Executive Summary

The purpose of this project is to create a low cost, easy maintenance, off-the-grid refrigerator. The design is based off of the Pot-in-Pot refrigerator which evaporates water from sand in order to create a cooling effect. Improvements over the Pot-in-Pot design include an insulated outer container, fans to produce forced convection, a water reservoir, and the ability to condense and reuse the water that is evaporated.

Our prototype was able to reach 22.3 °C with an ambient temperature of 38 °C. An optimum temperature for refrigeration of approximately 10 °C could be achieved in locations with a lower ambient temperature, and there are a few improvements that could be made over the current prototype to increase its effectiveness.

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Introduction

The purpose of this project is to develop a refrigeration device that can be used in third world countries. The device will not require electricity from a grid to operate, and many of its components will be made from materials that are locally available. Its design is based off of the Pot-in-Pot refrigerator, which relies on the evaporation of water from sand in order to cool the system. Our design will improve on the Pot-in-Pot's performance in many areas.

Background

Refrigeration is an important step in developing healthy and well-nourished societies. Refrigeration provides a means to preserve food longer and prevent spoilage and the possibility of disease from bacteria. Further, refrigeration is also necessary to store and maintain certain vaccines and medical reagents. Without refrigeration these will spoil and no longer be capable of preventing or treating disease. Current methods of refrigeration in the modern world are energy intensive, requiring electricity from non-renewable sources, but over 25% of the world does not have access to regular electrical power.

A current device that is used in Africa and third world countries is the Pot-in-Pot refrigerator which was invented by Mohammed Bah Abba in 1995. It consists of two pots, with sand between the pots which is saturated with water. The water is absorbed into the outer pot and evaporates off of the surface, which causes a cooling effect. The device is inexpensive and very easy to make, however it requires dry air and windy conditions in order to be effective, and it uses a lot of water. Other similar products are the Janata Cooler and a charcoal cooler, which also rely on the evaporation of water.

Our device will be similar to the Pot-in-Pot, but will have many improvements. The outer container will be insulated in order to prevent heat loss to the outside air. Water will be evaporated from the sand by forcing air through helical tubes with a solar powered fan. The water evaporated from the sand will then be condensed so that it can be reintroduced into the system, allowing the device to operate using less water. The target temperature for the device is below 10 degrees Celsius.

Concept Generation

For this proposed solution, several configurations were considered. Initially it was thought that a condenser could be used on the device that was very small relative to the outer walls. Under this assumption it would be located at the top of the device with the air entrance and fan at the bottom. After the water was condensed it would just drip through sand under the force of gravity. For the interior, the pipes would run vertically connected by rings at the top and bottom. It would make the most sense for assembly and manufacturing to have all the porous piping consist of straight segments. The initial configuration can be seen below in Figure 1 and Figure 2.

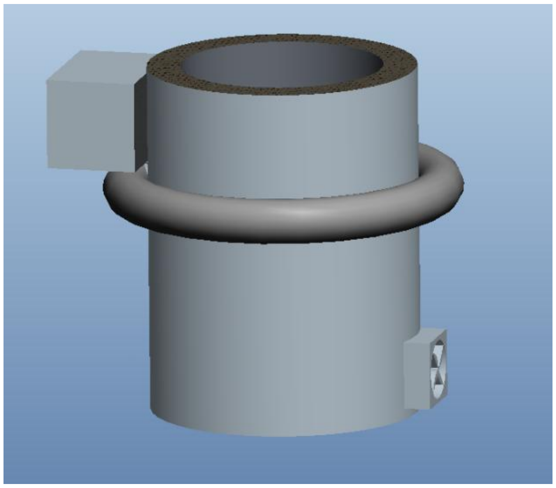

Figure 1: Initial Configuration

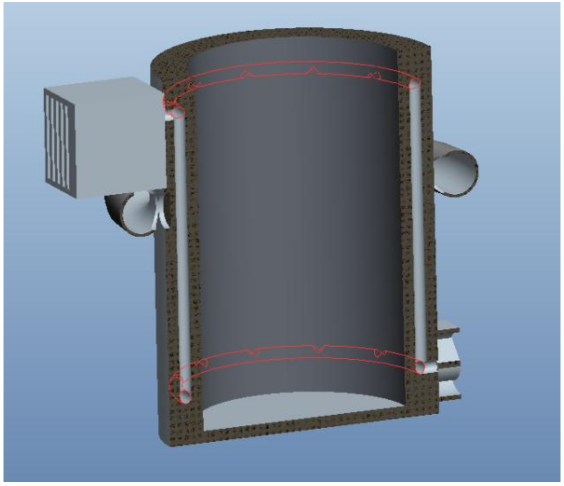

Figure 2: Interior

After researching further, it was determined that it is not feasible to have a small condenser without an external power supply. The most effective way to achieve consistently lower temperatures than ambient air would be to use the cool underground. After exiting the cooler the air will travel underground to a depth of approximately 4 feet. A pump is now required to retrieve the condensed water and reintroduce it into the system. Beneath the device a small reservoir of water was also added to allow the pumping to be limited to only once a week. Testing confirmed that the capillary action of sand will provide enough force to pull water up the length of the device. Sitting at the bottom of the container in this water bath allows the sand to pull in water as needed. The last major design change was to arrange the porous pipes in a helix rather than a network of many straight tubes. This allows more refined control over the path the air takes. This configuration was presented in a design review to mostly positive feedback. Its layout is shown in Figure 3.

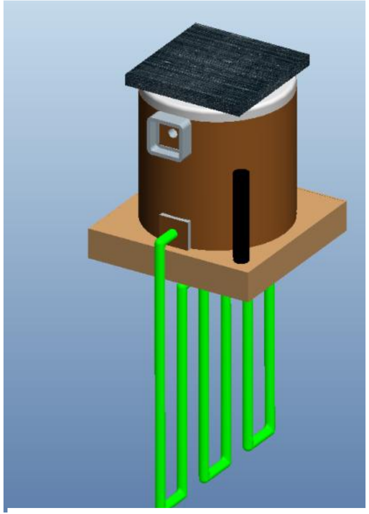

Figure 3: Second Major Iteration

Other thoughts that were considered but later abandoned include raising the device off the ground to prevent the transfer of radiating heat, or moving air with another source of power such as a bicycle. This was seen as too much of a situational requirement and not good design. Briefly it was talked of expanding the scale of this project to serve several families instead of just one. Given the timeframe and limited testing resources, this was decided to be unrealistic.

