Solar Sausage for Water Desalination

Midterm report

Team Number: 7

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Abstract

The topic of this senior design project is applying the Solar Sausage to the need of potable water in developing countries. The goal is to incorporate a desalination system with the Solar Sausage. The project must continue on the idea that the Solar Sausage is a cost-efficient way to concentrate solar energy. The design must be easily operated and maintained, transported and stored, and meet the budget requirement of $5,000 while attempting to remain as cost effective as possible. Performance specifications must be met such as reaching the liquid's phase shift temperature, desalinating water to less than 1,000 ppm, and maintaining a pressure differential of 0.001 psi between Solar Sausage chambers. Thus far, the group has visited the facility and met with Mr. Ian Winger in order to further their knowledge of the background of this invention. The group has been informed on many specifications about the Solar Sausage and its operating conditions. Research has been conducted on different desalination techniques as well as location characteristics such as weather and potable water scarcity. Using a decision matrix, the group decided the open trough method would be the best choice. In the future, the group plans to finalize decisions on the desalination technique, product specifications, and overall design of the apparatus. In order to reach this, the group will continue to meet with all the advisors and mentors and continue to construct a prototype from this assistance. This will ensure that the group will continue to work on a steady path.

1 Introduction

This senior design project involves using a Solar Sausage to desalinate saline water. This is an entrepreneurial project expanding on the work of Mr. Ian Winger, FSU scientific research specialist. The objective behind this project is to research different thermal desalination techniques and incorporate one into the solar sausage converting saline water into potable drinking water. Desalination is a technique most heavily used in Middle Eastern Countries. It is a very energy intensive process that relies on existing and reliable energy sources. Madagascar is the preferred location of choice based on the country's scarcity to clean drinking water sources as well as poor conditions related to this issue. Madagascar is also preferred based on its relative weather conditions similar to Tallahassee where the testing will be conducted. The end design and prototype will hopefully be applicable to other regions in need meeting similar standards and deficiencies as Madagascar.

Mr. Ian Winger has provided the materials for the Solar Sausage. The team started the construction process of the Solar Sausage and desalination apparatus. Temperatures reached by the collector must be around 100^{o}C to be sufficient for evaporation to take place as well as vapor condensation to occur at a satisfactory rate. There are a lot of technical specifications that need to be determined by the group. The temperature to reach phase change must be determined as well as the geometric parameters that will provide a sufficient water supply for a single household.

2 Project Definition

2.1 Background research

Desalination as a practice has been in use a long time, it just happens to be a very energy intensive. Osmotic Drives, the act of driving saline water through a small membrane, at its most efficient requires about 1.5 kWh/kgal [1]. Middle Eastern countries are the world leaders in producing clean drinking water through desalination; countries include Saudi Arabia, United Arab Emirates and Israel. Due to the Middle East involvement there is an abundance of literature available on desalination. Their largest facilities use multi-flash desalination, where the saline water is reheated multiple times at lower pressure [2]. Multi-Flash desalination plants are often built in conjunction with power plants in order to utilize the waste heat, else it becomes a very energy intensive process [2].

While large scale desalination plants require electricity or the waste heat from a power, low cost desalination devices utilizing solar thermal energy only produce enough water for personal use [3]. These methods for using solar thermal energy at a small scale can be applied with Mr. Winger's invention to desalinate water at a much larger scale.

Mr. Ian Winger invented an inflatable parabolic trough referred to as Solar Sausage. The Solar Sausage, a long 50ft cylinder, made of Mylar Polyester with a reflective membrane along the middle, is more efficient than traditional mirrors at concentrating sun light [4]. At 1/20th of the cost and 1/50th of the weight of traditional parabolic mirrors, Solar Sausage can be used to create low cost solar concentration system capable of reaching 400°C within a few minutes of exposure to direct Sunlight [5]. This device heats around 50 gallons per day of fluids to high temperatures that can be used for power generation and water heating.

2.2 Need Statement

Partnering with the College of Engineering our team has been tasked with creating a desalination system. In the developing world, access to clean drinking water is not often available or available on a consistent basis. Unclean water leads to sick children whose education suffers as they miss school. Economic opportunities are lost if a parent is sick from unclean water or spends most their day in search of clean water [6]. This leads to a cycle of poverty that only access to clean drinking water can break. This drives the need for a cheap and low tech system capable of desalinating water and supporting the potable water needs of a small village family. Thermal desalination devices currently exist but with small capacities, with current technology invented by Mr. Winger a large scale thermal desalination device is possible.

“Much of the under developed world still lacks access to clean drinking water.”

2.3 Goal Statement & Objectives

The need of this clean water is hoped to be resolved through the senior design project encompassed around the Solar Sausage which provides heat in a cheap fashion. This leads to the goal of desalinating water with the Solar Sausage’s assistance.

“The goal of this project is to create a solar desalination system using the Solar Sausage.”

