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HIGH TEMPERATURE WASTE PASTEURIZER

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ABSTRACT

The primary objective of this project is to transform human waste into a safe to use fertilizer using renewable energy. The pasteurization system that was created will benefit those in underdeveloped countries, specifically Haiti, because there is currently a lack of sanitation concerning disposal of human waste and scarce fertile ground. Specific goals include reaching and maintaining a temperature of 63°C for 1 hour in order to eliminate the pathogens contained in human waste, containing and disposing of unwanted outputs of the pasteurizer including pathogens and combustible gas, and using resources available in Haiti. The developed product uses solar energy to heat and hold the necessary temperature and should pasteurize the waste from a family of 3-5 people in roughly two and a half hours. The main components of the device include an outer bucket to contain heat, an inner bucket to hold the waste, a lid and frame assembly with attached reflectors for focusing the sunlight onto the lid, and a temperature indication device called an iPooP (indicator of Pasteurization of our Poop). If this device was used in underdeveloped areas of the world a household would benefit by obtaining fertilizer for their home gardens and disposing of their waste in a safe, sanitary way.

INTRODUCTION

The development of sustainable technologies that can provide an improved quality of life to those in underdeveloped countries has become a goal of many engineering groups. In many places around the world, tasks that most people have come to think of as simple are made very complicated due to the lack of proper resources. In Haiti, using the toilet is a sanitary issue because there is no sewage system in rural areas. For this reason, human waste disposal is a major concern. The long term goal of this project is to develop an inexpensive waste pasteurization system that will allow households of three to five people in Haiti to safely use their waste as a free fertilizer for home gardens and crops.

Several different methods of safely sanitizing waste have been developed and implemented, such as the Peepoo bag. The Peepoo bag [1] is a bag in which waste can be disposed of by coating the contents with a non-hazardous chemical that kills pathogens over a time period of a couple hours to a few weeks. This project is similar to the Peepoo bag because it does not use potable water and it converts the waste into a fertilizer. An advantage that this project has over its predecessor is that the pasteurization device is reusable and is able to turn the waste into a safe to use fertilizer in less time. Pasteurization occurs by heating the waste using solar energy. Based on the achieved temperature and the exposure time of the waste, the harmful pathogens will be killed rendering the waste safe to use. At higher temperatures pasteurization occurs faster, while lower temperatures require significantly more time.

DESIGN PROCESS

Preliminary Design

One of the first steps taken by the design team was to review the product needs and specifications provided by the customer. A list of customer needs and required specifications was provided by the customer as a starting point and was expanded by the design team to more clearly focus the project's scope. The needs were ranked by the customer in terms of importance. These needs were translated into a specifications list with assignable metrics to gauge design performance. Table 1 shows the customer needs and the engineering specifications. Each specification is listed next to the primary customer need that is fulfilled.

CUSTOMER NEEDS IDENTIFIED			SPECIFICATIONS DERIVED*				
Customer Need #	Description	Customer Ranking	Spec #	Importance	Description	Measure of Performance	Engineering Units
CN1	Contain pathogens during process	9	ES3	9	Contain pathogens, do not allow unsafe leakage of untreated wastes	Is there leakage?	Binary (Yes/No)
CN2	Make end product free of pathogen	9	ES1	9	Provide heat to waste using renewable energy in order to kill pathogens	Temperature, Time	degC, hours
			ES9	9	Does the entire sample of human waste contain safe pathogen levels	Temperature	
CN3	Cost <$50	9					
CN4	Safe human interface	9	ES2	9	Vent combustive gasses in order to prevent explosions and smell	Amount of methane inside chamber	ppm
			ES4	9	Temperature of the access door or handle	Temperature	degC
CN5	Environmental resistance	9	ES6	3	The product should withstand the winds experienced by Haiti	Does the product withstand outdoor wind	mph
CN6	Easily repaired	3					
CN7	Easy to load/unload	3	ES7	3	Customer must be able to easily add, stir (optional) and remove waste	Time to add, stir and remove material	minutes
CN8	Easy to use	3					
CN9	Easy to relocate	3					
CN10	Use local materials	3					
CN11	Minimize time required to pasteurize	1					
CN12	Meet the needs of a family of 3-5 people	1	ES8	3	Volume of product accommodated	Volume	Liters
CN13	Communicate to the user that temperatures have been reached	1	ES10	1	Show Disinfection has taken place		

