Project E3: Portable Desalination System

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Introduction

California has been facing a serious long-term drought and is constantly looking for new methods to resolve and accommodate this issue. With a new desalination plant in Carlsbad, the state is investing in the conversion of seawater into drinking water using reverse osmosis. Lack of water supply is a common and serious issue throughout the world, especially in third world countries that may have access to ocean water, but not freshwater to drink. With developing countries and our own state in mind, the team was challenged to create a portable desalination system that used non-grid energy.

Objective

The team is currently working with CleanSpark, a startup company that focuses on the integration of renewable energy in a clean, affordable, and sustainable way. The team is to design and construct a portable desalination system, which specifically converts ocean water into drinking water. This project has multiple parameters it must follow:

1) Utilize renewable energy, eliminating any use of grid energy in order to be sustainable
2) Produce a significant amount of potable water: 10 gallons per day was the original goal set
   a) Due to constraints, the goal was altered to 1 gallon per day
3) Must be transportable, for testing purposes and showing the client: sedan or truck
4) Budget of $400~$500 for the entire system

Background & Theory

- Thermal distillation: water molecules are separated from salt ions in evaporation. The evaporated mass will contain pure water molecules, which is collected through condensation.
- Mass of water evaporated can be predicted by (Jafarkazemi):

$$m_{theor.} = A_p\,[\alpha\, CG(t) - \varepsilon\,\sigma\,(T_A^{\,4} - T_\infty^{\,4}) - U_L(T_A - T_\infty)]\,/h_{vap} \qquad (1)$$

   - $A_p\,[\alpha\, CG(t)]$: incoming radiative heat into evacuated tube collector (ETC)
   - $\varepsilon\,\sigma\,(T_A^{\,4} - T_\infty^{\,4})$: energy emitted from absorptive layer
   - $U_L(T_A - T_\infty)$: heat loss through conduction within ETC
- Efficiency of system is determined by: $\eta = m_{exp}/m_{theor.}$ (2)

Design Methods

Based on extensive research regarding the various methods of desalination, desalination via thermal distillation was found to be the best fit the scope of this specific project.The different components (Figure 1.1 - 1.4) and their roles in the desalination process are as follows:

1) **Heating of Seawater via Concentrated Solar Thermal Heating Design**
   a) Parabolic Trough Solar Concentrator
      i) Parabolic geometry collects irradiation of ~2.5 ft^2 area and concentrate it onto a single line
   b) Evacuated Tube Solar Collector (ETC)
      i) Uses an internal vacuum between double-walled glass and a high absorption material
      ii) Transfer that heat to a internal copper pipe circuit
   c) Copper Pipe Network
      i) ½" copper pipe is used to hold the incoming seawater as it heats to its boiling point
      ii) Water vapor escapes through a smaller ¼" copper pipe, leaving residual salt and other contents
2) **Cooling of Resultant Water Vapor**
   a) Graham Condenser
      i) Incoming water vapor is pushed through the downward helical glass spiral
      ii) Spiral is surrounded by a cooling fluid
      iii) Allows for the transfer of heat away from the steam and the condensation of desalinated water
   b) Coolant Water Pump and Solar Panel Power Source
      i) 5W pump used to circulate cooling fluid: powered by a small solar panel
3) **Incoming Water Supply**
   a) Seawater Feed Tank and PVC Network
      i) Simple large tank with network of PVC pipes connecting to the copper pipe network
      ii) Same water level inside of the ¼ " Copper Pipe and seawater feed tank due to Bernoulli's eq.