Device Overview

The final design of the refrigeration device contains two major parts: the evaporator and the condenser. The refrigeration cycle has the following processes: forced convection, evaporation, condensation, water pumped back in. The main components involved in construction of the device are as follows.

A 10-gallon Gatorade cooler was used to house and insulate the food storage and heat removal component of the refrigerator. Two 1 ½ inch holes were cut and fitted with PVC tubes to air passage for air into and out of the device. Two small holes were cut in the lower half of the container and fitted with small lengths of clear tubing to act as water level meters. The precut hole at the bottom was used to connect to a pump to bring in water to the device.

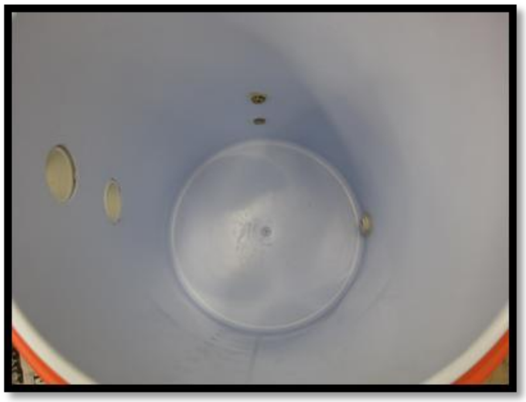

Figure 4: Empty Container with Holes Cut

An aluminum frame was built to separate area for water storage in a reservoir and area for sand. The frame is made of a base circle and an upper ring held together by three supports and wrapped in permeable cloth. This allows for water to seep from its reservoir into the sand contained in the frame. The top ring is sealed to the walls of the container to prevent sand from falling into the water reservoir.

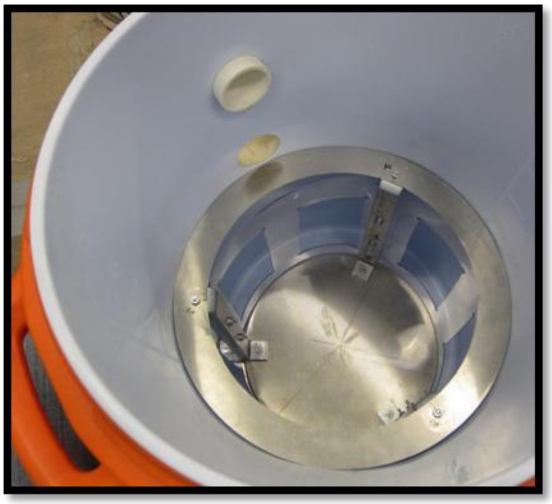

Figure 5: Aluminum Frame

For air to flow through the sand and pick up moister, coils of porous “airflow” tubing were created. These coils were made by rolling chicken wire into tubes, folding those tubes into rings, and wrapping them with permeable cloth.

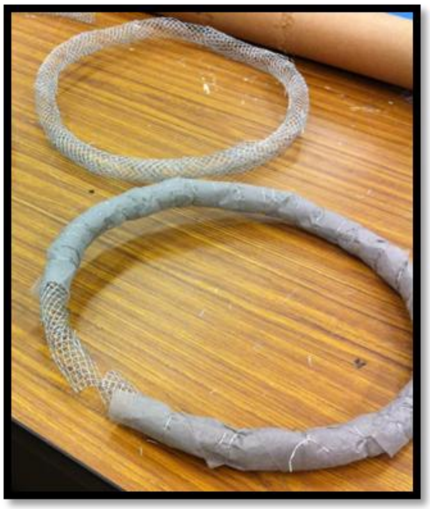

Figure 6: Airflow Tubes Under Construction

The inside bottom area of the aluminum frame was filled with sand. The airflow tube coils were put in lining the walls and connected to the air entrance and exit holes. A 7 inch diameter clay pot, made specifically for our project by the Pao Ceramics Lab, was placed inside the coils. The pot is glazed on the inside to protect food.

Figure 7: Airflow Tubes Surrounding Clay Pot

Sand was filled in up to the top rim of the pot. A plastic ring cover was placed over the sand to keep it from getting into the pot. In the small space above the pot, a roll of insulation was placed to stop the device from having to cool this extra unused area.

Figure 9: Sand Filled In

Figure 8: Insulation on Top

A simple pump was built with PVC tubing and two one-way values. A plastic tube is stuck into the entrance of the pump and its other end can be put into any source of water, such as a 2 liter for initial filling, or the water collector underground in the condenser. The exit of the pump was attached to the bottom hole in the container leading to the water reservoir inside.


Figure 10: Pump Used to Fill Reservoir

Figure 11: Fully Assembled

A computer fan rated at 100 cfm is attached to the air entrance tube to the container by means of a cross-sectional area reducer made from polycarbonate plastic. The air exit tube from the container is connected to a polycarbonate box holding a temperature and relative humidity meter.

A flexible plastic hose is attached to the box holding the meter at the air flow exit and leads underground acting as a condenser. For testing purposes, a constant ground temperature was simulated using a water-bath keeping water at a constant temperature. The flexible tube is coiled inside the bath and exits into a PVC container at the bottom. All water that condenses in the tubing runs down into this collection container.

Figure 12: The Water-Bath on Left and the Cooler Container on Right

The container is connected to an airflow exit pipe made from PVC which leads to the surface. At the surface another computer fan is connected to the tube using another cross-sectional area reducer. The fan is set to pull air out from the condenser underground. This aids the airflow greatly attempting to compensate the head loss incurred from imperfect pipes and sharp turns.

