SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Organic Phase Change Materials as Thermal Energy Storage for Automated Solar Seawater Desalination System

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ARTICLE INFO

Article history:
Received 20 June 2024
Received in revised form 25 September 2024
Accepted 10 October 2024
Available online 30 October 2024

Keywords:
Desalination system; seawater; solar irradiance; organic PCMs; evaporation

ABSTRACT

A prototype of an automated solar seawater desalination system equipped with thermal energy storage was designed and developed to analyze experimentally the effect of adding organic phase change materials (palm wax and beeswax) to the desalination system's efficiency. The desalination machine was set up with two configurations: with organic and without organic PCMs. While the setup without a PCM can produce an average of 30.8 mL per day and convert 2.056% of the total volume of input water to an output peak of 48.5 mL using solar energy, the setup with a PCM can produce an average daily water production of 68.9 mL and convert 4.6% of the input water volume with the highest record output of 104.5 mL compared to configurations without PCM, the organic PCM system with a 1:1.2 mixture of beeswax and palm wax can produce an average of 123.7%.

1. Introduction

Solar desalination is a renewable energy process harnessing solar power to reutilize impure water and condense the vapor into potable water [1,2]. It combines the humidification and dehumidification processes similar to the hydrological cycle [3-5]. This process involves salt concentration and chemical removal in seawater, and it can reduce the salt concentration limit to 500 ppm per liter [6]. There are two general types of the desalination process: thermal-based and membrane-based [7,8]. The process that opens through thermal energy to evaporate the seawater and condense the vapor is a thermal- based technology. Methods have been developed using thermal points, a specifically solar-based process produced in equatorial regions worldwide [9,10]. In the Philippines, according to the National Renewable Energy. An experimental device has been developed, a solar-based concentrating machine for desalination that has been able to produce water with 37 ppm of total dissolved solids using a 20,000-ppm feedwater [11,12]. The use of solar radiation and Fresnel lens has been actively used in the previous years developing hybrid technologies. Using two or more lenses can significantly increase efficiency by around 40 % compared

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https://doi.org/10.37934/arfmts.123.1.1221

to a single lens. Solar stills and PV cells are also used to do the same effect using a double slope PCM unit [3,13]. The advancement of technology in automation has brought benefits in harnessing solar energy. To significantly maximize solar power, methods such as single and dual-axis solar power tracking system has proven to ensure energy efficiency and reliability instead of fixed solar collectors. For an optimal position angle in the solar concentrator, the shortest vaporization time was achieved where the lens was positioned at 30° to the horizontal [13,14].

Seawater desalination system equipped with a solar tracking system (STS) for lenses and solar panels at a low cost and effort project shows significant increase in production of potable water [15]. A similar study that focused on investigation and cost analysis on a nano-fluid- based desalination system with the same integrated STS has shown the effects of solar still. The Fresnel lens increased the total efficiency and productivity by 27.5% [16]. Applying the Fresnel Lens on the double slope single basin solar still could have industrial liquid waste with a pH value of 14 into drinkable water [17]. With a similar configuration and experimental design, an exergy performance analysis study was conducted in the same year that utilized Paraffin wax as phase-changing materials and solar panels has increased daily production by 7.43% by extending the operation during evening [17,18]. Humidification and dehumidification desalination were investigated using a recovery and thermal energy storage system that utilizes paraffin wax, an inorganic phase material that also enables increased water production; however, it mainly uses electric heaters and is assisted by solar energy [19,20]. Thermal energy recovery storage has increased the productivity of desalination systems [21,22]. Many studies utilize solar stills with phase change materials to store heat during sunshine and use them during nighttime to increase daily water production. Using latent paraffin wax as thermal energy storage has been proven for its uniform melting point, safety, and high latent heat [23-25]. Paraffin wax is an inorganic and renewable material commonly used in candles.