Experimental Methods

Set Up of System

1) Seawater fills input tank to calibration line
2) ETC and solar panel faces directly at the sun
3) Graduated cylinder placed at the output of system
4) Cooling liquid (excess seawater) pumped through condenser

Data Measurements

1) Omega Rugged Pipe Thermocouple looped within ETC
2) A LICOR pyranometer used for GHI measurements
3) Values from instruments logged with in-house programmed Arduino Uno
4) Volumetric measurements from graduated cylinder are taken by observer (per 15min)
5) System is angled if needed, and direction is recorded

Water Quality Testing

1) Marineland Water Care Multi-Test Kit for basic water quality testing
2) Nitrate, nitrite, hardness, chlorine, alkalinity, and pH values tested using kit
3) Strips held in water, left to dry for 60 seconds and compared

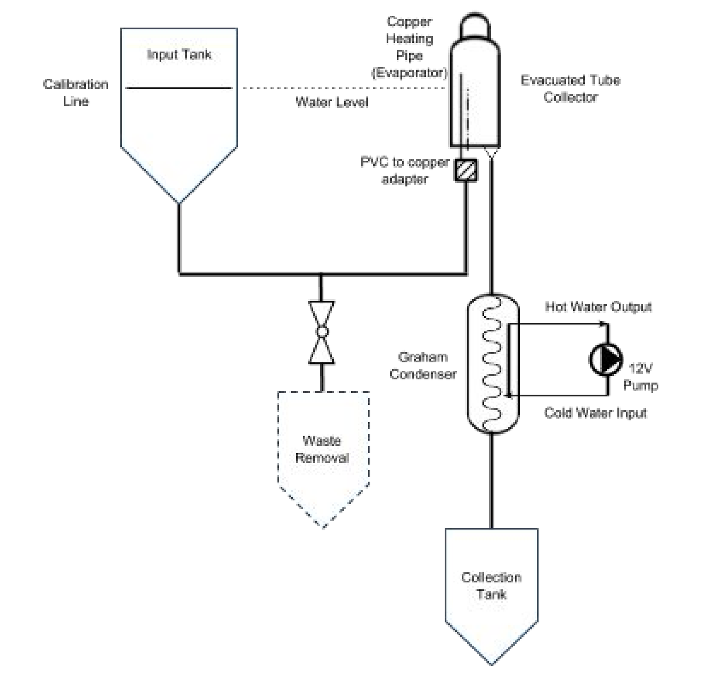

Figure 1.1 *Process flow diagram of planned design.*

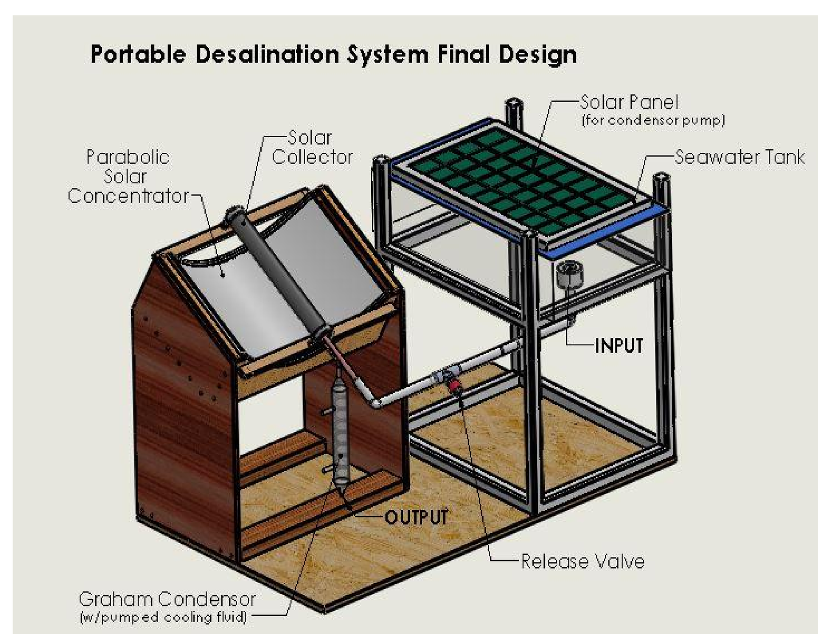

Figure 1.2: *A CAD drawing of the final design of the Portable Desalination system, done on Solidworks. The system includes the following main components: seawater tank, evacuated tube solar collector, parabolic solar concentrator, and graham condenser.*