*Each Engineering Specificaiton is listed next to the primary customer need adressed

Table 1: Customer Needs and Engineering Specifications

A number of assumptions were required to adequately guide the design process. Two key assumptions that significantly impacted the product's design were that the product would be designed for the rural communities of Haiti to use and partially build, and that the time and temperature necessary to kill all pathogens provided by Feachem [2], as shown in Figure 1, was accurate. These two assumptions were critical pieces of data that impacted the design concepts from its early stages and throughout the duration of the project.

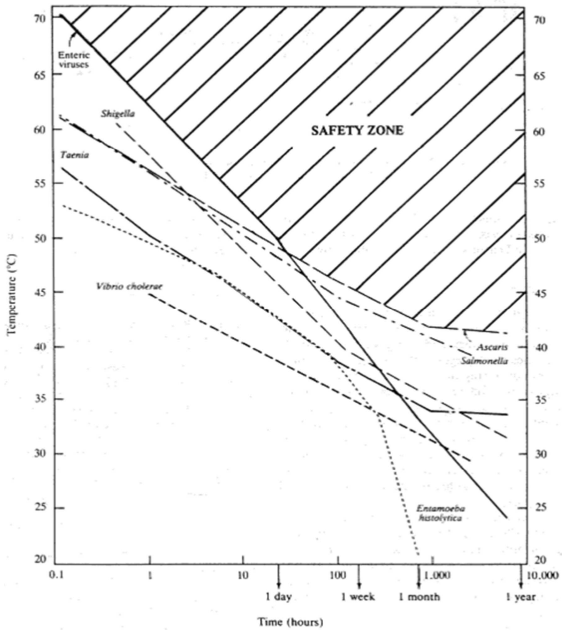

Figure 1: Response of Pathogens to Time and Temperature

Design Benchmarking

In order to ensure that all of the necessary options were considered, the required functionalities of the product were broken down and individually considered. A morphological chart was created to individually break down these concepts and generate multiple solutions for each function. Furthermore, a number of benchmarks were investigated to explore similar projects for design ideas and product baseline information. Two main benchmarks were selected for analysis due to their relevancy: the Capetown Project and the CooKit solar cooker. The Capetown Project [3] was a pasteurization project performed by the Worcester Polytechnic Institute in 1997. The purpose of the project was to safely pasteurize the contents of two composting toilets much faster than traditional methods. Their design was a large solar hotbox constructed primarily of aluminum and plastic. The project was successful and was able to pasteurize the contents of the waste in approximately seven hours of constant sunlight. This benchmark was selected because it was the only other project that dealt specifically with human wastes and renewable energy. The CooKit solar cooker [4] is a low cost solar cooker that utilizes reflective surfaces to focus solar energy on a black pot to cook the contents. The product was created by the Solar Cookers International non-profit group in 1994. The goal of the project was to create a simple and cost effective tool that could utilize renewable energy to perform the everyday task of cooking a meal. The design uses two reflective surfaces made of foil and cardboard to reflect sunlight on a pot that is sealed in a plastic bag. This benchmark was selected due to its low cost design and simplicity.

Using these benchmarks, as well as the concepts of the morphological chart, a Pugh chart was created to compare the team's top 5 designs. There were two iterations of the Pugh charts performed, with the first iteration using the Capetown project as a datum and the second iteration using the CooKit solar cooker as the datum. Using these tools, the team was able to reduce the number of design concepts from five to three. These three concepts were analyzed and combined into one design that incorporated the best features of each design.

FEASIBILITY ANALYSIS AND EXPERIMENT

Feasibility of Heating Required Mass of Waste

To estimate the energy required to heat the mass of the waste to be pasteurized, the waste was assumed to have the properties of water because about 90% of human waste in underdeveloped countries is made up of water. The following equation was used to determine the wattage needed to heat the waste with different time and temperature combinations required to successfully pasteurize waste.

$$q = \frac{m \cdot C_p(T_{final} - T_{initla})}{\Delta t}\ [W] \qquad (1)$$

In Equation 1 above, q is the power required in watts, m is the mass of waste to be heated, Cp is the specific heat of water, $T_{initial}$ and T_{final} are the starting and final temperature of the waste, respectively, and Δt is the pasteurization time. Table 2 shows the energy needed for three pasteurization requirements, which were taken from Figure 1.