Figure 13: Exit Fan from Condenser

To illustrate the operation of the device, please referrer to Figure 14: Device Operation when a [#] indicator is given. Water must first be pumped into the water reservoir from an outside source. A flexible tube or hose is connected to the pump and placed in any source of water [1]. For our testing conditions, approximately 14 liters of water was pumped into the water reservoir. As the water level rises inside the device, two meters on the side of the container fill-up and indicate how much water there is inside.

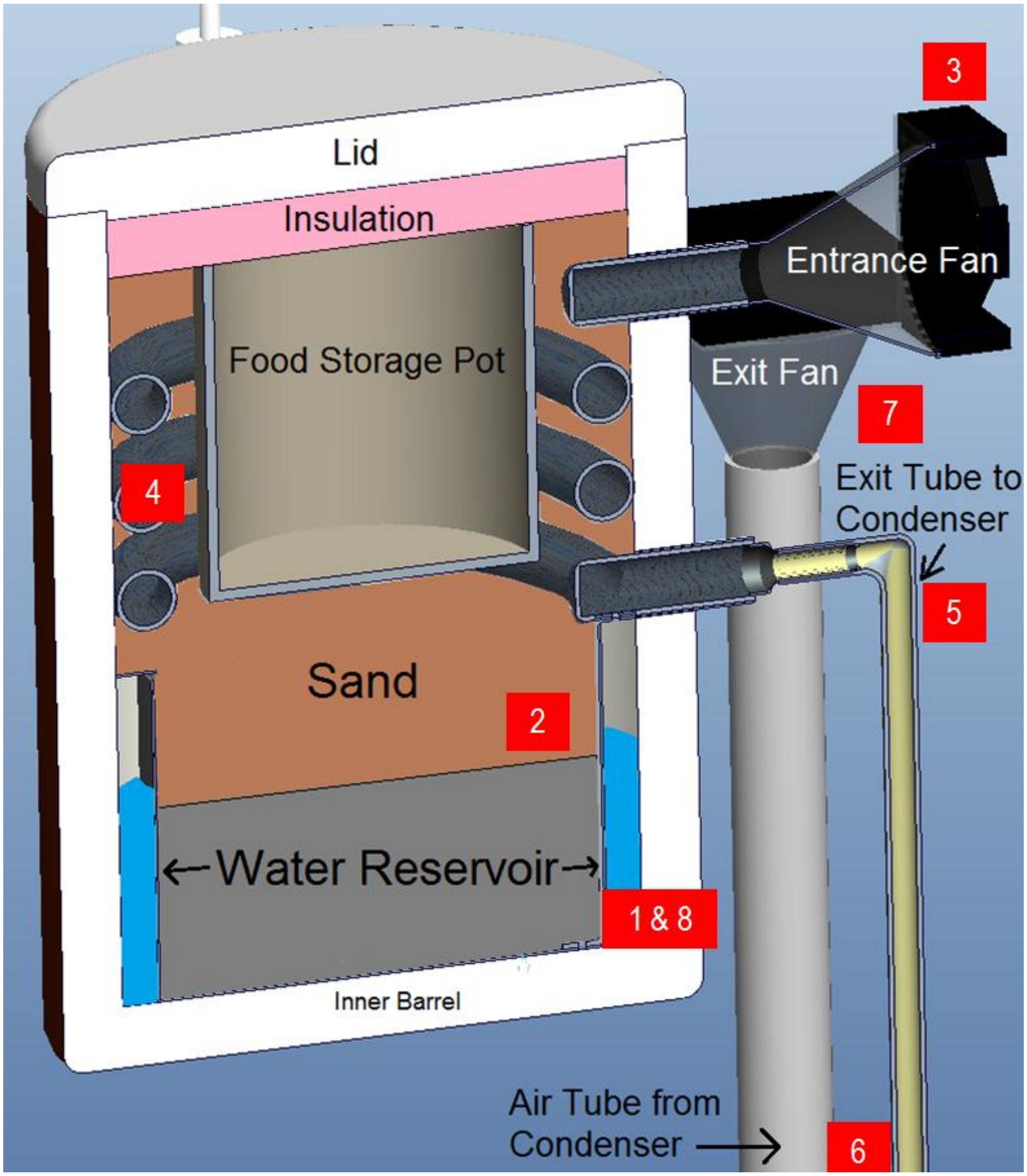

Figure 14: Device Operation

The water comes in contact with the sand inside the permeable cloth walls of the aluminum frame. The sand saturates with water [2] because of capillary action within the sand. Fine grain sand was used because of initial experiments showing that the rate of saturation in sand relies on the size of grains. Smaller grains and larger surface area increase the rate of capillary action. The cross-sectional area of the water reservoir was kept small in comparison to the area of the sand to also aid in increasing the saturation rate.

Once the sand is saturated with water, the fans are turned on. Ideally the battery they are connected to would be charged using a small solar panel. The fan connected to the entrance of the airflow tube pushes air into the tube [3]. The air is ideally at a low relative humidity, and as it is pushed through the helical porous airflow tubes, it evaporates water from the sand and carries it along [4]. This process removes heat from the sand and the lowers the temperature inside the container. As water evaporates from the sand into the forced flow of air, water from the reservoir continuously keeps the sand fully saturated, allowing the cycle to run for as long as the battery lasts for the fan.

The air now containing moisture leaves the container through the exit tube located below the entrance [5]. It flows through the flexible hose which is coiled in the water-bath. As the air flows through the tube, the change in temperature below the dew point allows the water to condense. The condensed water runs down the length of the hose and collects in a water container at the bottom [6].

Once the air has shed as much water as possible into the condenser water collector, it is pulled back up to the surface through a pipe connected to the exit fan [7]. This completes the cycle of air flow. The usable condensed water stored at the bottom of the condenser is then pumped back into the water reservoir in the insulated container using a flexible tube or hose connected to the pump [8].

