Low-Cost Solar Desalination Device

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Abstract
The goal of this project was to develop a low cost solar desalination device. This design will allow one to convert salt water into desalinated drinking water. The device used no input power other than solar radiation to evaporate and condense the water. An advanced heat transfer simulation was developed to better understand how the system functioned. The software package, Maple, was used to solve the complex and interconnected thermal circuit. The most important output value was the rate of water condensation in the system. Using the theoretical information obtained from the simulation, a low cost preliminary prototype was designed, built, and sent to Bali, Cameroon for real-time data collection. The collected data was used to optimize and prototype a final design concept. The final design used a clear plastic tent structure that allowed maximum radiation in as well as a surface to collect the water vapor. A supported black tray was used for the seawater which helped to promote the rate of evaporation. The condensed water slid down the clear plastic tent, between a half inch gap, and collected in a plastic sac on the bottom of the system. The frame was made of aluminum which made it light weight, yet sturdy enough to support the weight of the water. The final design maintained the key objectives of the project by remaining passive, functional, and affordable. The prototype cost less than $150, theoretically produced over 4 liters of desalinated water, and experimentally produced just under 1 liter, in poor working conditions.

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The Need for Project

One of the best and most cost effective ways to provide drinking water to impoverished regions is to use the sun's radiation to desalinate seawater.

Oceans cover more than 70% of the Earth’s surface and contain over 95% of the Earth's water. While there is an abundance of seawater, it cannot be used for daily activities such as agriculture and consumption. This leads to the issue that 1 in 8 people in the world do not have access to safe and drinkable water. Since access to useable water is an essential part of everyday life, there is a need for a way to desalinate seawater that is both effective and affordable.

There are many ways to desalinate water. Two examples are reverse osmosis and the use of pressure to drive water through a filter. These methods are expensive and only functional on a large scale; they would not meet the needs of a low income region. Through research, it was decided that solar desalination is the most effective method that suits the target demographics' needs. The sun's radiation evaporates the water leaving only salt behind. Once evaporated, the water re-condenses and collects into a specific storage container. The fresh, condensed water is free of salt and safe to drink.

The Design Project Objectives and Requirements

The solar desalination device must be able to produce 2-4 liters of drinkable water a day while remaining entirely passive. It uses only the sun's radiation to drive the desalination process.

Design Objectives

The main objective of this design was to provide a low cost way to desalinate seawater into drinkable water. Other objectives included using only the sun's solar energy to drive the desalination process while still creating enough water to support a family for a day (2-4 liters). The design should be simple, easy to maintain, and require little to no oversight during the day.

Design Requirements

The design should be completely passive, using only solar energy, similar to a simple solar still. It should have no breakable parts, control systems, or moving parts. The materials need to be corrosion resistant, light weight, and durable enough to withstand daily use over an extended period of time. The final design should be small enough to be carried and set up by one person with no oversight. In optimal conditions, the device should produce 2-4 liters of desalinated water per day. The final
The concept of solar desalination is that the price of the design should cost less than competing products and still produce more fresh water.

**Design Concepts Considered**

Through extensive patent and product research, an initial design was developed and prototyped. The prototype was then shipped to Bali, Cameroon for initial feedback and testing.

Using information gathered from research, each member of the team developed 5 preliminary design ideas and sketches. These preliminary ideas were then put through a decision matrix, based on actual feasibility, cost, and alignment with the overall project goals. Next, the sketches were narrowed down to 3 different ideas that were combined in order to form an initial design. Once the initial design was completed it was prototyped. This preliminary prototype was then shipped to Bali, Cameroon for functionality testing and feedback.

The initial design used a clear plastic top that allowed sunlight to enter and evaporate the seawater. The clear plastic top was also used to catch the water vapor and condense it, then feed it into a collection area. The tray used to hold the salt water was painted black in order to absorb more heat. The tray was supported off the ground and had no contact with any metal surfaces in the system. This prevented any of the absorbed heat from being lost through conduction to the ground or other components in the system.

This device was partially buried under ground to test an optimization concept. The idea was to take advantage of lower subterranean temperatures, which would promote a larger temperature difference within the system. Theoretically, this would increase the rate of condensation in the system.

Other components of the preliminary prototype design included a PVC tent frame with 12 magnets that were used to hold the plastic sheet in place, a 4” diameter PVC pipe to collect the desalinated water, and an angled aluminum sheet metal...
inside of initial prototype

trough for additional area to condense the desalinated water. The condensed water then slid down the clear plastic tent and aluminum trough into a collection tube.

The preliminary prototype was tested in Cameroon with some initial success. When the black tray was filled with 500 mL of salt water and tested for 8 hours, the preliminary prototype produced 150 mL of desalinated water. It left 180 mL of salt water un-evaporated. Therefore, 170 mL of water escaped the system in the form of water vapor during testing. With this feedback it was determined there were substantial leaks in the system that needed to be addressed for the final prototype design.