As stated in the goal statement Team 7’s goal is to create a desalination system using the solar sausage, the system must be easily transported to a small African village. The project becoming more defined, Team’s 7 objectives became clearer

- Must provide a sufficient amount of potable water for a small community located in Madagascar
- Must stay within allowable budget
- Must simplistic in nature so that locals could easily be trained to operate and maintain
- Solar Sausage must be easily transported and installed

2.4 Constraints

Team 7 was given two constraints by the instructors and mentors on this project; to use the solar sausage and a budget of $5,000. The other constraints where developed by the team based on the operating environment and the local villagers using the desalination system. As the project continues to develop the constraints listed below will be subject to change

- Budget of $5000
- The system must be durable and able to withstand moderate weather conditions
- The system must have low to no emissions
- The system must be simple and easy to operate for locals
- Measurements must be precise and consistent
- The group only consists of four members so the workload for each person will be greater
- Project must be conducted in a timely fashion, and completed by the end of the school year
- Maximum temperature is reached during primary sunlight hours from 10 AM to 3 PM
- Must have a means to store fresh water after desalination
- Must have materials capable of operating with saline water as the working fluid

3 Design and Analysis:

3.1 Functional Analysis

There are many components and specifications that are crucial for the Solar Sausage project. A source to saline water is the first necessity in order to begin the desalination process. The components included in the design are a storage tank, inflated Solar Sausage, a heat transfer method, and a condenser. The storage tank will hold the saline water and release it into the desalination process. The Solar Sausage has a reflective film that will maximize the light that is captured by the energy receiver. Increased temperature will cause the fluid to undergo phase change. The condenser will use a heat extraction method in order to convert the vapor back to liquid and the soluble water will be released and stored for later use.

3.2 Design Concepts

The group utilizes two heating methods for the three designs. One design incorporates a heat exchanger the other two designs utilize direct heat transfer. Each design consist of a Solar Sausage used to concentrate sunlight, a saline water storage tank, a condenser, and a desalinated water storage tank.

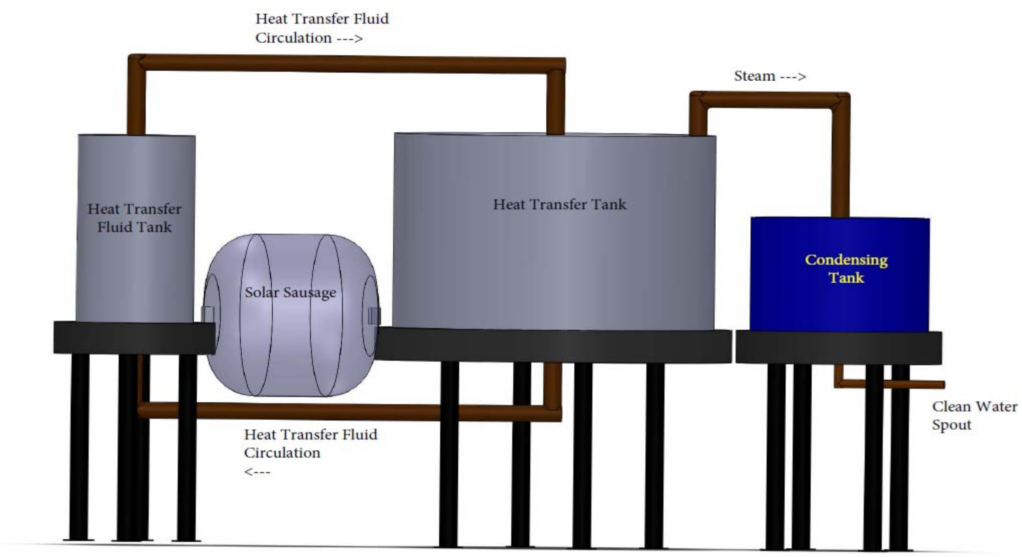


Figure 1. Design 1 - Heat Exchanger Method

The first design incorporates a heat exchanger to bring the water to boiling point. Unlike the other two design, this design requires an extra tank to store the eutectic salt, as can be seen above in Figure 1. The heat transfer fluid tank not only stores the eutectic salt but induces thermal syphoning to circulate the eutectic salt. The heat transfer tank is where the heat exchanger is located. The design has the advantage in that its operating hours extend beyond 3pm. As the eutectic salt will continue to circulate and stay at high temperatures far beyond peak sun hours, which would allow for an increase in the production capacity.

There are numerous disadvantages to this system; that being its lack of portability, cost, and use of non-environmental friendly compound. The exchanger is a closed system in itself requiring an extra tank increasing the size of the size of the system and decreasing its portability. The heat changer will requires large amounts of metal tubing with good thermal conductivity and extremely malleable, materials with these properties are expensive leading to higher cost. The utilization of a eutectic salt, introduces a corrosive element to an area where they do not have proper facilities or training to dispose of it, this increases the systems negative impact on the environment.