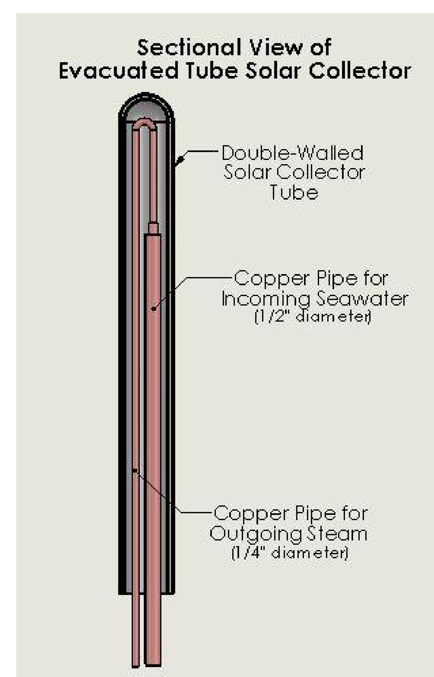

Figure 1.3 *A CAD drawing of the sectional view of the evacuated tube solar collector (ETC), done on Solidworks. ½" diameter pipe enters the collector and is reduced to a ¼" diameter pipe, which loops back around to exit the ETC.*

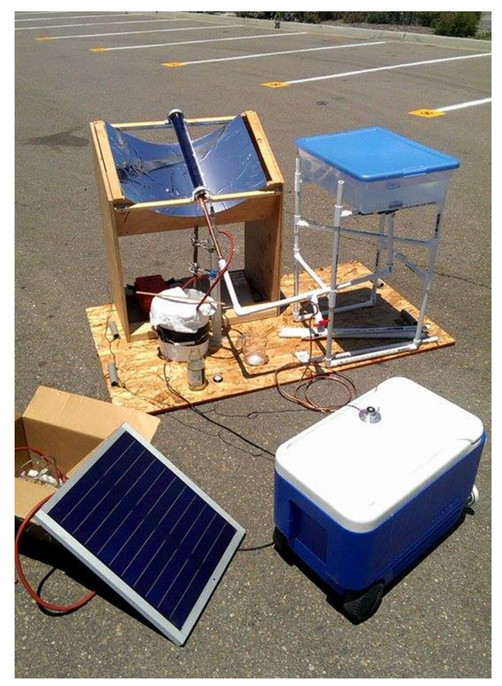

Figure 1.4 *Photo of testing set up and final system design on (6/6/2015)*

Experimental Results

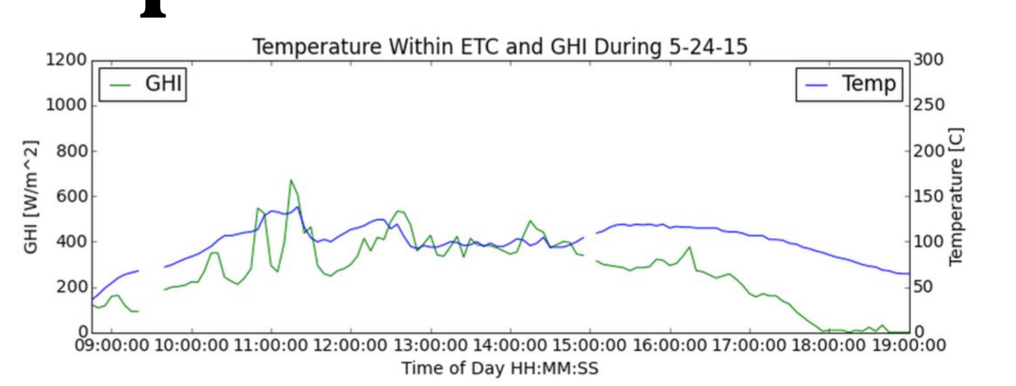

Figure 2.1: *Temperature response within an ETC with mild intensity irradiance on (5/24/15). Weather conditions include overcast conditions throughout the day.*