Systems with PCM configurations are developed and run using inorganic phase change materials such as paraffin wax and metals; others have modified it by using nanoparticles. Replacing the inorganic materials with organic phase change materials will allow using renewable materials rather than non-renewable phase change materials such as paraffin wax and metals [20]. These gaps established the need for more efficient methods and configurations to increase daily water production for solar desalination systems desalination systems using an Arduino-based Solar Tracking System to automate the inclination of the Fresnel lens. The specific objectives are (1) to design a solar seawater desalination machine equipped with Fresnel Lens with a heat exchanger and organic Phase Change materials as thermal energy storage; (2) to fabricate an automated solar seawater desalination system, and (3) to conduct a test for effectiveness and productivity with two different setups: with and without organic PCMs.

The study aimed to seek new ways of desalination systems using available materials to help increase the availability of water resources and to delineate preventing possible water crises worldwide. And, to soothe the effects of excessive extraction of groundwater. The study focused only on the desalination system using sunlight and organic phase change materials; it also covered the fabrication of prototypes and analysis of the effectiveness of organic phase change materials in desalination.

2. Methodology

2.1 Conceptual Framework

Figure 1 illustrates the conceptual framework of the study. The input states that the survey requires saline water, solar energy, organic Phase-Change materials, and temperature as the medium for this research. This research aims to design and fabricate an automated solar seawater desalination equipment equipped with organic PCMs and functionalize it for data gathering. The production of potable water and the resulting prototype of a desalination machine equipped with organic PCMs and the effectiveness of PCMs on the productivity of potable water forms the output of this research.

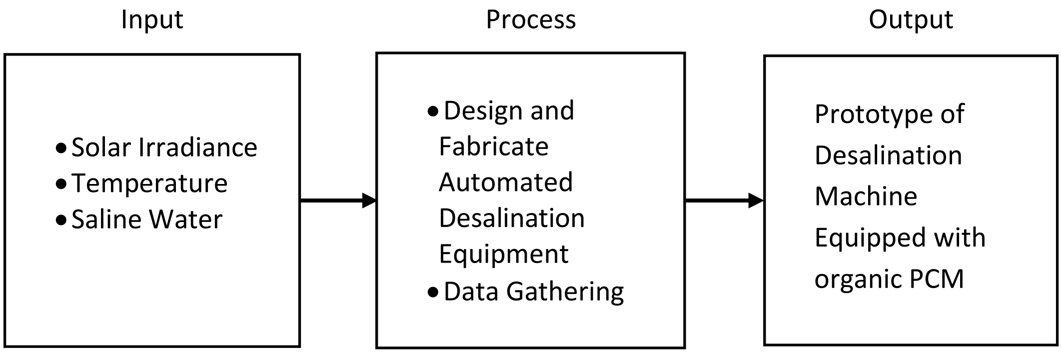


Fig. 1. Input, process, and output diagram

2.2 Materials and Resources

The materials used in this study are instruments that help gather relevant data. The following instruments used are Pyranometer, a device that measures solar irradiance from a hemispherical field of view incident on a flat surface. The pyranometer has a sensitivity of 5 to 20 µV/W/m² and a maximum of 2000 W/m² operational irradiance. ExTech Salinity Refractometer measures the refractive index of the liquid medium. The portable refractometer has a minimum and maximum measurement of 0% and 18%, respectively, with an accuracy of ±0.1 % and resolution of 0.1% Brix.

Pyranometer augmented with a DataTaker DT80 Series data logger was used to measure and log the solar irradiance recorded per second. The DataTaker has 5 to 15 analog and 12 Digital (expandable using CEM20 modules), high-speed counter inputs, and phase encoder inputs. It can operate from - 30°C to +70°C and has a maximum of 85% humidity, which is non-condensing. It auto-logs into a spreadsheet the per-second recorded solar irradiance during the experiment.