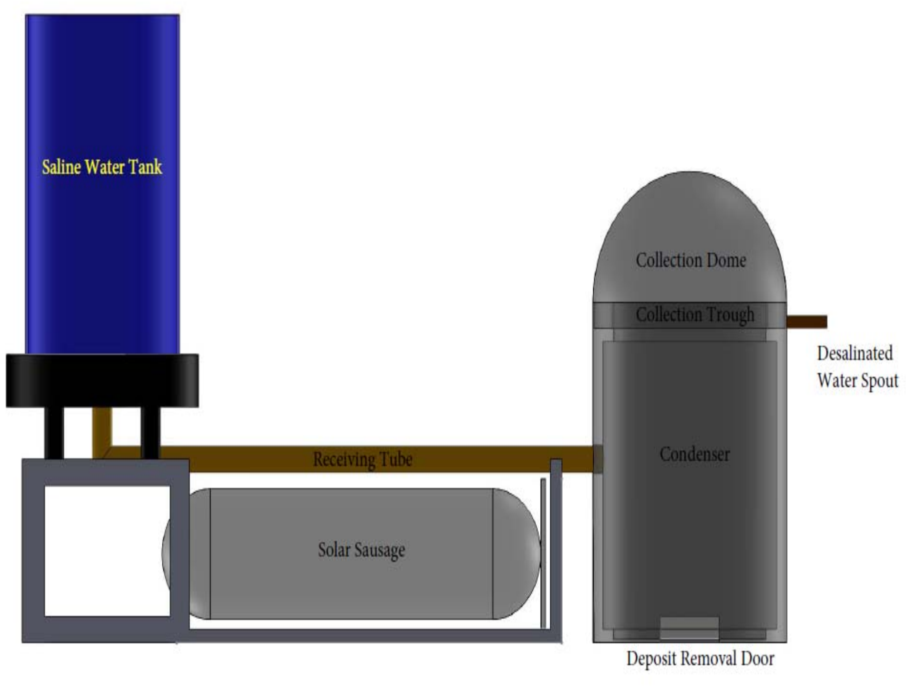


Figure 2 Design 2 - Direct Heat Transfer

The second design has a saline water tank that is suspended some height in the air. The height of the water tank drives the water through the receiving tube. The focal point of the Solar

Sausage is on the receiving tube and heats it to temperatures near 400℃ [4]. Once the water has the length of the receiving tube it will have reached boiling point and undergone a phase change. As the steam exits the receiving tube and enters the condenser saline deposits drop to the bottom as steam rises into the collection dome. As the desalinated steam condenses it drips down into the condensing trough and exits through the spout.

There are many advantages to this the design, in its simplicity and portability, but the design also has its numerous disadvantages. This design uses gravity to drive the water through the receiving tube eliminating the needs for a pumping system, lowering the cost. The direct heating method eliminated the needs for the heat transfer fluid tank as in the first design decreasing the cost. The system could be easily disassembled, due to the simplicity of its components increasing its portability.

As mentioned there are numerous disadvantages to this design including saline buildup, irregular flow, and limited operating time. Saline will build up in the receiving tube and will also corrode the tube, this will require some king of cleaning method or the inclusion of extra receiving tubes decreasing the simplicity and increasing the cost of this design. As the water level in the saline water tank decreases the velocity of the fluid in the receiving tube decreases, this will result in a higher temperature steam at the receiving tube exit changing the condensing requirement. Since this design utilizes direct heat transfer its operating time is limited to peak sun hours.

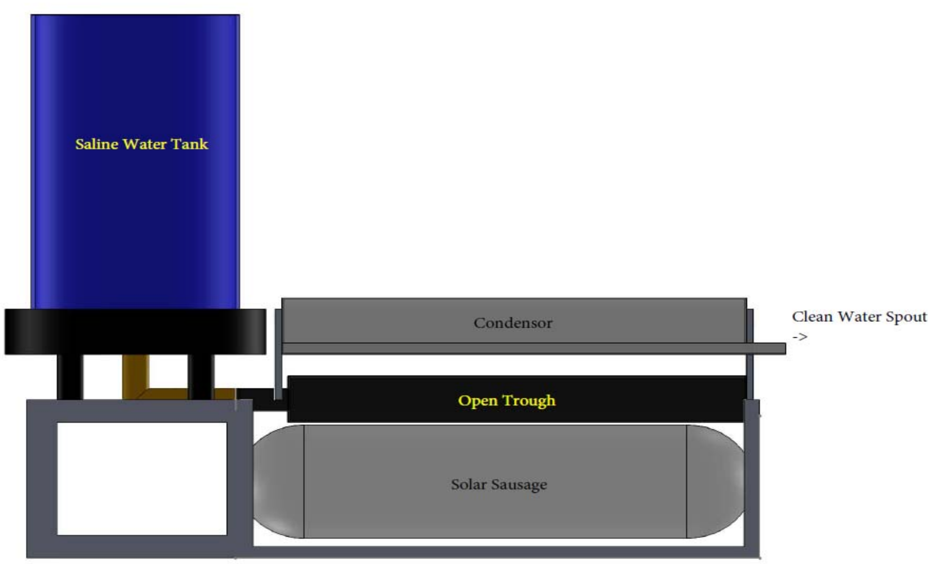


Figure 3. Open Trough

The third design uses direct heating method like the second design. Unlike the second design, this design uses an open trough instead of a receiving tube. The open through fills with water fed to it from the saline water tank. The Solar Sausage heat the trough surface to near $400℃$ causing the water to evaporate. The steam rises into the condenser which is located right above the open trough. As the steam condenses the droplets drip down into troughs located on both sides of the condenser. As the clean water builds up in the troughs it forces its way out of the clean water spout located on the one side of the condenser.

This design has many advantages, the first being that it does not have its own free standing condensing tank. By having the condensing dome, from the second design, directly over the open trough the space required for the system to operate or to be transported greatly decrease. This increases the portability and increases the simplicity. The open trough provides an easy way to remove the saline buildup, after each use someone can simply scrape the saline out of the open through simplifying the system. As in the second design since it utilizes direct heat transfer it can only operate between peak sun hours. The second disadvantage being that the trough covers a large a large portion of the Solar Sausage's reflective material compared to the receiving tube in the second design. This would require a larger solar sausage increasing the cost and size of the system.

The largest component of this project is the Solar Sausage, its dimensions in the end determine the overall size of the system. The team wants to develop a desalination system that can be applied to any production capacity and any geographical location, only requiring a change in the scale of the system. Thus it is desired to be able to develop an equation relating the production capacity, the saline concentration and the geographical location into account. The Solar Sausage is a parabolic reflector that concentrates thermal radiation, thus its size can be directly related to the energy required for the saline water to undergo a phase change.