Manufacturing and Assembly

Because the aim of this project was to be as simple as possible, most components of the device were bought and required few modifications to be put together. To hold certain components together permanently, two-part epoxy was used, but almost no glue is necessary other than to seal parts that could leak water. Only three components of the device were manufactured: the porous airflow tubing, the reservoir frame, and the air cross-sectional area reducer for the fans.

The porous airflow tubing, although manufactured, used simple materials that could be locally found in many places around the world. Chicken wire fencing was used to create a frame for the permeable cloth. Any material that has many holes or large gaps could also work for this function. The only stipulation is that the tube must be able to withstand the pressure of the sand. In our case, the chicken wire was rolled into long tube length of a chosen diameter. Then using a bent piece of PVC pipe, the coils of the tube were created by pulling the pipe through the wire tube as shown in Figure 15. The coils were then wrapped with the permeable cloth, which was held together by tying loops of string spaced every few inches.

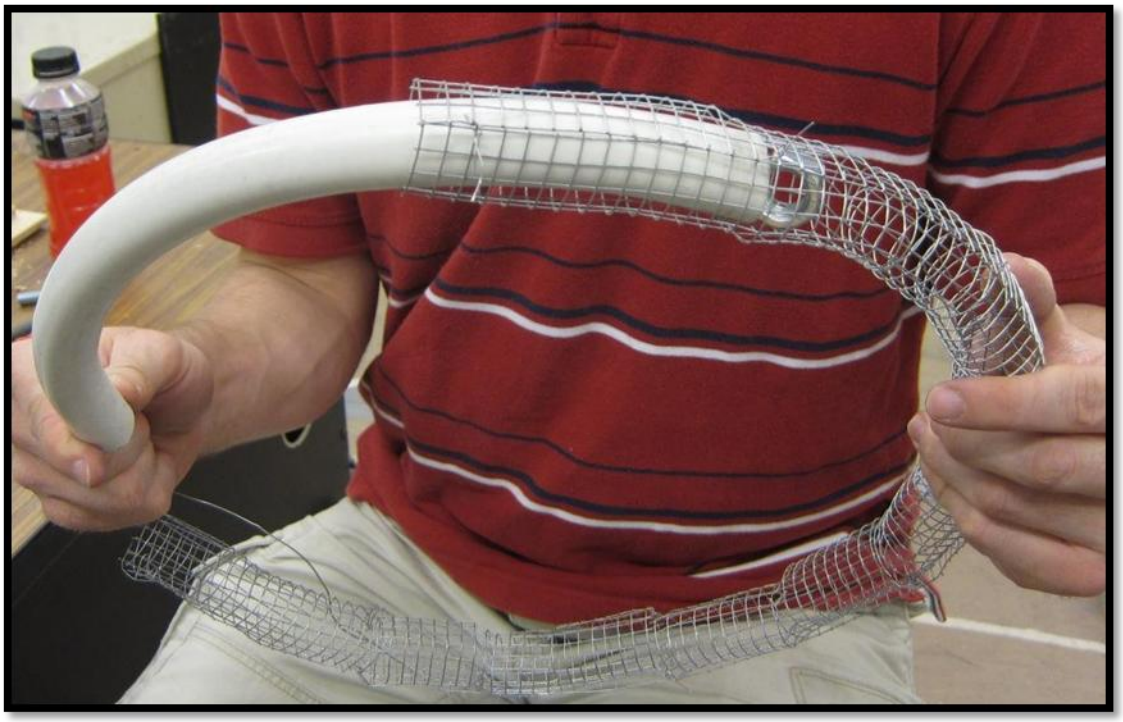

Figure 15: Creating Wire Coils

The aluminum frame and both polycarbonate plastic cross-sectional area reducers were cut using a water-jet. Parts for each of the components were modeled in CATIA and imported into the water-jet cutting program. Both of these parts could have been made by hand with some careful drawings, but for our purposes, the water-jet was the easiest and quickest solution. The rendering of the part is shown below with detailed drawings in Appendix D.

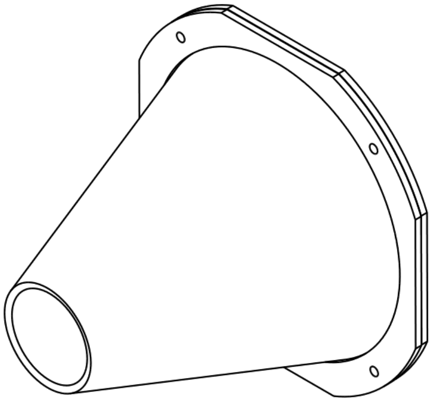

Figure 16: Isometric of Reducer

Analysis

Analyzing the water evaporation cooler begins by drawing a control volume. As seen in Figure 17, the control volume is drawn inside the evaporative coils and around the sand and pot cylinder. This control volume allows the analysis to be simplified to a simple input and output heat transfer equation. The outside cylinder of evaporative coils is assumed to have a constant temperature that is the average of the inlet and outlet temperatures to ambient conditions. The outlet temperature was determined from initial tests performed at 38°C.

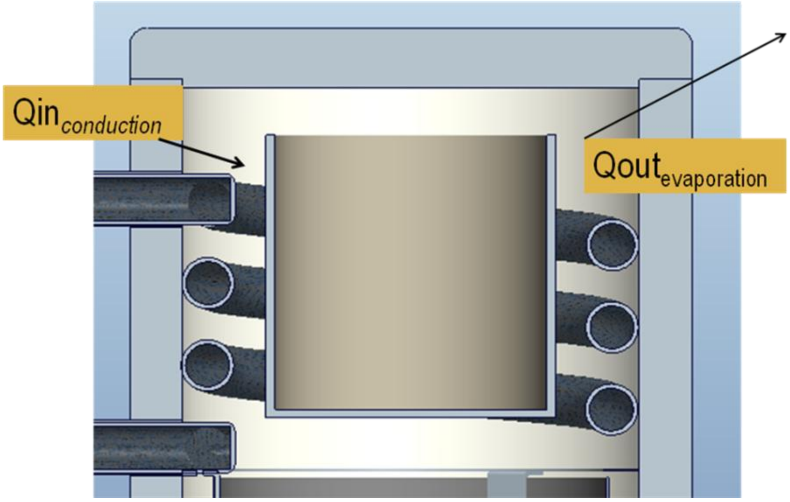

Figure 17: Evaporation Control System

With a constant temperature in the tubes the system analysis can be simplified to the energy balance in equation 1.

