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SCHOOL OF SCIENCE, TECHNOLOGY, ENGINEERING & MATHEMATICS

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Renewable Energy Desalination System

Description of Problem

As of 2019, 1 in 3 people worldwide lack access to safe drinking water [1]. Ocean water is widely available, but conventional desalination methods are cost and energy intensive. Additionally, those who do have access to seawater often lack the resources to take advantage of energy intensive desalination. Energy intensive desalination methods also have a major impact to our ecosystems and climate. Climate change has contributed to water scarcity around the world [2]. Excessive use of traditional thermal desalination methods can ultimately reduce access to fresh water for some people.

Solution and Design Constraints

Evaporator Material Constraints

- **Glass temperature and melting point above 120 C**
- **Optically transparent**
- **Insulating**
- **Machinability**
- **Inexpensive**
- **Non-corrosive**

Material selected: Polycarbonate

System Requirements

- **Passive solar energy- no combustion or CO_2**
- **Inexpensive for consumer and to manufacture**
- **Minimal user input/maintenance**
- **500 ppm limit of total dissolved solids at outlet.**
- **Produce 750-1500 mL/day/person**
- **No local brine deposits (forward osmosis)**

Proposed Design

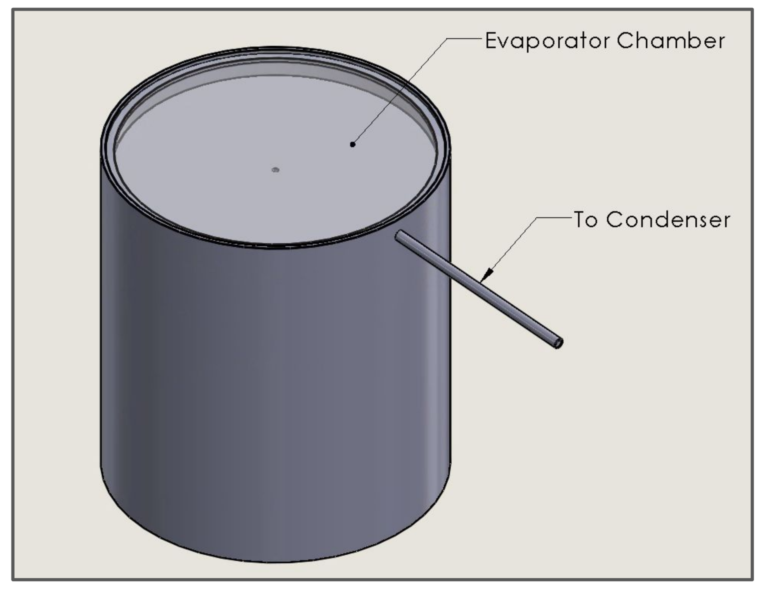

Figure 1: Evaporator module

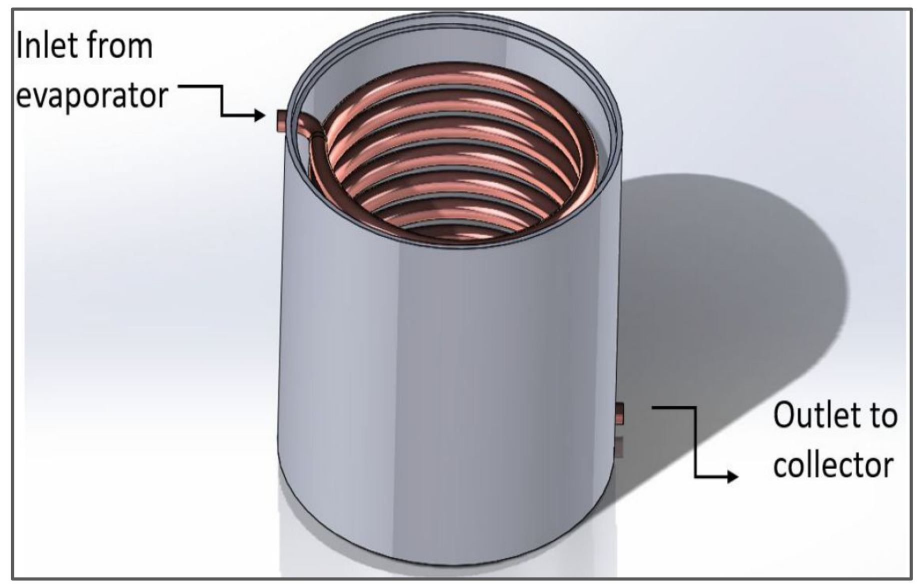