An equation was developed, through the use of basic thermodynamic equations, which estimates the required amount of reflective material [8]. This equation takes into account the capacity of the system, the saline concentration and the geographical location when calculating the amount of reflective material. The equation, whose derivation and nomenclature can be found on page A3-A5 in the Appendix, is shown below

$$A_{Reflective} = \frac{\left[(V \cdot C)\rho_{NaCl} \cdot c_{p_{NaCl}} + V(1-C)\rho_{H_2O} \cdot c_{p_{H_2O}}\right](T_p - T_i)}{t \cdot 1000 \cdot \cos\theta_l} L \quad (11)$$

Eqn. 11 can be simplified by making some basic assumptions about the properties of sodium chloride and water. The heat capacity of sodium chloride and water will be treated as constant and will be taken as the values below [8,9].

$$c_{p_{NaCl}} = 864 \frac{J}{K \cdot kg}$$

$$c_{p_{H_2O}} = 4180 \frac{J}{K \cdot kg}$$

The density of sodium chloride and water will also be treated as constant and will be taken as the values below [7,8]

$$\rho_{NaCl} = 2165 \frac{kg}{m^3}$$

$$\rho_{H_2O} = 997 \frac{kg}{m^3}$$

For all testing purposes the average salinity, C, will be used [10]

$$C = .035$$

Plugging these values into Eqn. 11 along with the operating time of five hours, $t = 18{,}000s$ and calculated loss coefficient, $L = 1.5$, the equation becomes

$$A_{Reflective} = .389V \frac{(T_p - T_i)}{\cos\theta_l} \frac{1}{K \cdot m} \quad (12)$$

It will be assumed that the water will be taken from a ground wale or ocean and expect the water to be around ~25°C or

$$T_i = 298.15K$$

Based on research saline content increases the boiling point of water a maximum of 2K, this would make the desired end temperature 102°C or [10]

$$T_p = 375.15K$$

Plugging these values into the Eqn. 11

$$A_{Reflective} = \frac{30 \cdot V}{\cos\theta_l} \frac{1}{m} \quad (13)$$

Where V is the volume of the saline water and θ_l is the latitude of the location where the system is being implemented.

3.3 Evaluation of designs

Using engineering judgment, the group ranked the concepts on a weighted decision matrix. Table 1 depicts the results between the different methods and the deciding criteria.

Table 1. Design Concept Decision Matrix

Decision Making Factors	Weighting	Heat Exchanger	Direct Heat Transfer	Open Trough
Cost	9	4	8	9
Portability	8	1	7	6
Water Output	8	8	8	7
Simplicity	6	4	6	9
Eco Friendly	5	9	9	9
	Weighted Decision	177	273	284

3.3.1 Criteria, Method, Selection

Table 1 shows the criteria chosen, as well as the weight of each. The criteria are decreasing in weight from top to bottom and this weight is multiplied by each concept's ability to satisfy the criteria. The overall score for each concept is determined by the sum of all of the decision making factors. Cost, portability, and water output are the most important factors. Cost is crucial because the Solar Sausage is meant to be a more cost efficient alternative to harnessing solar energy. This is an entrepreneurial project that will ideally be mass produced in the most cost efficient way possible. Portability is important because these desired locations have natural disasters and other forces that may ruin the system. Therefor the mechanism must be able to be deconstructed, stored away, and then reassembled easily. Lastly, the system should be to produce a sufficient amount of water yet be simple requiring few components and can be easily maintained by villagers.

3.3.2 Design Selection

Using the weighted decision matrix, Table 1, the criteria, design and product specification to judge each design. The team selected

"Design 3: Open Through"

4 Methodology

The group will produce a cost efficient solar sausage desalination system with respect to the budget, time frame, and resources given. The best design concept is chosen using a decision matrix that focus on cost, portability, water output, simplicity, and level of environmentally friendly. Upon choosing the best overall design, the group will transfer into an experimental design phase in which we begin to make calculations based on the theoretical design. This will help narrow and specify materials required for specific parts such as the receiving tube to optimize the design according to previously set specifications such as portability and cost. The construction and assembly of the solar sausage will begins shortly after to test and observe the thermodynamic properties of a functioning solar sausage. For a further in-depth description of future plans for the project, see Gantt Chart in section 4.1 Schedule.

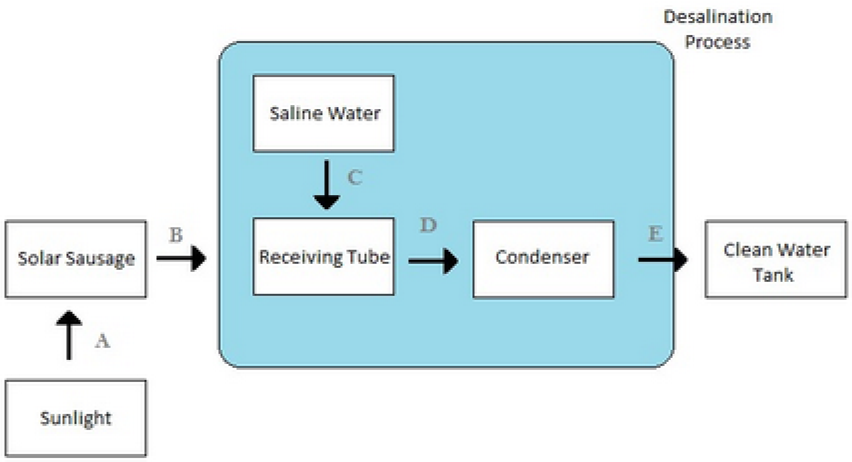


Figure 4. Block Diagram of Solar Sausage Desalination Process

Located above, Figure 1 shows the process of the solar sausage to produce potable water. The solar sausage harnesses and focuses the energy from the sun to heat the saline water. This allows for a phase change as the saline water undergoes an evaporation process. The fluid can then further be condensed to collect and store the fresh water. Specifics at each stage in the process are listed below corresponding to the alphabetic notation in Figure 1:

A: Sunlight is captured within the solar sausage.