2.3 Design Procedure

The design criteria are the explicit objectives in designing the prototype to achieve the desired output. The following criteria are needed: capacity, functionality, cost-effectiveness, convenience, load conditions, durability, and economical feature. The capacity of the design must be able to produce a minimum amount of output. The capacity of the design must be able to circulate and hold 1.5 liters of saline water and produce an output of greater than 50mL per day with a minimum energy cost. The heat transfer analysis for thermal energy storage determines the capacity of the desalination equipment. This also shows how much water output can be produced from desalination equipment. The prototype's functionality will be the basis of water output production, and the impact of solar irradiance and organic PCMs on the daily water output determines the machine's efficiency.

The design constraints are limits set on the design of experiments. These include restrictions placed on the method that does not influence it, as well as restrictions placed to make a plan better. The constraints are observed: Capacity constraints, functionality constraints, Cost constraints, Material constraints, durability constraints, and economic constraints. The capacity of the prototype may have losses along the process. The portion of produced output water can be lost and condensed in some areas inside the design. Functionality constraints in the design are failures and errors since it deals with moving parts in the solar concentration and the electronic configurations of the automation plan. As illustrated in Figure 2, with the following labels: 1- solar rays; 2- angled glass roofing; 3- water vapor; 4- saline water basin; 5- PCMs (beeswax and Palm wax); 6- collection hole; 7- condensate; 8- water flowing to boiler; 9- water flowing out of boiler; 10- boiler; this vapor close-loop mode is used to actualize the continuous process of evaporation and condensation. The window time at peak hours is between 10 AM to 3 PM; the Fresnel lens is to move 7.5 degrees every five minutes. The sunlight at (point 1) will hit the glass roofing and thermally increase the temperature of the interior of the glass housing. A pump is placed in the saline water basin (point 4) and pumps the water in the loop where a single heat exchanger coil is suspended inside a boiler. The boiler has water that absorbs heat from the concentrated sunlight redirected by the mirrors. The water flows back to the saline water basin continuously until the temperature rises to reach the dew point temperature. At point 3, water will start evaporating and condensing at the glass roofing, sliding down to the walls. At point 5, PCMs are placed beneath the basin, and at point 7, condensates flow down until it reaches point 6, where the water is being collected. The outer part of the tank will be made with insulation to reduce heat loss and for safety purposes.

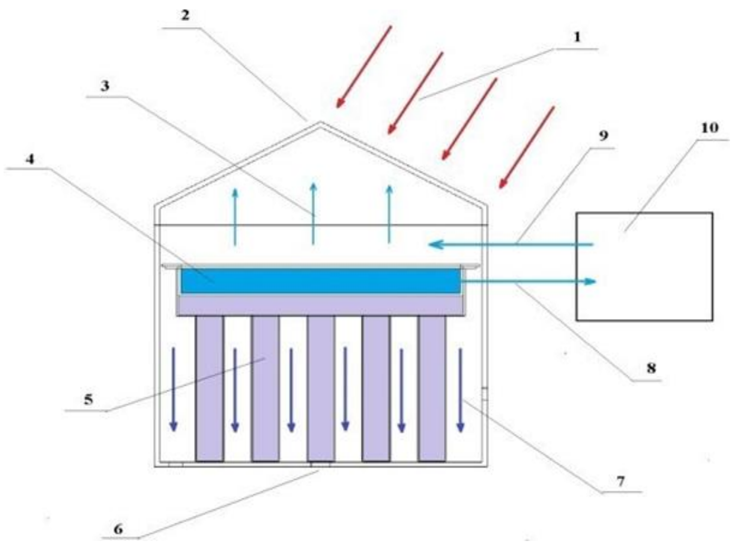


Fig. 2. Schematic drawing of the solar desalination system

As the relative positions of the concentrator and the boiler are shown in Figure 3. To harness the most energy from the sun for this investigation, a sun tracking system will be used. Using electrical tools, the lens may align itself with the direction of the sun's location [26]. A reflective mirror will refocus the concentrated light into the boiler chamber.