$$Qin = Qout \qquad \text{(eq 1)}$$

The heat conduction in is modeled as a heat transfer across a cylinder seen in equation 2.

$$Qin = \frac{2\pi Lk(Ts1-Ts2)}{\ln\left(\frac{r2}{r1}\right)} \qquad \text{(eq 2)}$$

The heat loss due to evaporation is modeled as equation 3.

$$Qout = \dot{m}Hfg \qquad \text{(eq 3)}$$

With these three equations the needed evaporation can be calculated based on system dimensions and initial ambient conditions.

The evaporation rate of air over a surface of water is a complicated model and is best described by empirical models. The model we used is the Langmuir Equations seen in equation 4.

$$\dot{m} = \frac{P}{2\pi R\sqrt{\frac{T}{M}}} \qquad \text{(eq 4)}$$

R is the gas constant for water and M is the molecular weight of water. The Langmuir equation gives the possible evaporation rate for the initial conditions. The evaporation rate is then multiplied across the surface area of the tubes. The surface area is determined by the diameter of the tube and the number of coils. The delta temperature is then manipulated to make the evaporation rate and evaporation energy loss equal the input from outside ambient heat for different tube configurations.

Using this data, Figure 18 was generated for the steady state temperatures with different configurations of tubes. The equations were modified to increase the height of the pot to make it match the height of the coils of tubes. This results in an increase in volume as the number of tubes is increased. This increase adds to the amount of energy needed to cool the pot. This leads to a temperature floor that no matter the configuration of tubes the delta T will not be greater than 18.3° C. Lowering the ambient temperature continues to result in the same delta T. At 35° C the final temperature is 16.7° C. With ambient temperatures below 28° C it is possible to go below 10° C.

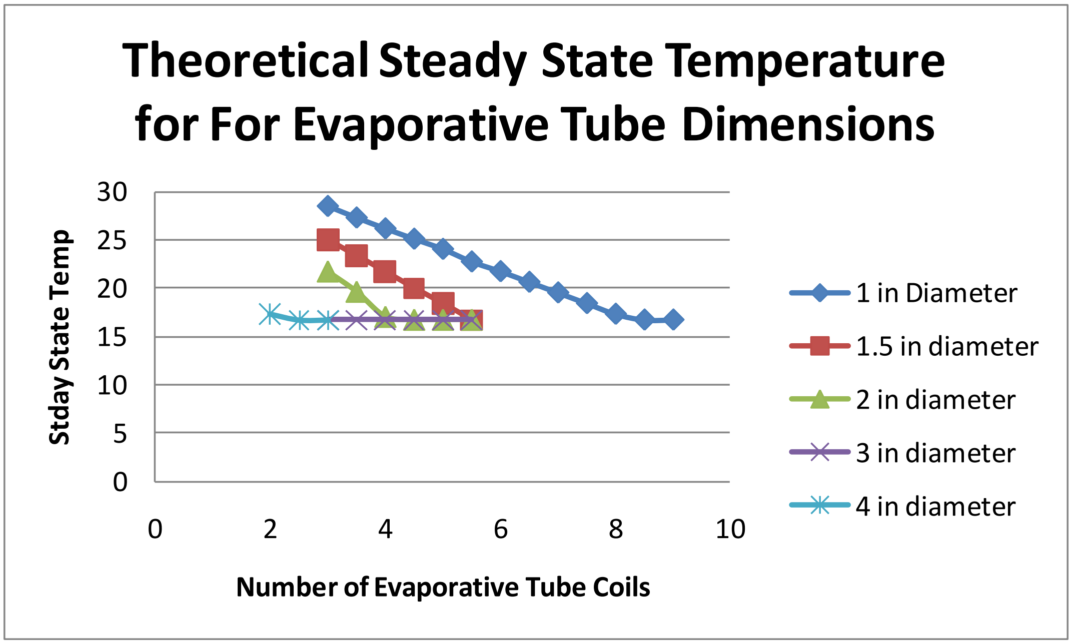

Figure 18: Predicted Steady State Values for Different Tube Configurations

Another significant factor is the k value for wet sand. This value is more difficult to change however, because the wet sand is fundamental to the function of the cooler. Keeping all other things equal the design floor at 35° C with a k value of 1 is 4° C under optimal conditions.

After the air travels through the evaporative airflow tubes it is pushed underground in order to condense the water out of the moist air and allow it to be recycled back into the system. This works on the simple principal that underground temperatures remain fairly constant through the year combined with an understanding of psychrometric tables. The ground temperature fluctuates through the year but remains close to the yearly average temperature. The size of the fluctuation varies with the depth in the soil as seen in Figure 19.

Through testing it was found that the exit relative humidity from the evaporative tubes was 75% and the exit temperature was 32^{o} C. Finding this point on a psychrometric chart shows a dew point temperature of 28.3 ^{o}C. This value was then compared to tables showing the measured ground temperature of cities across the world. Cities were highlighted that were in areas that had proper ambient conditions and ground temperatures below the dew point temperature. Even regions in desert climates have ground temperatures below the necessary dew point (These values can be seen in Appendix A). With desert ground temperatures below the dew point, blowing air through underground pipes will result in condensed water in quantities large enough to pump back into the refrigerator.