B: The reflective material within the solar sausage reflects and focuses the sunlight onto the receiving tube.

C: Saline Water flows into the receiving tube from a saline water storage tank. This tank is filled manually.

D: The receiving tube heats the saline water to utilize the natural process of evaporation. The fluid is then deposited into the condenser where fresh water condenses, separated from the salt.

E: After condensation, the fresh water is collected into the clean water tank. This clean water tank acts as a holding tank where potable water can be retrieved as needed.

The process of the solar sausage allows for the transformation of saline water into fresh, drinking water using solar energy.

4.1 Schedule

Located in the appendix is the Gantt Chart for the fall semester that ends on December 5th, 2014. The chart is broken down into four phases, system constraints, concepts development, design finalization, and materials research and selection. The schedule, if followed, has all design work including CAD drawings, calculations and dimensions completed by November 25th, 2014. As the project develops the schedule is subject to change as more resources get added or removed, making these dates tentative. This leaves over a week for the team to prepare for the next semester that begins in January.

The first phase is determining the system constraints, the design and performance specifications were developed and are listed above in the constraints section. The concept development phase is the longest of 21 days, early during this phase the preliminary designs are analyzed for their validity and the best one is selected. The best design's measurable quantities needed to meet the performance specifications such as phase change energy, compressor analysis and many more are calculated. These measurable quantities will allow the values such as the receiving tube diameter and Solar Sausage length to be determined. In the design finalization phase the team meets to discuss the specifics of the design and vote on whether or not we are satisfied with the design. Upon approval the CAD drawings, which will be used for construction in the spring semester, will be completed with appropriate dimensions by November 25th, 2014. In the final stage (material research and selection), the team prepares for spring semester. The team will research vendors, necessary equipment for construction and machinist; this should allow the team to begin the construction process as soon as the spring semester begins.

4.2 Resource Allocation

There are four team members in the design group that will be responsible for completing the required task. The task allocated to each team member is displayed in the table for each member. The labor hours for task not yet completed and will be updated with the actual labor hours as the project progresses.

Table 2. Resource Allocated to Alex Filardo

Resource	Resource Type	Labor Hours	Expected Completion Date
Design Specifications	Intellectual	4	Oct. 8, 2014
Saline Water Corrosiveness	Research	3	Oct. 15, 2014
Evaporation Input Energy	Intellectual	2	Oct. 21, 2014
Solar Sausage Length Analysis	Intellectual	5	Oct. 29, 2014
Condensing Techniques	Research	4	Oct. 31, 2014
CAD Drawings	Intellectual	10	Nov. 24, 2014
Pipe Selection	Material/Fiscal	2	Dec 5, 2014
Total Labor Hours		**30**	

Table 3. Resource Allocated to Joseph Hamel

Resource	Resource Type	Labor Hours	Expected Completion Date
Performance Specifications	Intellectual	4	Oct. 8, 2014
Heat Exchanger	Research	5	Oct. 15, 2014
Condensation Energy	Intellectual	2	Oct. 21, 2014
Head Loss Calculations	Intellectual	3	Nov. 2, 2014
Condensation System Requirements	Intellectual	7	Nov. 2, 2014
CAD Drawings	Intellectual	10	Nov. 24, 2014
Total Labor Hours		**31**	

Table 4. Resource Allocated to Alex Stringer

Resource	Resource Type	Labor Hours	Expected Completion Date
Design Specifications	Intellectual	5	Oct. 8, 2014
Conduction Research	Research	3	Oct. 15, 2014
Solar Intensity Research	Research	4	Oct. 15, 2014
Solar Concentration Analysis	Intellectual	5	Oct. 24, 2014
Temperature Regulations	Research/Material	2	Nov. 4, 2014
CAD Drawings	Intellectual	10	Nov. 24, 2014
Storage Tank Selection	Material/Fiscal	2	Dec 5, 2014
Total Labor Hours		**31**	

Table 5. Resource Allocated to Crystal Wells

Resource	Resource Type	Labor Hours	Expected Completion Date
Performance Specifications	Intellectual	4	Oct. 8, 2014
Madagascar Demographics	Research	2	Oct. 12, 2014
Heat Transfer Fluids	Research	3	Oct. 15, 2014
Receiving Tube Materials	Material	5	Oct. 21, 2014
Minimum Diameter Calc.	Intellectual	1	Oct. 31, 2014
Water Storage	Material	3	Nov. 4, 2014
CAD Drawings	Intellectual	10	Nov. 24, 2014
Structural Material	Research	2	Dec. 5, 2014
Total Labor Hours		**30**	

5 Conclusion

At the conclusion of this semester, there should be a final design concept that has been conceptually and numerically proven successful in absorbing sunlight through the Solar Sausage, desalinating water through our desalination apparatus, and moving and storing the water in an efficient manner. Engineering detailed sketches should be made of the idea providing these features. The maximum distillate water flow output will be achieved for the Solar Sausage from the raw materials readily available by Ian Winger. This will be a scalable technology that ideally will be translated from our prototype to a larger scale in order to provide for the village of Madagascar.

6 References

[1] Seawater Desalination Power Consumption." Sustainable Solutions for a Thirsty Planet. WateReuse Association, 1 Nov. 2011. Web. 23 Sept. 2014. <WateReuse Association>.