The desalination machine was set up in a wide-open outdoor space and laid under the sun. One and a half liters of saline water was set aside, and another 20 ml of the same fluid was to be separately examined for basis and parameters and prepared [3,27,28]. A fully charged power bank is to be connected to the power supply port of the Arduino. Set the switch down and secure the stepper motors and the water pump to the power supply. Lift the roofing to the thermal energy storage and fill the basin with 1.5 liters of saline. Then the two 6mm Polyurethane hoses for condensate collection and carefully close the thermal energy storage are connected. All hoses are related, and the Fresnel lens is aligned until the incident light is directly focused on the solar still. The switch is up, and I checked the LCD to see if the DHT11 has readings. Record the initial readings displayed in LCD, including humidity and air temperature inside the thermal energy storage. The readings for solar irradiance using the device are recorded. Using a thermocouple, measure the temperature of the saline water and the PCM temperature. After the end of the duration, the collected condensate samples are measured for volume. And portable refractometer was prepared, and using the dropper, 1ml of sample was extracted and the cover plate of the refractometer was opened. Place a few drops of fluid and close the cover plate. And ensuring that the sample fluid is spread evenly to the entire surface of the prism without air bubbles or void spots. Hold the refractometer in the direction of a light source and look into the eyepiece. And the reading in the circular field with a scale on the line where blue and white regions meet.

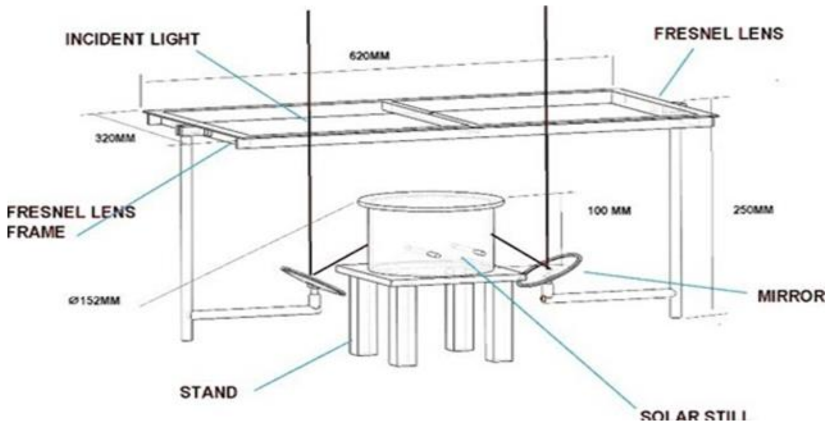
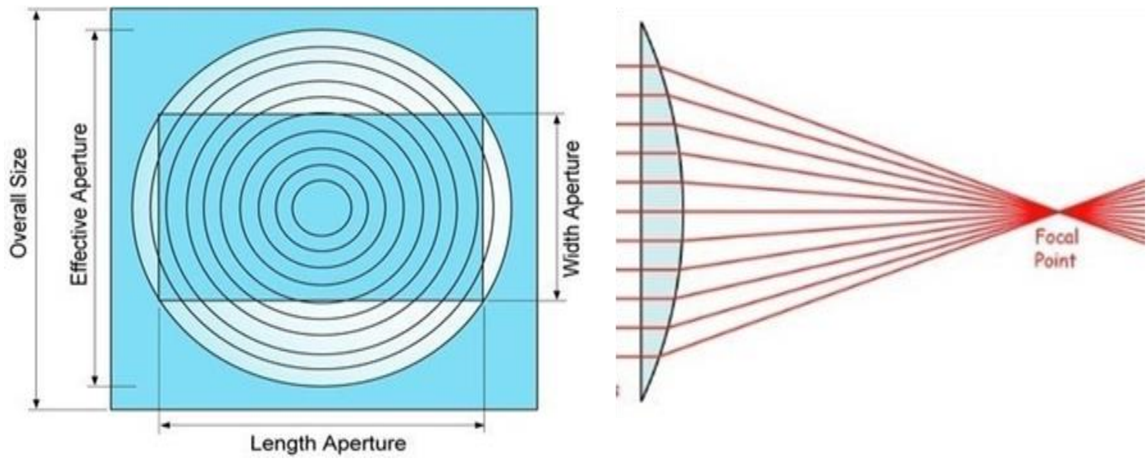


Fig. 3. The relative position of the lens and the mini- boiler

As shown in Figure 4, the working principle of the Fresnel lens as light passes through. The concentrated sunlight must be redirected using a mirror, using trigonometric property and similar triangles; it is found that the 12mm diameter mirror must be placed at 220mm directly below the line of the incident light, and the mirror is to be tilted 45 degrees to make a perpendicular line of reflection [3,11,29].