Pasteurization Time [hrs]	T_{final} [C]	ΔTemp [C]	q [W]
1	60	35	46.12
10	53	28	36.89
24	50	25	32.94

Table 2: Energy Necessary to Eliminate Pathogens through Heating

The time for the waste to heat from room temperature ($T_{initial}$ was assumed to be 25°C) to the pasteurization temperature (T_{final}) was conservatively assumed to be 1 hour for each case. Therefore, the total time the waste would need to remain in the pasteurizer is the pasteurization time plus the heat up time.

Feasibility of Energy Available from Reflective Panels in Haitian Environment

Due to the lack of solar irradiance data for Haiti, the solar irradiance data of the environment of Puerto Rico was used to estimate solar conditions of Haiti because the two environments can be considered synonymous. This data was retrieved from the Typical Meteorological Year [5] database. The average conditions for each day for the past forty years were used to determine the amount of energy able to be obtained from the proposed reflective panels in the environment of Haiti. The solar panels were assumed to have an efficiency of 30%. It was calculated that the average conditions of 306 days out of the year were adequate to provide the previously determined necessary energy to pasteurize the waste in one hour (46.12 W), for at least 5 hours of the day.

Feasibility of Thermal Environment within Outer Bucket

The proposed design was modeled symmetrically using ANSYS software. The axis of symmetry shown in Figure 2 represents the point from which the inner bucket, outer bucket and lid are radially symmetric. The appropriate material properties were applied and the collected energy determined to be feasible was applied to the top of the lid of the modeled design. Several different stand materials were modeled to determine which stand would allow the best insulation of the waste within the inner bucket. Stands of concrete, rebar, PVC pipe and combinations of the three were each modeled because each of those materials can be easily found in Haiti. The model that best concentrated the energy on the waste and also provided adequate support used PVC pipe legs on which to balance the inner bucket, with a layer of concrete about one inch thick on the inside bottom of the outer bucket to hold the PVC stand in place and promote further stability by lowering the center of gravity. Figure 2 shows the steady state results of this design. The waste within the inner bucket was heated to a temperature between 59.8 °C and 63.4 °C. If the waste is maintained at the minimum temperature reached in this model, pasteurization should be completed in two to three hours according to Figure 1.