[2] Aintablian, Xanthe. "Desalination Expands as Technology Becomes More Affordable." Water Desalination. AboutEducation. Web. 23 Sept. 2014.

[3] West, Tyler. "Low - Energy Desalination Units for Developing Countries." Web. 23 Sept. 2014. <http://www.pitt.edu/~tew32/WA3.pdf>.

[4] Group Seven, Ian . Personal interview. 8 Sept. 2014. FAMU-FSU College Of Engineering Building A Atrium.

[5] Sams, Jack. "Inflatable Solar Energy Collector (the "Solar Sausage")." Technology Opportunity. Florida State University Office of IP Development and Commercialization. Web. 21 Sept. 2014. http://www.research.fsu.edu/techtransfer/technologyopportunity/documents/energy/winger2.pdf

[6] "Safe Drinking Water Is Essential: Why Is Safe Water Essential?" Safe Drinking Water Is Essential. National Academy of Science, 1 Jan. 2008. Web. 21 Sept. 2014. <http://www.drinking-water.org/html/en/Overview/Why-is-Safe-Water-Essential.html>.

[7] Winter, Mark. "Sodium Chloride." *Sodium Chloride*. WebElements. Web. 13 Oct. 2014. <http://www.webelements.com/compounds/sodium/sodium_chloride.html>.

[8] Engel, Yunus A. *Fundamentals of Thermal-fluid Sciences*. 4th ed. Singapore: McGraw-Hill, 2012. Print.

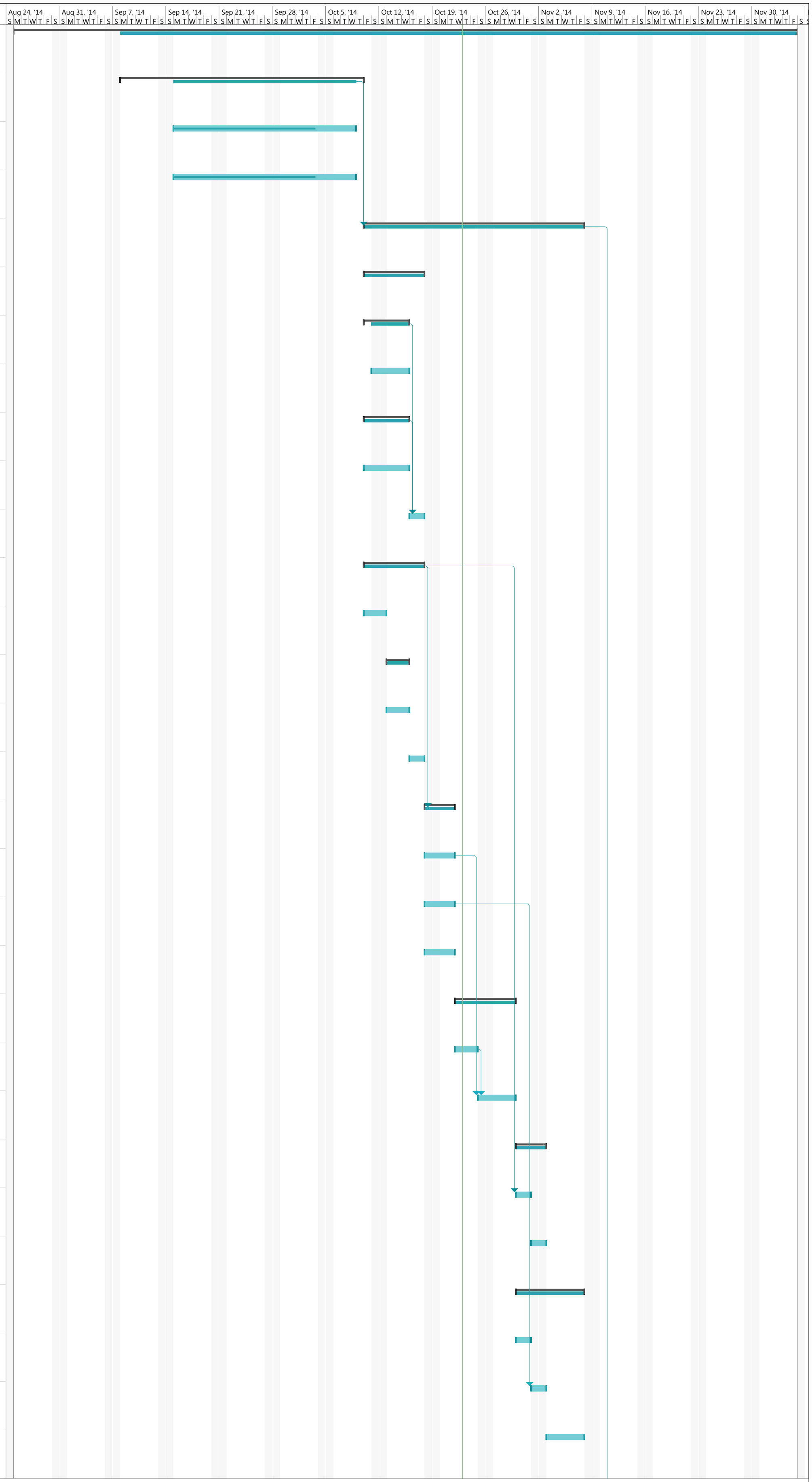
[9] De Leon, N. "Specific Heat and Heat Capacity." *Specific Heat*. Indiana University. Web. 21 Oct. 2014. <http://www.iun.edu/~cpanhd/C101webnotes/matter-and-energy/specificheat.html>.

