase the durability of the system.

<u>Customer Need Category 2:</u> **Solar Pasteurizer should be <u>safe</u>**

Clean output water will be the final output of the pasteurizer by heating the incoming water above the highest required temperature to kill the pathogens which is 65˚C. The solar pasteurizer will be using a 160˚F (71.1˚C) thermostat valve that will open upon pasteurizer reaching that temperature.

The sediment in the water will be addressed by using a filter that includes a strainer, in the incoming water storage tank (bucket). The filter will be attached to the outer diameter of the tank (bucket), therefore leaving no room for the sediment to enter the tank through the sides.

A water testing procedure will be applied to the final prototype to ensure the quality of the end product. Furthermore, there is a test measuring if the water has reached the equivalent safety zone by an applicable change in temperature (Please refer to Testing procedures).

Customer Need Category 3: **Solar Pasteurizer should be versatile**

The feedwater subsystem is designed in such a way that does not differentiate the water source. Due to the easy accessibility of the incoming water storage tank (bucket) the user will be able to pour water collected from a stream or a river as simply as gathering water from a faucet. However the limitation on the water storage tank in this particular design is 5 gallons. Since the source of the incoming water does not play a role, the unit can be easily integrated to the existing water system.

Once the solar pasteurizer is assembled together, it can serve small populations, namely home applications with for an average family size of 10.

Pictorial directions as to the usage of the unit will be provided to make it more universally applicable and easy to incorporate in different cultures. However, the effectiveness of the solar pasteurizer will depend on the intensity of the solar radiation; therefore the outcome calculated in this design might not be applicable in other countries where the climatic conditions differ drastically.

Customer Need Category 4: **Solar Pasteurizer should be easy to operate**

A usability test will be carried out on the unit by a diverse population of different language, race, and cultural background as well evaluations by experts in the field (Please refer to the Usability Testing procedure). This information will be useful in optimizing the product for the target population.

There will be a preventive maintenance manual included with the final product to reduce break-downs and the cost associated with it.

Appendix I – Design Drawing Packet

The following is a package of drawings that show our latest design. The drawings are broken down by category (CAT) number in which each CAT number pertains to a specific area of the pasteurizer design.