(a) (b)

Fig. 4. (a) Parts of the Square PMMA Fresnel Lens, (b) Working principle of Fresnel Lens

2.4 Testing System

The testing and data gathering were conducted at the University of Mindanao Research Hangar, and the tested input seawater was taken from Astorga Beach, Santa Cruz Davao del Sur. Each testing started every 8 AM for setting up and refilling of basin water and collection of samples. The system was integrated with an automated mechanism using a microcontroller, sensors, and actuation devices. To test the system, the configurations were operating at two different conditional setups; (1) the thermal storage tubes are emptied and will not use any PCMs; and (2) the tubes are filled with organic PCMs, which are palm wax and beeswax [6,14,27]. All recorded data were summed to get its average. Physical properties such as water input temperature, heat exchanger temperature, PCM Maintaining temperature, air ambient temperature, and humidity were measured using a thermocouple and temperature sensor and recorded. To calculate the output water salinity, a portable refractometer was used. Each daily output, about 1mL of the sample, is taken and placed on a sliding glass. By directly looking through the eyepiece, a displayed scale for specific gravity and salinity with a refractive index, the bounded region of blue and white colors is where the measurement will be taken.

3. Results

Table 1 shows the output volume and corresponding salinity collected over 30 days on two different setups. The water input is fixed to a constant 1500mL information before the start of the experiment, and the water output is collected through a gutter that channels down through a tube and flows to a collection bottle. Each daily work is over a duration of 24 hours, gathered every 7 AM before the start of another experiment. The collected water sample is then tested using a portable refractometer to measure their specific gravity and salinity.

Table 1
Conditions of Parameters of Input and the output

Day No.	With organic PCM		Without organic PCM	
	Output	Salinity	Output	Salinity
1	35 mL	0.1 ppt	48.5 mL	0.02 ppt
2	40.5 mL	0.02 ppt	25 mL	0 ppt
3	75 mL	0 ppt	18.5 mL	0 ppt
4	54 mL	0 ppt	32.5 mL	0 ppt
5	80.5 mL	0 ppt	30.6 mL	0 ppt
6	39.5 mL	0 ppt	41.5 mL	0.1 ppt
7	42.5 mL	0 ppt	35.5 mL	0 ppt
8	67.5 mL	0 ppt	29.5 mL	0 ppt
9	83 mL	0 ppt	10.5 mL	0 ppt
10	67 mL	0 ppt	32.5 mL	0 ppt
11	95.5 mL	0.01 ppt	25.5 mL	0 ppt
12	84.5 mL	0.01 ppt	33.5 mL	0 ppt
13	96.5 mL	0 ppt	28.5 mL	0 ppt
14	104.5 mL	0.01 ppt	32.5 mL	0 ppt
15	67.5 mL	0.01 ppt	37.5 mL	0 ppt

The peak temperature of the two setups, those with the organic PCM and without organic PCM. Each design has 15 samples, referred to as the number of days. Figure 5 shows the peak temperatures of the setup with organic PCMs, shaded with the color blue, are notably higher than that of the design without organic PCMs [30].