[10] "Ocean Water: Salinity." *Oceanography*. Office If Naval Research. Web. 18 Oct. 2014. <http://www.onr.navy.mil/focus/ocean/water/salinity1.htm>.

[11] Sinha, Sayontan. "Solar Insolation." *Solar Insolation*. Web. 21 Oct. 2014.

7 Appendix

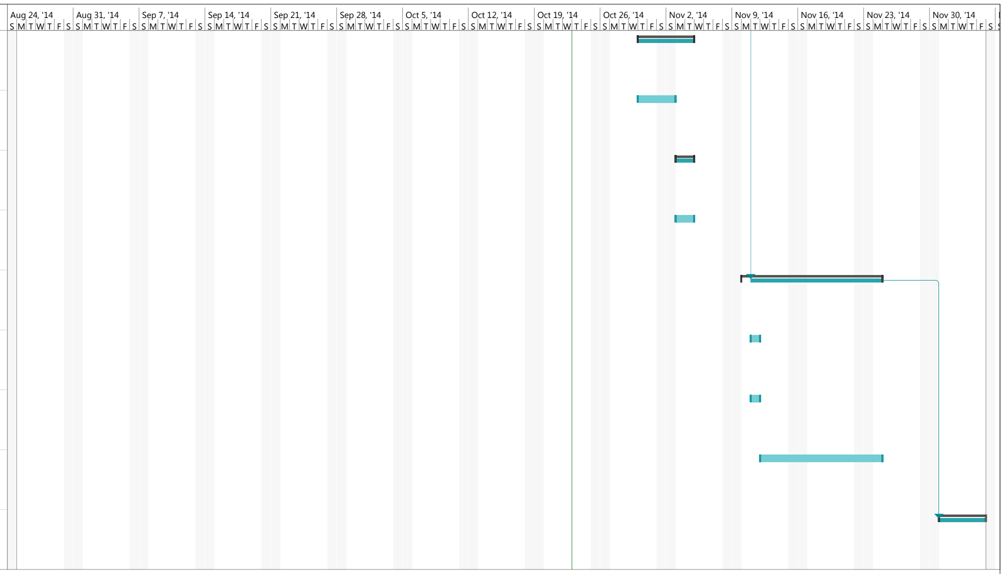
ID	Task Name	Duration	Start	Finish
1	**Senior Design Fall Semester**	**75 days**	**Mon 8/25/14**	**Fri 12/5/14**
2	**System Constraints**	**24 days**	**Mon 9/8/14**	**Thu 10/9/14**
3	Design Specifications	18 days	Mon 9/15/14	Wed 10/8/14
4	Performance Specifications	18 days	Mon 9/15/14	Wed 10/8/14
5	**Concept Development**	**21 days**	**Fri 10/10/14**	**Fri 11/7/14**
6	**Heat Transfer Method**	**6 days**	**Fri 10/10/14**	**Fri 10/17/14**
7	**Heat Exchanger Research**	**4 days**	**Fri 10/10/14**	**Wed 10/15/14**
8	Heat Transfer Fluids Research	4 days	Sat 10/11/14	Wed 10/15/14
9	**Direct Heat Transfer Research**	**4 days**	**Fri 10/10/14**	**Wed 10/15/14**
10	Saline Water Corrosivenes Research	4 days	Fri 10/10/14	Wed 10/15/14
11	Heat Transfer Method Selection	2 days	Thu 10/16/14	Fri 10/17/14
12	**System Capacity Selection**	**6 days**	**Fri 10/10/14**	**Fri 10/17/14**
13	Madagascar Demographic Research	2 days	Fri 10/10/14	Sun 10/12/14
14	**Madagascar Geographic Research**	**3 days**	**Mon 10/13/14**	**Wed 10/15/14**
15	Solar Intensity Research	3 days	Mon 10/13/14	Wed 10/15/14
16	Set Capacity	2 days	Thu 10/16/14	Fri 10/17/14
17	**Phase Change Energy Analysis**	**3 days**	**Sat 10/18/14**	**Tue 10/21/14**
18	Evaporation Energy Input	3 days	Sat 10/18/14	Tue 10/21/14
19	Condensation Energy	3 days	Sat 10/18/14	Tue 10/21/14
20	Receiving Tude Material Selection	3 days	Sat 10/18/14	Tue 10/21/14
21	**Solar Sausage Analysis**	**6 days**	**Wed 10/22/14**	**Wed 10/29/14**
22	Solar Concentration Analysis	3 days	Wed 10/22/14	Fri 10/24/14
23	Solar Sausage Length Analyisis	4 days	Sat 10/25/14	Wed 10/29/14
24	**Pipe Flow Analysis**	**3 days**	**Thu 10/30/14**	**Sun 11/2/14**
25	Minimum Diameter Calculations	2 days	Thu 10/30/14	Fri 10/31/14
26	Head Loss Calcualtion	2 days	Sat 11/1/14	Sun 11/2/14
27	**Condensor Analysis**	**7 days**	**Thu 10/30/14**	**Fri 11/7/14**
28	Condensing Techniques Research	2 days	Thu 10/30/14	Fri 10/31/14
29	Condensing System Requirements	2 days	Sat 11/1/14	Sun 11/2/14
30	Condensor Selection and Design	5 days	Mon 11/3/14	Fri 11/7/14



Project: Senior Design

Task | Project Summary | Manual Task | Start-only | Deadline
Split | Inactive Task | Duration-only | Finish-only | Progress
Milestone | Inactive Milestone | Manual Summary Rollup | External Tasks | Manual Progress
Summary | Inactive Summary | Manual Summary | External Milestone