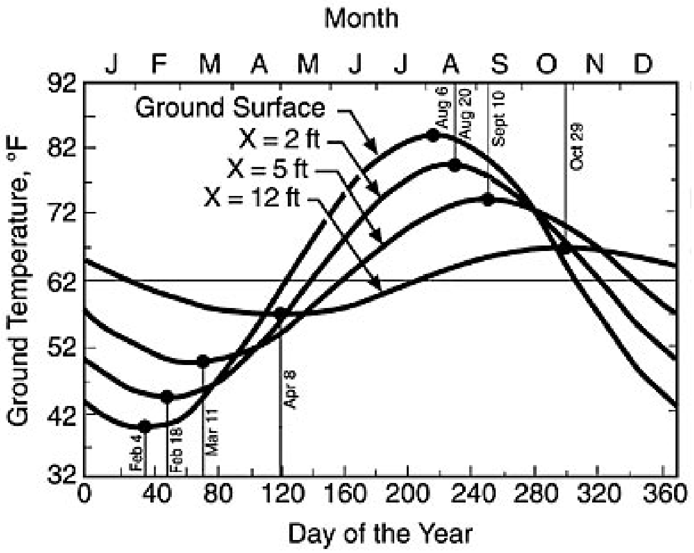

Figure 19: Temperature Fluctuation

Materials and Cost

Because there is no one set configuration of our device, the materials used and its cost could vary quite a bit. Our own design process went through several iterations of certain parts, such as creating three different versions of cross-sectional area reducers for the fans. Table 1 generalizes costs for essential items for a single iteration of a working model. The table breaks the necessary items into two categories. The first set is items that can be found locally in many parts of the world. The second set is items that may need to be purchased or ordered. If the necessary local items are available, the device could cost around $150. If all parts had to be purchased, the cost would be around $170.

Table 1: Bill of Materials

Item	Production Cost
Plastic Barrel	$14.00
Sand	$0.00
Wire Mesh	$3.00
Cloth	$2.00
Clay Pot	$1.00
Sub Total	**$20.00**
Fans	$42.00
Battery	$25.00
Solar Panel	$50.00
Plastic Tubing	$6.00
Epoxy	$10.00
Pump	$20.00
Purchase Sub Total	**$153.00**
Total	**$173.00**

Testing Procedure and Parameters

A combined 56 hours and 10 trials were spent directly observing our device in operation. Testing was primarily conducted in a walk in incubator owned by the biology department who generously allowed open access. The average temperature in the incubator room was 38°C and consistently kept under 20% relative humidity. This was meant to simulate daytime conditions in a dry climate. A few tests were also conducted in cooler and more humid conditions to observe the performance in areas that are not ideal. Shown below in Table 2 are the testing parameters for each of the trials run.

Table 2: Testing Configurations

Trial	Entrance Fan	Exit Fan	Larger Fan at Entrance	Condenser Run	3 Turns of Airflow Tube	5 Turns of Airflow Tube	Ambient Temp. 38 °C (Daytime)	Ambient Temp. 21 °C (Nighttime)
1	X			X	X		X	
2	X			X	X		X	
3	X	X		X	X		X	
4	X	X		X	X		X	
5	X	X			X		X	
6	X	X			X			X
7	X	X				X		X
8	X	X				X	X	
9	X	X				X	X	
10			X			X	X	

Given in the Results section is a brief summary of each trial's result, and the context with which it should be considered. Full testing data is presented in Appendix C.

Results

Trial 1 4/4/2011

Conducted in Lilly, this trial was the device's first operation. Due to leaks within the pump system, the device was filled from the top with water from a water fountain. It was discovered that the extreme temperature that the water was chilled to brought the device to an unreasonably low temperature and during operation it just increased from there.

Table 3: Trial 1

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Exit Relative Humidity	Run Time hrs
1	11.5	20.0	37.2	67%	6

Due to the inconsistent starting temperature this trial was deemed as an outlier and is not considered an accurate representation of the devices operation. An unexpected issue was that the water bath, simulating underground conditions, was not able to maintain a temperature of 20°C in the incubator. The temperature steadily rose from 20°C to 27°C over the length of the test. The major take away from this test was the need for another fan at the exit of the condenser.

Trial 2 4/6/2011

Also in the incubator, this trial was conducted two days later after the room and device's temperature had equalized.

Table 4: Trial 2

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Exit Relative Humidity	Run Time hrs
2	26.8	23.6	37.8	74%	3.5

During this trial it took only three and a half hours to reach steady state. This is the last time the device was tested with only one fan. This trial represents the first time that a lower than ambient temperature trend was observed.

Trial 3 4/11/2011

Trial 3 showed the first time tests were conducted when the device had equalized to the ambient conditions. An exit fan was attached to the condenser to help with the low airflow. This trial was also conducted with a Pot-in-Pot simulation run side by side with a fan pushing air over it. The summary of the tests results are shown below in Table 5.

Table 5: Trial 3

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Exit Relative Humidity	Run Time hrs
3	34.1	28.3	38.5	68%	5

During each test much more information was collected than in Table 5, and some interesting trends can be observed by looking closely at the data presented in Figure 20.

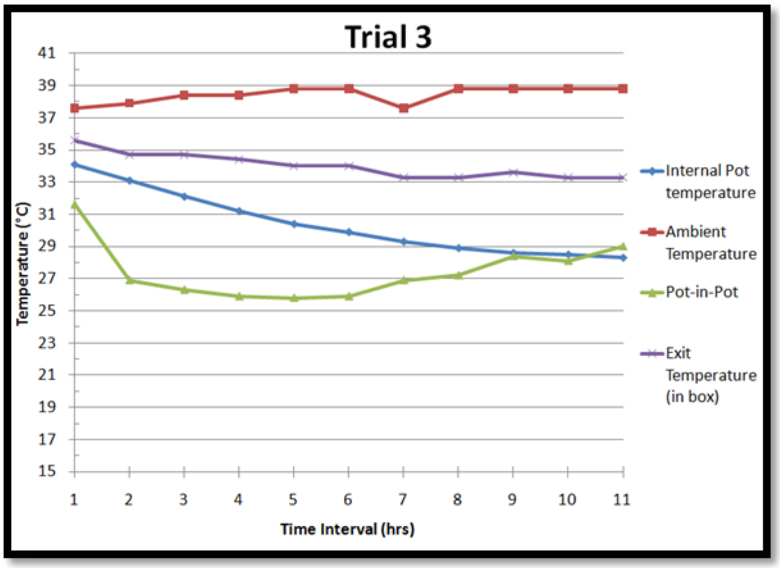

Figure 20: Trial 3

The ambient temperature remains right around 39°C for the duration of the test, providing near perfect conditions for changes to be observed. Other interesting points include how quickly the Pot-in-Pot's temperature dropped, but also how fast (about 3 hours) the temperature started rising again. The outlet of the device also remained relatively constant.