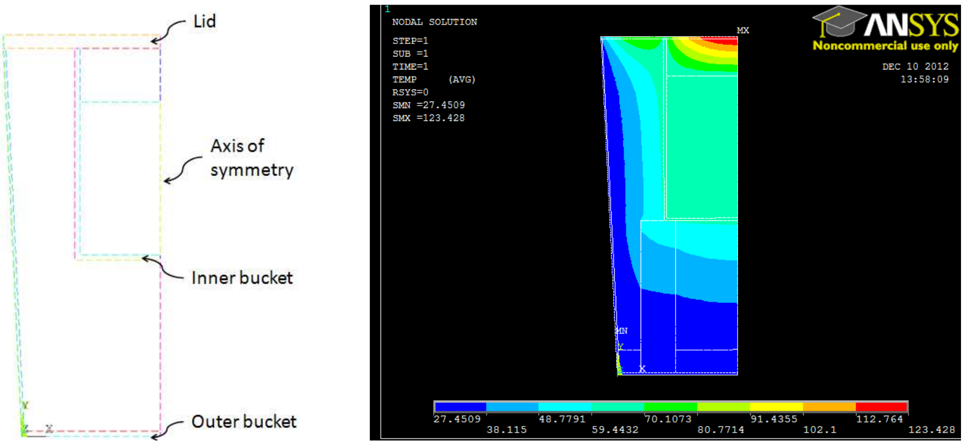

Figure 2: ANSYS Feasibility Analysis Diagram and Data

Testing of Sun-Oven Solar Cooker Benchmark

The Sun-Oven, an existing solar cooker which uses reflective panels like those modeled for the Waste Pasteurizer, was acquired from Rochester Institute of Technology's Industrial and Systems Engineering Department and tested to determine the temperature reached within the product. The data collected proves that reflective panels can focus adequate energy from the sun to a localized container. Three trials were run on a partly cloundy day in Rochester, NY: Trial 1was conducted using a small stainless steel pot as the inner container, with no adjustments made to the reflector angles and not during peak sunlight hours. Trial 2 was conducted with a small stainless steel pot as the inner container, with adjustments made to the reflector angles to provide maximum effectiveness, and not during peak sunlight hours. Trial 3 was conducted using a large black pot as the inner container, with adjustments made to the reflector angles to provide maximum effectiveness, and during peak sunlight hours. The pot was filled with water to simulate waste in each trial.

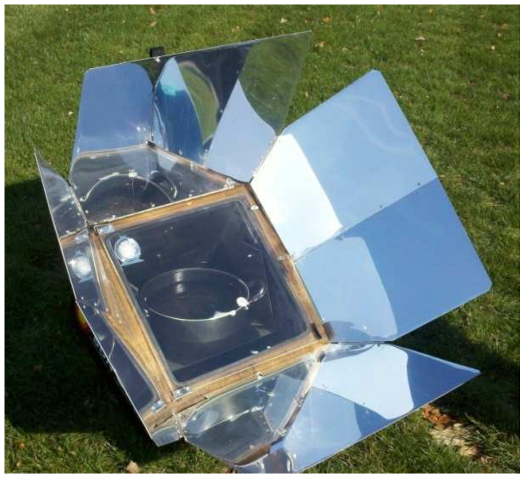

Figure 3: The Sun-Oven Solar Cooker

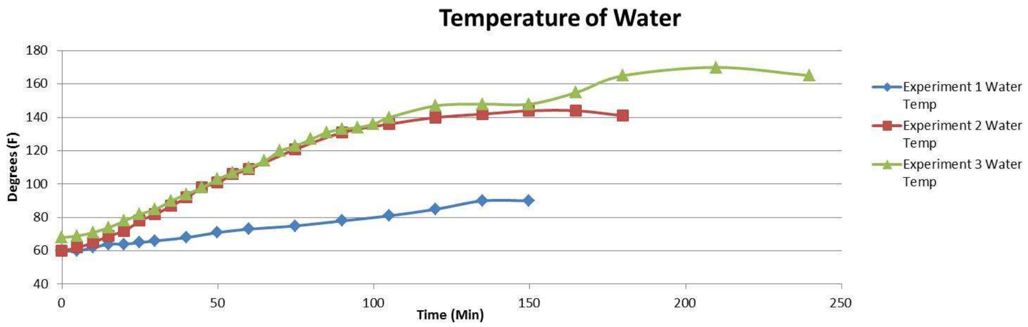

Figure 4: Experimental Data from Sun-Oven Benchmark Experiment

This experiment proved that with the reflectors optimally adjusted, the water within the solar cooker was able to heat to 60 °C (140 °F) in roughly two hours. Considering the significant differences in solar irradiance and the outside temperatures of Rochester versus Haiti, it is expected that this same test would have taken less time to achieve the necessary water temperature in Haiti. This was determined to be acceptable for the waste pasteurizer design.

THE BUILD

Prototype Design

Many considerations were taken in the construction of the prototype. Knowing that the project was aimed to be mass produced in Haiti, the design needed to reflect the operating conditions of the environment. The most notable aspect of the design is the material selection. The materials used to create the design are nearly all readily available in Haiti and/or are low cost supplies. Another advantage of the design is that most of the components do not need to have specific properties or be of an exact measure. The only components that require specific materials are the polycarbonate lid and the aluminum iPooP. The purpose of this was to simulate the presumed method of construction in Haiti and to facilitate repairs. This robustness allows for the Haitians to utilize scrap materials to construct or repair the device as needed, rather than rely on specialized parts or assembly processes.

iPooP Construction

Temperature indication was one of the bigger challenges the design faced. The implied restriction on electronic components made it necessary to consider other alternatives. Wax was selected to meet this need. Paraffin wax proved to be the most versatile since the melting point could be adjusted based on the wax blend, and it was reusable. The idea for using wax came from the Water Pasteurization Indicator (WAPI) [6] device used to indicate safe drinking water in under developed countries. A WAPI relies on visual inspection of the unit to determine if the wax had melted. Since the waste being pasteurized was not clear like water, relying on a view of the melted wax was not pursued.