ID	Task Name	Duration	Start	Finish
31	**Water Storage**	**4 days**	**Thu 10/30/14**	**Tue 11/4/14**
32	Saline Water Storage	3 days	Thu 10/30/14	Sun 11/2/14
33	**Desalinated Water Storage**	**2 days**	**Mon 11/3/14**	**Tue 11/4/14**
34	Temperature Regulation	2 days	Mon 11/3/14	Tue 11/4/14
35	**Design Finalization**	**11 days**	**Mon 11/10/14**	**Mon 11/24/14**
36	Design Validation Meeting	1 day	Tue 11/11/14	Tue 11/11/14
37	Final Design Vote	1 day	Tue 11/11/14	Tue 11/11/14
38	CAD Drawings	9 days	Wed 11/12/14	Mon 11/24/14
39	**Material Research and Selection**	**5 days**	**Mon 12/1/14**	**Fri 12/5/14**



Project: Senior Design

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

Nomenclature

$V - Volume\ of\ Saline\ Water$

$\rho_{NACl} - Density\ of\ Sodium\ Chloride$

$\rho_{H_2O} - Density\ of\ Water$

$M_{NaCl} - Mass\ of\ Sodium\ Chloride$

$M_{H_2O} - Mass\ of\ Water$

$c_{p_{NaCl}}$ – Heat Capacity of Sodium Chloride

$c_{p_{H_2O}} - Heat\ Capacity\ of\ Water$

$C - Saline\ Concentration\ in\ Water$

$E_{NaCl} - Energy\ to\ Raise\ Saline\ to\ Desired\ Temperature$

$E_{H_2O} - Energy\ to\ Raise\ Water\ to\ Desired\ Temperature$

$T_i - Initial\ Saline\ Water\ Temperature$

$T_p - Temperature\ for\ phase\ change\ to\ occur$

$E_{Total} - Total\ Energy\ Required\ to\ Raise\ Saline\ Water\ to\ Desired\ Temperature$

$t - time\ of\ peak\ solar\ hours$

P – Minimum power input

$L - Solar\ Sausage\ Loss\ Coefficient$

$P_D - Power\ Delivered\ from\ from\ Sun$

$S_0 - Solar\ Insulation\ along\ the\ Equator$

$S - Solar\ Insulation$

$\theta_l - The\ latitude\ of\ the\ selected\ location$

$A_{Reflective} - Area\ of\ the\ Reflective\ Material$

To do this the selected capacity must first be converted to volume, *V*, in units of m^3. Using the saline concentration, *C*, the volume of water and sodium chloride can be calculated

$$C = .035$$

[4]. Then using the density, the mass of the water and sodium chloride can be calculated using the capacity, *C*, and the volume, *V* [1, 2].

$$M_{NaCl} = (V \cdot C)\rho_{NaCl} \qquad (1)$$

$$M_{H_2O} = V(1 - C)\rho_{H_2O} \qquad (2)$$

Then using the heat capacity of sodium chloride and water the minimum energy required to raise the sodium chloride and water to the desired temperature [8,9]

$$E_{NaCl} = M_{NaCl} \cdot c_{p_{NaCl}}(T_p - T_i) \qquad (3)$$

$$E_{H_2O} = M_{H_2O} \cdot c_{p_{H_2O}}(T_p - T_i) \qquad (4)$$

The total energy needed is just the sum of the Eqn. 3 and 4 above

$$E_{Total} = \left[M_{NaCl} \cdot c_{p_{NaCl}} + M_{H_2O} \cdot c_{p_{H_2O}}\right](T_p - T_i) \qquad (5)$$

Using the total energy and the operating time frame of the system, t, the minimum power requirement can be calculated. Using the operating time the minimum power input can be calculated

$$P = \frac{E_{Total}}{t} \qquad (6)$$

Next the solar sausage loss coefficient, L, needs to be calculated. The solar sausage has three compounding points of loss. A ~16% loss when entering the solar sausage, and ~10% reflective membrane loss and another ~12% loss when exiting the Solar Sausage. The the loss coefficient was calculated to be

$$L = 1.5$$

The Solar Sausage loss coefficient is used to calculate the total power that must be delivered from the sun is

$$P_D = P \cdot L \qquad (7)$$

Plugging in Eqn. 5 and 6 the equation becomes

$$P_D = \frac{\left[(V \cdot C)\rho_{NaCl} \cdot c_{p_{NaCl}} + V(1-C) \cdot c_{p_{H_2O}}\right](T_p - T_i)}{t} L \qquad (8)$$

The heat radiated from the sun is referred to as solar insulation, and is in units of watts per meter squared. Along the equator the solar insulation is the largest, this value will be referred to as S_0 [11]. This value, at peak solar hours, is equal to

$$S_0 = 1000 \ \frac{W}{m^2}$$

This values various based on the locations latitude and the solar insulation can be for a given latitude can calculated using

$$S = 1000 \cdot \cos\theta_l \qquad (9)$$

Since we know the solar insulation for a given geographical area and the required energy required to heat the water to boiling point. Then the required area of the reflective, $A_{reflective}$, material can be calculated by simply dividing the power to be delivered the sun, P_D, by the solar insulation, S, for that location

$$A_{Reflective} = \frac{P_D}{S} \qquad (10)$$

Plugging in Eqn. 8 and 9 Eqn. 10 becomes

$$A_{Reflective} = \frac{\left[(V \cdot C)\rho_{NaCl} \cdot c_{p_{NaCl}} + V(1-C)\rho_{H_2O} \cdot c_{p_{H_2O}}\right](T_p - T_i)}{t \cdot 1000 \cdot \cos\theta_l} L \qquad (11)$$