Recommended Design Concept

The final design concept incorporates ideas from the previous prototype design, with improvements in functionality, simplicity, and overall cost.

Taking the information that was received from the preliminary prototype design and conducting further research, the final design was formulated. It encompassed simplicity, improved functionality, and maintained a lower prototyping cost than the preliminary design.

This design incorporated some of the key features from the previous prototype. It used a clear plastic tent on top, a supported black aluminum tray for the seawater, and collected the desalinated water underneath the black tray. Aside from these similarities the final design had many new components that improved function and output of the system.

The PVC tent frame structure was replaced with aluminum tubing which allowed for a more rigid and robust frame, that blocks less of the sun’s radiation. The angled aluminum trough and 4” PVC collection tube were also removed. The trough was replaced with a clear plastic bag with a spout used to dispense water at a controlled rate. The trough was removed because it
was not cost effective and created difficulties in setup. It was also determined that when the aluminum was buried under ground it conducted too much heat from the system. The inside temperature was decreased too much which limited the rate of condensation.

The black tray was increased in size from 2 ft\(^2\) to 9 ft\(^2\). This allowed more water into the system and spread it out into a thin layer that improved the rate of evaporation. A 1/2" gap between the tray and the inside edge of the frame allowed the condensed water to slide into the plastic collection sac. The frame was constructed of welds and screws that tightly closed the system and prevented the leaks that were experienced in the preliminary prototype.

**Analytical Investigations**

To better understand how the system functioned a complex heat transfer circuit was developed. This circuit took into account the various elements of the system such as convection, conduction, solar radiation, evaporation, and condensation inside and outside of the device. From this thermal circuit five nonlinear governing equations were developed and solved simultaneously. The main values that were found from these equations were the temperature of the inside air, tent frame plastic, bottom collection sac, and water production rates.

The results of the calculations included many variable inputs and assumptions that were averaged for a 10 hour period in the target location of Nouakchott, Mauritania. These inputs included an average solar energy of 738.6 W/m\(^2\), an average wind velocity of 7 m/s, and an average ambient temperature of 301.65K. Using these inputs and the governing equations, an average temperature of 318.93K for the air inside, 307.93K for the tent plastic, and 306.87K for the collection sac were found. The temperature differential between the outside and inside
along with the size of the device resulted in a condensation rate of 417.5 mL/hr. This translates to a total theoretical collection of 4.2 liters in a 10 hour period.

**Experimental Investigations**

After analyzing the data the final design was prototyped and tested on the roof of Snell Engineering. The prototype was tested on an overcast day with minimal direct sunlight, and a maximum temperature of 286 K (56°F). The black tray was filled with 4 liters of salt water, and sealed closed with bolts.

After 2 hours of testing, evaporation and condensation had started to occur. Streaks of water could be seen sliding down the plastic tent frame into bottom collection sac. The test was concluded after 6.5 hours. The final measure of desalinated water from the collection sac was 710 mL, with 1290 mL of salt water remaining un-evaporated. This means that while the evaporation and condensation rates were hurt by the poor conditions, there were no leaks in the system. Overall these results proved that the design would function. These results would improve with the more consistent and powerful sunlight that is found in the target location of Nouakchott, Mauritania.

**Key Advantages of Recommended Concept**

One of the key advantages of this design is its overall simplicity. The user only has to place the black tray on the supports, fill the tray with seawater, and then place the tent structure on top to complete the setup. The collection sac has a spout allows for easy transfer of the desalinated water into a bottle or bucket. Another advantage of this design is that it is lightweight and involves no oversight during setup or during the day, so the user can set it up and collect the water at any period of time.
Financial Issues

The total cost of the final prototype was $150. This will decrease in the future with mass production. This is because bulk prices of the aluminum needed are much cheaper than the low quantity purchases used for the prototype.

This price is already low and can be afforded by some of the areas that are targeted. This design will also repay itself very quickly, and will last 4-5 years without having to be replaced. To help with the distribution and costs, aid organizations such as Red Cross, can be contacted for bulk orders that will lower the final price even more.

Recommended Improvements

The next step would be to optimize the design in terms of the overall footprint to water output ratio. More research into better methods of evaporation and condensation should be conducted as well as the implementation of more user friendly components.

A key to the future improvement of this design would be to further optimize the overall footprint to water output ratio. This ratio can be improved both analytically, using heat transfer analysis, and experimentally, by developing next generation prototypes.

Another improvement would be to look into the optimization of the black body tray. Using alternative materials and form factors could significantly improve evaporation rates. One idea is to use a controlled flow dispensing mechanism. This will improve evaporation rates because the black tray can then heat up and evaporate small amounts of water without having to heat up the entire body of water, thus improving the efficiency of evaporating the seawater.

Other improvements would be to replace the rigid aluminum tent frame with collapsible rods, much like the ones
Collapsible Tent Rods used in camping tents. Also replacing the 12 bolts that seal the system with quick release latches would make the system more user friendly, while still maintaining a tight seal.