The alternative was a newly designed temperature indicator called the iPooP (Indicator of Pasteurization of our Poop). The iPooP utilizes the same concepts as the WAPI, but allows for the user to determine if the wax has melted non-visually. It is constructed of an aluminum tube that is divided into two chambers: a wax chamber and a spring chamber. The wax chamber houses a one inch thick disk of paraffin wax. The spring chamber houses a spring which rests on an aluminum divider piece. The divider piece has a hole through the center to allow a push rod to contact the wax. Using the push rod, the user can determine if the wax is in a liquid form or a solid form. If the wax is a liquid, the rod will push through to the metal bottom and the indicator line on the rod will align with the top of the iPooP. Conversely, if the wax is still a solid, the rod will not reach the bottom of the tube and the indicator line will not line up to the device. Figure 5 shows a typical WAPI compared to the iPooP (not to scale).

Figure 5: WAPI (Top) and iPooP (Bottom)

Wax Verification

Before using the wax in the iPooP, the melting point of the wax needed to be verified. Multiple waxes and additives were tested to determine the best compound to use for the prototype. The ideal melting point for the iPooP wax was 63 °C, which would require an approximate pasteurization time of one hour. In order to determine the melting point of the wax, each sample was brought to liquid state in separate test tubes by placing those test tubes in a beaker filled with water, which was then heated using a hotplate. Thermocouple probes were submerged in the liquid wax and attached to data loggers to record the time vs. temperature plots. The wax was then cooled back into a solid form while the temperature was recorded each second. The data for each sample was then plotted into cooling curves, which show the phase change of the wax.

As exemplified in Figure 6, the liquid cools at a steady rate initially, but the temperature plateaus for a few minutes before continuing to cool. In order for the wax to take the form of a solid it needs to ‘freeze’. This operation requires the wax molecules to lose energy, in this case through reduced heat. This change is not instant, hence the plateau on the graph. The temperature at which this change happens indicates the melting temperature.

None of the samples yielded a melting point that exceeded 63 °C, and so the wax with the highest melting point was selected. The Pillar wax was determined to have a melting point of 58.8 °C and was selected because it is more rigid than other types of wax tested. The sturdier wax will help to avoid confusion when pushing the rod into the iPooP because the user is less likely to push through the wax. Using a lower melting point would ultimately increase the necessary pasteurization time from 1 hour to about 2.5 hours, but since this is still well within the project scope it was used in the prototype.

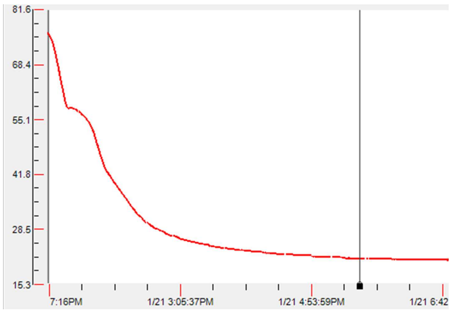

Figure 6: Pillar Wax with Melting Temperature of 58.8 °C

RESULTS AND DISCUSSION

The Final Prototype

The final prototype pasteurizer (as seen in Figure 7) consists of multiple sub components. The design was viewed as three separate pieces: the outer bucket, the inner bucket, and the lid/frame assembly. The outer bucket was a 5 gallon bucket made of high density polyethylene (HDPE). This outer shell was used due to their availability in Haiti and their low price. The inner bucket was a 4 quart Granite Ware stockpot. This item was selected due to its size, ability to absorb heat, and its demonstrated effectiveness in solar cookers. The lid/frame assembly is composed of many different materials, but the majority of it is made of polypropylene. Polypropylene was selected due to its low cost, its ability to resist deformation under high temperatures, and its ease of machining. These qualities made it easy and affordable to build a detachable unit. This versatility allows the lid/frame assembly to be put on any standard size 5 gallon bucket and turn it into a functional waste pasteurizer.