Trial 4 4/12/2011

Figure 21: Trials 3 & 4

This trial was run with the same set up as the previous test, shown in Figure 21. This test resulted in lower steady state values and compares well against the Pot-in-Pot design. The most encouraging fact is the exit relative humidity increases over 50%. This is the essential principle that our device operates on and also having this information allows theoretical condensation calculations to be made. Even with the deficiencies of the water bath as mentioned earlier.

Table 6: Trial 4

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Exit Relative Humidity	Run Time hrs
4	33.1	27.1	38.4	74%	7

This is the last time that testing was done in the configuration shown in Figure 21.

Trial 5 4/14/2011

From this test on the water bath was no longer connected to the exit of the device. The fan that was placed at the exit was moved to the exit of the porous tubing. This greatly increased the airflow within the tubing and improved its cooling power dramatically. This change did result in the loss of the exit temperature and humidity sensor however. This trial resulted in extremely consistent results and showed a dramatic decrease in temperature, initially leveling off quite quickly (2 hours). This trend is demonstrated in Figure 23.


Figure 22: Trials 4-9

Table 7: Trial 5

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Run Time hrs
5	33.9	23.9	37.9	7

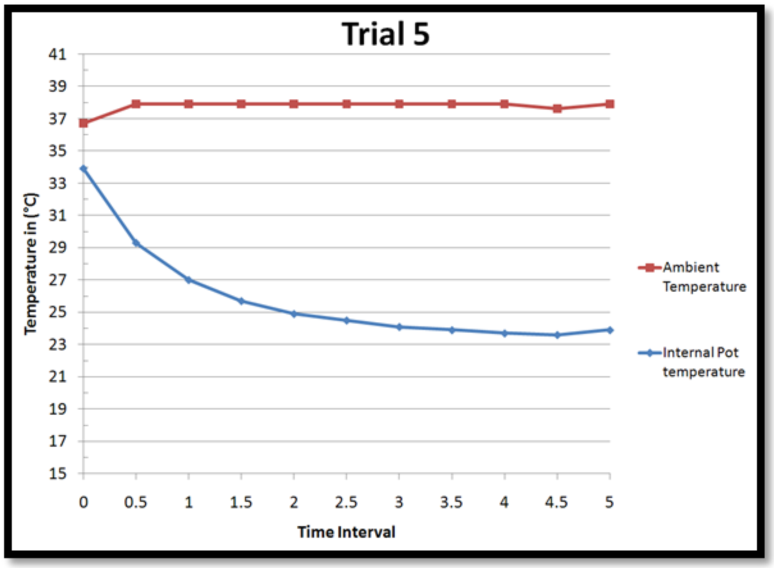

Figure 23: Trial 5

This trial showed a significant decrease in temperature (14°C from ambient), and because the only variable changed was the fan locations, it can safely be assumed that the increased airflow is the cause. The results are encouraging but no more modifications to the layout can be made externally. The only variable left to test in this configuration is operating the device in non ideal conditions, lower temperature and higher relative humidity.

Trial 6 4/15/2011

The next two tests were conducted in Room 4 of the Mechanical Engineering building, having both cooler and higher humidity conditions. These were done to see how large of an effect humidity has on the devices operation. A relative humidity rating of 60% is not uncommon for most of the world to experience. Research had told us that as the humidity goes up, the Pot-in-Pot loses its effectiveness. However, these were observational statements with no testing data to support this.

Table 8: Trial 6

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Ambient Relative Humidity	Run Time hrs
6	28.7	19.9	21.7	57%	4.5

While this test did achieve a lower temperature than any other trial, the drop from ambient puts it into perspective. During trial 5 there was a drop of 14°C from ambient, compared to trial 6 with a drop of only 1.8°C. If there is low relative humidity the air still has the ability to evaporate water thereby cooling the interior pot. However, saturated air, demonstrated by the conditions in room 4, drastically reduces the device's cooling ability.

Trial 7 4/16/2011

Again run in non ideal conditions (21°C, 60% relative humidity), the difference from trial 6 is that two more coils were added increasing the surface area of piping by over 60%.

Table 9: Trial 7

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Ambient Relative Humidity	Run Time hrs
6	25.5	18.2	21.7	58%	4

The results are similar to what we achieved in trial 6 only slightly increased (a drop of 3.5°C to 1.8°C). This is still not significant however and confirms the claim that the Pot-in-Pot loses effectiveness in more humid climates. Shown below in Figure 24 is a comparison of both tests done in room 4 in simulated nighttime and higher humidity conditions. Notice that a lower temperature was achieved but the drop form ambient is not impressive.