Figure 2: Condenser module

Experiments and Data

Our intended energy source, the sun, was simulated using an LED lamp with a 5000K equivalent temperature. The lamp was positioned directly over the insulated evaporator module and left on, simulating periods of daily sunlight. A 0.5 inch height of water was added into the evaporator chamber, which has a diameter of 4.75 inches. The condenser was filled with an ice bath to simulate a thermal sinking to the ocean floor. Upon concluding each experiment, we observed how much water had accumulated in the collector vessel. We also kept track of temperature behavior in the evaporator chamber with thermocouples in the transient state between room temperature and heating up to steady state. Experiments were repeated weekly with fine tuning of insulation, optimization of configurations, and leak mitigation.

Sources:
[1] "1 in 3 people globally do not have access to safe drinking water – UNICEF, WHO," *World Health Organization*. [Online]. Available: https://www.who.int/news-room/detail/18-06-2019-1-in-3-people-globally-do-not-have-access-to-safe-drinking-water-unicef-who. [Accessed: 01-Jun-2020].
[2] "The effects of climate change on water shortages," *Stanford Earth*. [Online]. Available: https://earth.stanford.edu/news/effects-climate-change-water-shortages#gs.7o9wgd. [Accessed: 01-Jun-2020].
[3] "Lumped Fluid Systems," *Fluid Systems Analysis*. [Online]. Available: http://www.dartmouth.edu/~sullivan/22files/Fluid sys anal w chart.pdf. [Accessed: 31-May-2020].