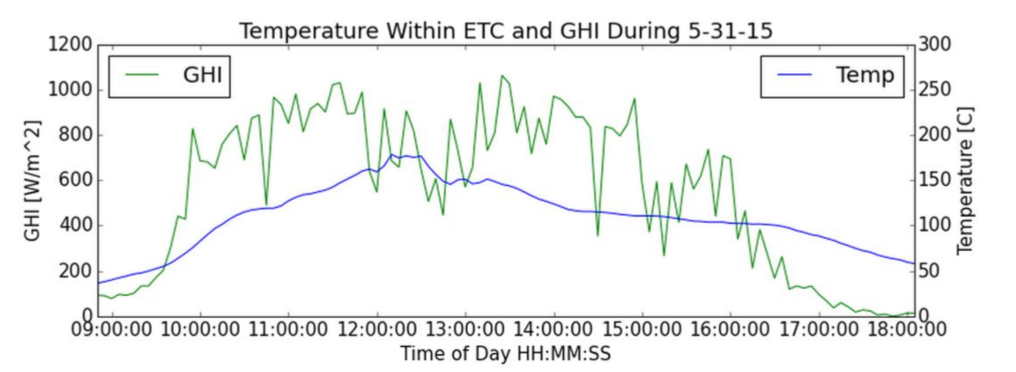

Figure 2.2: *Temperature response within an ETC with high variability on (5/31/15).*

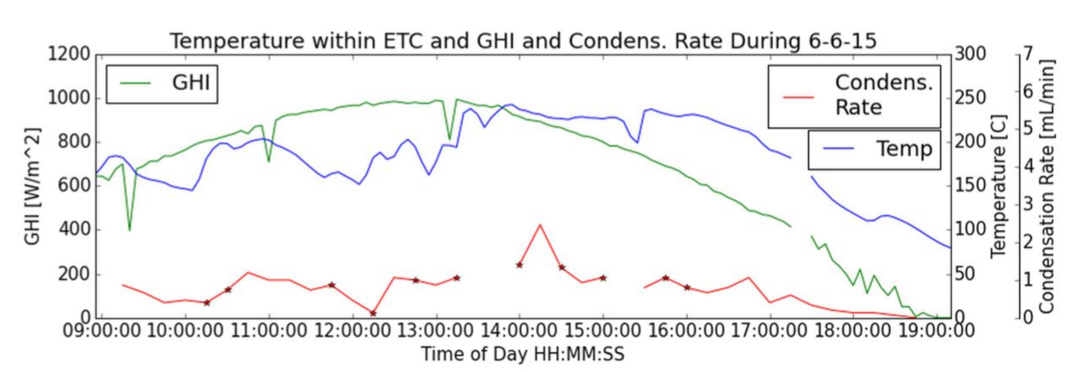

Figure 2.3: *Temperature response within an ETC over clear sky conditions on (6/6/15). Gaps indicate times where the system needed to be reset. Stars indicate times of re-directioning.*

Three different testing conditions:

- Mild intensity irradiance (5/24/15) | Cumulative output: **<10mL**
- High variability irradiance (5/31/15) | Cumulative output: **72mL**
- Clear sky irradiance (6/6/15) | Cumulative output: **408mL**

A mass flow rate was recorded for clear sky conditions on (6/6/15) and compared to the predicted mass output.