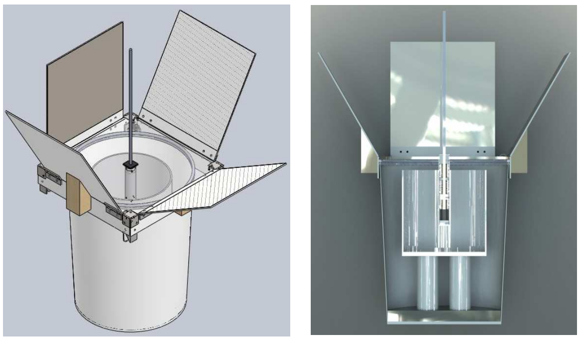

Figure 7: Waste Pasteurizer Isometric View (left) and Cross Sectional View (right)

One of the main considerations for this prototype was to minimize production costs. The goal of the design was to fall below 50 dollars mass produced. Based on the prototype that was constructed, bulk pricing of materials, and slight redesigns, a mass production price of $63.47 was achieved. Although this exceeded our goal, there are still some opportunities for reducing the costs further. One consideration would be to find a suitable replacement for the inner pot. This pot currently costs $14.71 by itself. Unfortunately, no bulk pricing options could be found. Furthermore this pot came with a lid and steamer insert that were not needed for this design. Setting up a deal with the manufacturer could lead to a significant discount. Another opportunity would be to perform a value analysis on the product design. By determining where certain functions and materials could be combined, the overall material needs should decrease. This decrease would result in further savings to the consumer, making this product more feasible for a Haitian family to purchase.

Testing

Multiple tests were performed on the final prototype to determine if it met the design specifications. These tests included heat, leak, wind, loading/unloading, and volume. The most critical tests to the overall performance of the prototype were the heat test and the wind test. These two tests ultimately determined if the pathogens in the waste were eliminated and if the unit was able to refrain from spilling the contents into the environment.

The heat testing was performed as a substitution for a solar test. Although a solar test would have been preferred, the local weather conditions would not permit a viable test condition. The substitute heat test captured all of the critical metrics the solar test would have provided, except the prototypes ability to convert solar energy into heat. To perform the heat test, a specialized lighting fixture was used to simulate how the prototype would react to the high heat. The fixture included eight 400 watt quartz working lights positioned about 2 inches above the tallest reflector panel. Before the lights were turned on, four thermocouples were attached to the iPooP, the water in the inner pot, the contained air, and the inner pot's handle. This setup generated approximately 70 watts per square meter onto the clear polycarbonate plate and resulted in the temperatures shown in Figure 8.