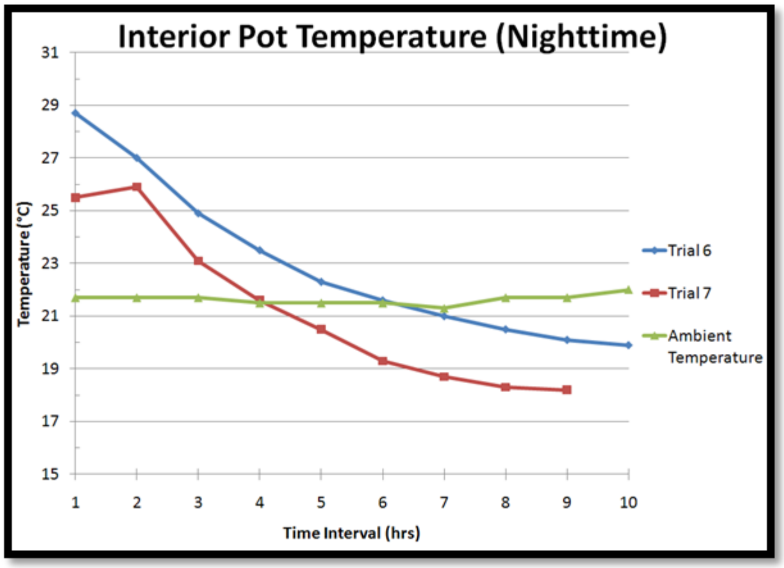

Figure 24: Non Ideal Conditions

Trial 8 4/17/2011

This test represents the first time the device is in operation back in the incubator with the expanded coil length. An interesting point to this test is that the interior had equalized in temperature with room 4, giving the starting temperature of 22.3°C. This is lower than any temperature previously achieved in the hot room.

Table 10: Trial 8

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Run Time hrs
8	22.3	22.4	37.9	4

A key point was that the temperature increased very little from the starting temperature of 22.3 °C.

Trial 9 4/19/2011

A few days were given to allow the device to normalize its temperature with the ambient conditions before the test was repeated. This trial was run under the same conditions as trial 8 but with the starting temperature closer to that of trials 3-5.

Table 11: Trial 9

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Run Time hrs
9	34.1	23.8	37.9	6.5

Under a new configuration of five instead of three coils, the device was not able to achieve a lower temperature. It actually arrived at the same steady state temperature as trial 5. Shown below in Figure 25 is a summary of tests 3, 5, 6, 9, and the Pot-in-Pot from trial 4.

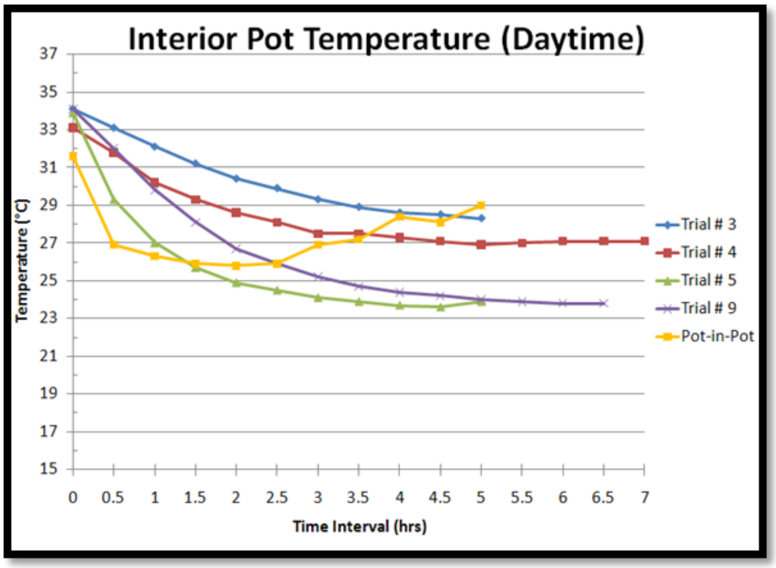

Figure 25: Testing Summary

Figure 25 shows a consistent downward trend of the steady state temperature from trials 3, 4, and 5. Interestingly, trial 9 and 5 arrived at the same temperature at the same time. It's thought that the additional head loss caused by lengthening the tubing for trial 9 reduced the initial drop in temperature. The most dramatic difference is noted by comparing the Pot-in-Pot to any other trial run. All temperature readings show a consistent decrease and a smooth transition into steady state. The Pot-in-Pot has no steady temperature and varies drastically over periods as short as half an hour. Its constant maintenance and inconsistencies in performance make it very unattractive as a cooling device.

Trial 10 4/20/2011

Trial 10 was done to test conditions if airflow is dramatically increased. The thought was to use the fan initially providing airflow over the Pot-in-Pot.

Table 12: Trial 10

Trial	Starting Temperature °C	Final Temperature °C	Ambient Temperature °C	Run Time hrs
9	31.8	24.2	38.2	6

While a larger fan was placed at the entrance there was very little airflow that exited the device. It's thought that the diameter change from around nine inches to fewer than one and a half caused too great a pressure drop. The airflow simply wasn't able to sustain itself through the length of piping. That being said, the temperature drop of the internal pot was comparable to any other tests conducted.

The Pot-in-Pot was tested at the same time but in this trial there was no forced airflow over the outer pot. The interior pot never wavered beyond the starting point and failed to cool even when continually being watered. This is one large advantage that our device has over the Pot-in-Pot configuration.

Conclusions and Recommendations

The Pot-in-Pot refrigerator is an innovative method of maintaining lower than ambient air temperature for food preservation. However, the container is not insulated, there is no proper lid, water must be added with a frequency to make it impractical in desert climates, it relies on wind which is unpredictable, and it is unable to maintain a constant steady-state temperature. Our device addresses all of these issues. Our device employs forced rather than free convection and is able to condense and reuse a portion of the water that it has evaporated, it has an insulated outer container, and it is able to maintain a steady-state temperature that is lower than what the Pot-in-Pot is able to achieve. Our prototype was able to reach a steady-state temperature of 22.3 °C with an ambient temperature of 38 °C, for a difference of 15.7 °C.

There are a few possible improvements that could be made over the current prototype. The diameter of the airflow tubes could be increased to 4 inches, which is the same diameter as the fans. This would eliminate the need for a nozzle between the entrance fan and the airflow tubes, which would greatly reduce the head loss in the system. The larger diameter airflow tubes would also provide a larger surface area for evaporation. The height of the water reservoir could be made smaller, which would reduce the excess volume that needs to be cooled. Finally, silica gel dehumidifier packets could be placed at the entrance fan in order to reduce the relative humidity of the air coming into the system. This would increase the cooling rate and also allow the device to be used in areas where the ambient humidity is a little higher.