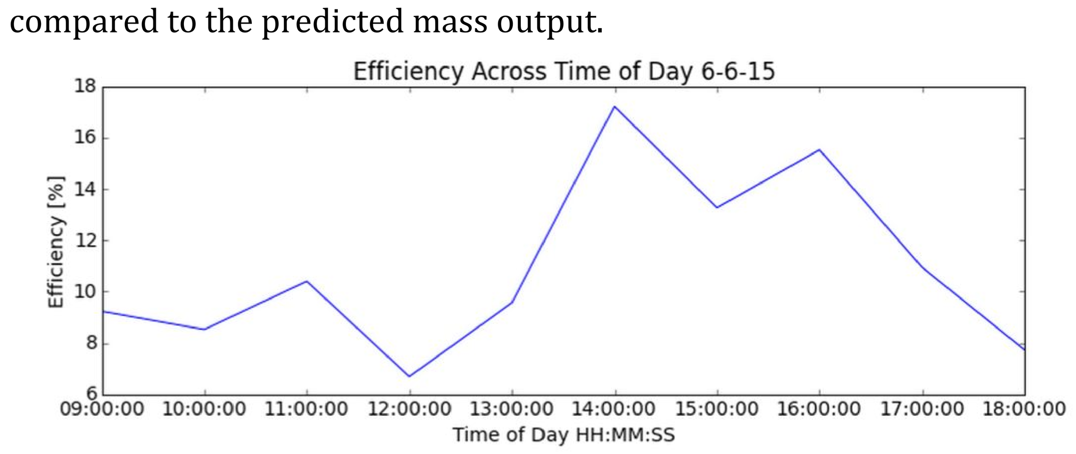

Figure 3: *Efficiency across time of day, values of mass rate are averaged over 1. Efficiency was determined by equations (1) and (2) and measured condensation rate.*

Water quality tests were performed on resulting water that indicate changes in the following properties:

	Input	(6/6)	(5/31)	Standard
Hardness	150 -300 ppm	150 ppm	150 ppm	x
Alkalinity	300 ppm	0 ppm	80 -120 ppm	x
pH	8.4	<6.2	6.8	6.5-8.5

Table 1: *Quantitative testing results of seawater input, water from (6/6/15) and (5/31/15)*

Figure 4: *Water quality testing results of seawater input, water from (6/6/15) and (5/31/15)*

Discussion

1) ***Effectiveness of an ETC for solar distillation***
   a) ETCs retain high temperatures
   b) Large heat loss from convection (90-80%)
2) ***Water quality output of design***
   a) Alkalinity and hardness decreased in output sets
   b) Acidity increased in testing sets by at least 1.5
3) ***Considerations***
   a) (5/24/15) and (5/31/15) trials were conducted in Genesee Highlands Park, while (6/6/15) was conducted in Regents Parking Lot
   b) (6/6/15) trial: corrections of the solar collector to face directly to the sun.
   c) (5/31/15) and (6/6/15) trials included the final closed loop design; however, allowed for convective heat losses from within the tube to surroundings.

Conclusions

The following conclusions were made as a result of the analysis and data from the experimental trials:

1) ***ETC proved to be efficient means of solar collection***
   a) Efficient in retaining heat despite fluctuating GHI values from passing cloud cover or overcast skies.
2) ***Distillation positively correlates with temperature***
   a) Recorded condensation rate data for (6/6/15) trial reveals the greatest value for condensation rate coincided with peak temperature at 2:15 PM
   b) Entire trend of flow reveals a relatively stable and steady rate
   c) Later hours of the day (sun set): decreasing GHI and temperature values results in decreasing the condensation to a stop.
3) ***Water quality slightly altered and purified***
   a) Preliminary water quality tests reveal a decrease in pH, hardness, and alkalinity compared to the original seawater
   b) More extensive tests must be done to assure drinkability
   c) Some of the qualities of seawater were mitigated through the distillation process

Future Work

The following points are key concepts and goals for the future development of this project:

1) **Larger capacity solar collector**
   a) Enable for a greater surface area of water to be exposed to heat
   b) Scaling into larger model would increase volume of distilled water output
2) **Weather-proof the Unit**
   a) Sturdier materials can be used for the frame and support of the tank
3) **New metal material**
   a) Replace the copper in the collector in order to prevent Verdigris buildup and oxidation of the copper that contaminates the water product
4) **Solar Tracking**
   a) Incorporate a solar tracking system that moves the parabolic reflectors
   b) Maximizes solar collection

Acknowledgements

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References

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3) Jafarkazemi, Farzad. *Evacuated tube solar heat pipe collector model and associated tests.* Journal of Renewable and Sustainable Energy (2012)