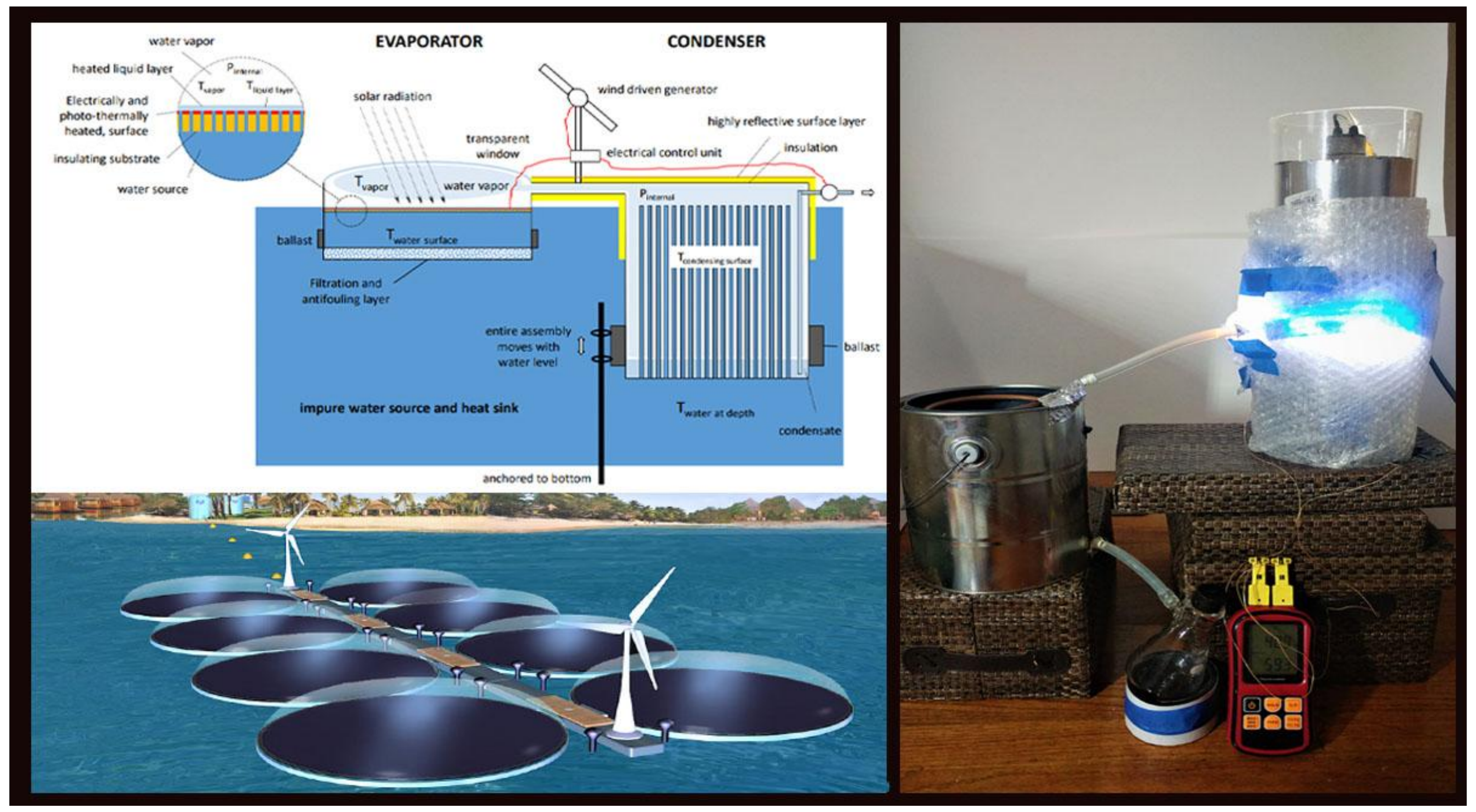

Figure 3: Diagram and Concept on Left, Experimental Model on Right.

Experiments and Data Continued

Although the intention is for the system to be partially submerged in the water to be purified, most of our experimentation was performed by sealing the orifice in the evaporator plate and simply placing the small layer of water on the plate surface. This was sufficient in determining the rate at which the water could be vaporized by the light source.

Future work would include submerging the system to test and refine the mechanism of forward osmosis: as water is vaporized off the plate, the remaining salinity of the remaining water increases. This creates a concentration imbalance between the water above and below the plate, which by forward osmosis draws more water onto the plate to restore balance. In addition to maintaining water level above the plate and flow through the system, this mechanism ensures that salt deposits from saturated brine do not form on the plate by replenishing it with lower concentration saltwater. This is how we accomplish our stated goal, to leave no brine deposits in the shores in which the system operates.