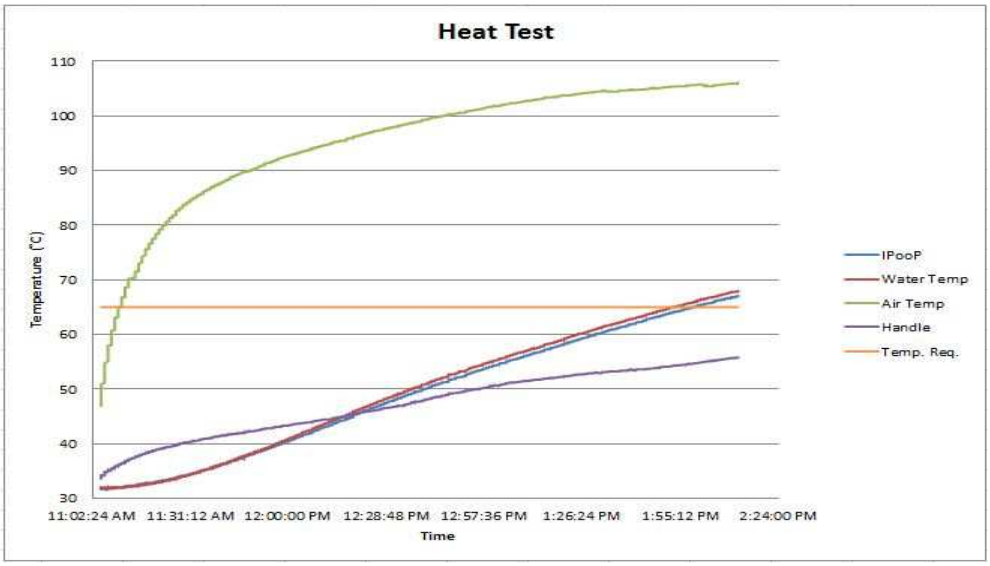

Figure 8: Plotted Temperatures from the Heat Test

The wind testing was performed on the Rochester Institute of Technology's campus. Due to the size and shape of the prototype, it was impossible to use one of the wind tunnels owned by the institute. Instead, the wind testing was performed outdoors on a particularly windy day. An anemometer was used to record wind speeds. The test was setup so that each reflector panel angle was directly normal to the wind's direction. This was to ensure that each panel angle could withstand a direct gust of wind without breaking or tipping. The target wind speed of 25 miles per hour (mph) was unable to be reached during the testing periods. The highest recorded wind speeds were 20 mph on the reflector panels. At these wind speeds there were no signs of failure. For this reason, it was believed that the target wind speed of 25 mph would not be able to tip or break the device.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Significant progress has been made towards developing a personal waste pasteurizer. Most of the design specifications were either met or exceeded. The results of the tests were all promising, indicating that this project could really be useful to underdeveloped nations such as rural Haiti. In retrospect, the team would have liked to have handled a few tasks differently. In designing and building the iPooP there were many opportunities for improvement including: creating detailed drawings sooner and researching high melting waxes more thoroughly. There was little machining experience within the group and as a result, the machining of the aluminum tube took much longer than anticipated.

Future Recommendations

The design team has some recommendations for future iterations of the project. As with any project, numerous constraints are present that do not allow for all design alternatives to be explored. Finding a suitable material for the inner pot proved to be challenging. It was important to meet the required volume while still fitting into the outer bucket. Most of the standard cooking pots that were researched were either too wide or they did not hold the proper volume. The inner pot that was selected met both needs, but it was a fairly expensive ($14.71) when trying to keep under a 50 dollar mass production cost. A lower cost alternative that meets both needs would be helpful in making this design more feasible for a Haitian family.

Another weakness of the current design is the way the iPooP is connected to the lid/frame assembly. Currently, there is a hole drilled through the polycarbonate where the iPooP rests. This required a significant amount of silicone to seal it. It also made the iPooP a permanent fixture on the lid, making the load/unload process more complicated. The current design forces the user to either have a separate stand or to rest the frame on the iPooP. If the iPooP were removable or adjustable to different pot heights the unit would be much easier for the user to handle and use.

One last recommendation would be to perform a true solar test. Due to the inclement weather, solar testing was not an option. There were very few sunny days that would provide adequate solar energy. Also, the cold weather would have most likely reduced the temperature gains significantly. Solar testing is a critical aspect to determining the feasibility of the prototype. Hopefully for future teams the weather will be more adequate for testing.

REFERENCES

[1] Bhanoo, S. N. (2011, September 26). The peepoo, a biodegradable toilet for the developing world. Retrieved February 14, 2013, from http://www.nytimes.com/2011/09/27/health/27toilet.html?_r=0

[2] Feachem, Richard G., David J. Bradley, Hemda Garelick, and D. Duncan Mara. *Appropriate Technology for Water Supply and Sanitation.* Washington, D.C.: Transportation, Water and Telecommunications Dept., World Bank, 1980. Print.

[3] Case study: Yosemite national park. (2009). Retrieved February 14, 2013, from Cape Town Project Centre website: http://wp.wpi.edu/capetown/homepage/projects/p2009/gardens/project-components/accomplishments/composting-options-for-the-proposed-sanitation-facility/pasteurization/case-study-yosemite-national-park/

[4] CooKit. (2013, February 8). Retrieved February 14, 2013, from Solar Cookers World Network website: http://solarcooking.wikia.com/wiki/CooKit

[5] National solar radiation data base. (2008, August 8). Retrieved February 14, 2013, from http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

[6] Water pasteurization indicator. (n.d.). Retrieved February 14, 2013, from http://www.sunoven.com/products-page/accessories/water-pasteurization-indicator-wapi

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