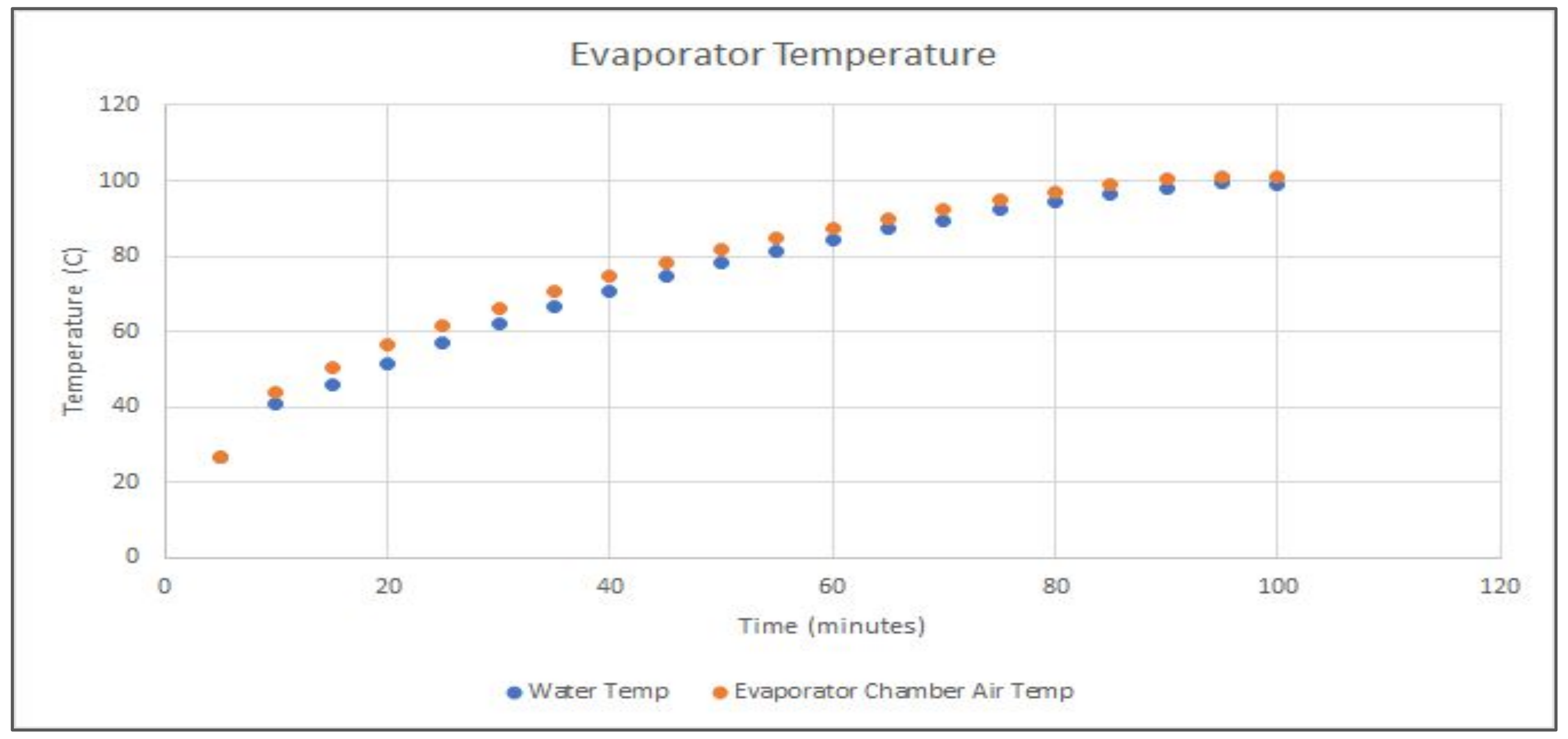

Figure 4: Evaporator transient temperature response to step input from LED lamp.

Physics

The system is primarily driven by the temperature difference between the evaporator and condenser. The maximum possible thermal efficiency of the system is the Carnot efficiency. For this system the evaporator can reach a high temperature of 100 C and the condenser a low of 4 C. The maximum thermal efficiency would then be 25.7%. We have simulated these conditions with our ice bath condenser, but in reality we would thermally tether our condenser to the ocean floor, far offshore, to achieve this temperature gradient.

For optimization purposes the system could be reduced to a linear time invariant circuit model. The vapor pressure in the evaporator chamber being a pressure source, the connecting tube a resistance and inertance (analogous to inductance) [3]. Given major nonlinearities in the transient evaporator, a computational model based on Dr. Tai Lam's mass transfer model was used to understand the relationships between evaporator chamber geometry and freshwater output.

We identified heat loss out of the evaporator chamber as a major source of inefficiency. The obvious solutions were insulation and a well-sealed system. Any remaining heat loss could be modeled using simple heat loss equations.

In order to boost output, we also theorized that a clean, modest energy source like wind or solar could be used to add to the energy input into the evaporator. Even a 1 sq. ft solar panel, generating roughly 15 Watts, could power a resistive heating element that would negate some of the undesired heat loss that occurs.

Results/Conclusion

Our resultant physical model was a successful demonstration of a simple, low energy system that could be scaled up to meet the safe drinking water needs of lacking communities. The system could be scaled up to the point of large, offshore plants that require no electricity. Given wind or solar power, these plants could even pump the fresh water to shore.

Our highest output achieved through optimization experiments is equal to 53 mL of pure water per ~18 sq. inch area plate, per 12 hours, or 4.4 g water desalinated/plate-hr. This suggests that to satisfy minimum constraints of 750 mL/day/person requirement, the system would need to be scaled up by a factor of about 14, for a plate area of ~1.75 sq. feet (0.16 sq. meter).

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