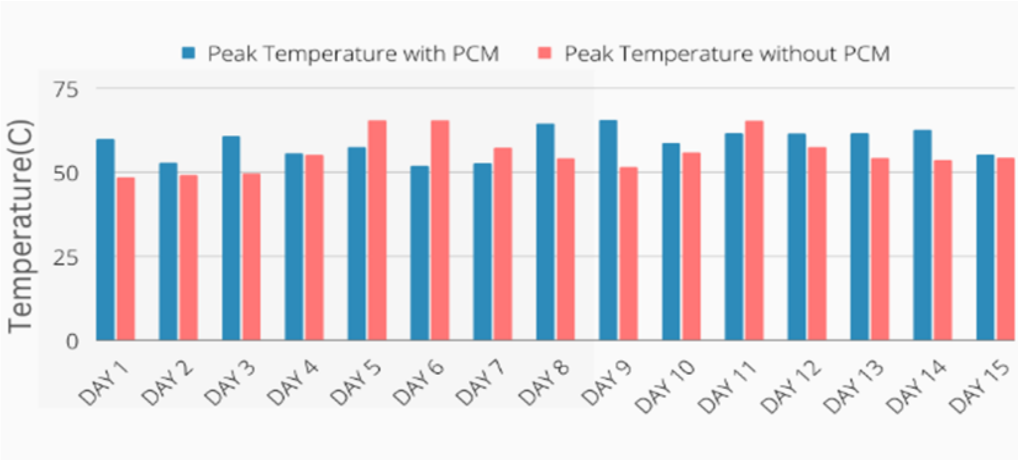


Fig. 5. Comparison of peak and starting values of daily water input temperatures

Figure 6 shows the changes in temperature in accordance with the irradiance every 30 minutes during the testing between the two setups with two weather conditions: clear sunny weather and sunny with cloudy afternoon conditions. As shown in the graph in Figure 6, as the solar irradiance increases, the input water temperature also increases. Also, it shows that cloudy weather conditions may result in solar irradiance and low temperature. Thus, clear sunny weather has the highest solar irradiance and temperature of the water basin [26].

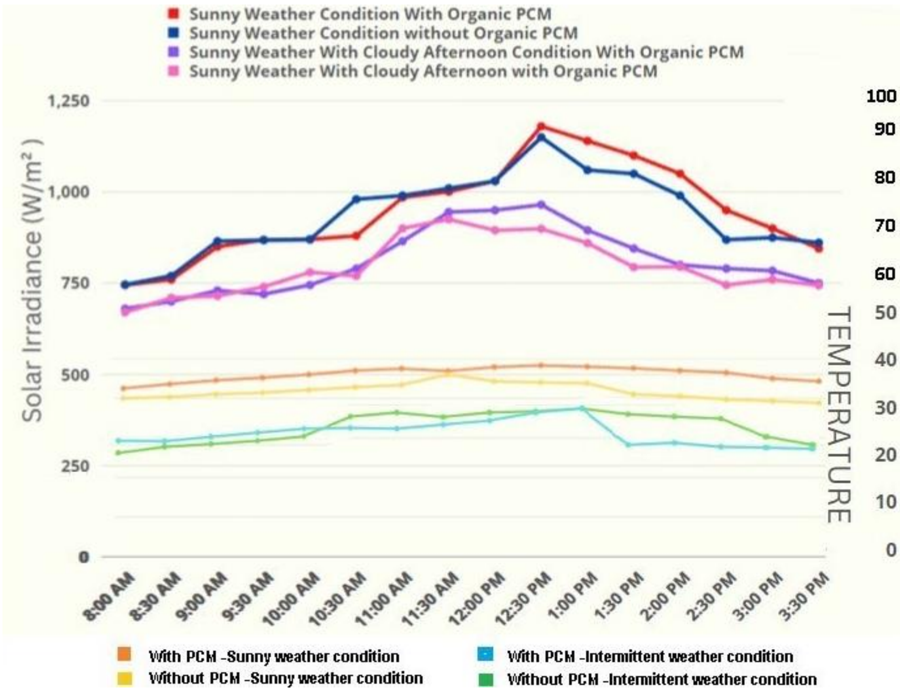


Fig. 6. Comparison of peak and starting values of daily water input temperatures

This indicates that a design equipped with organic PCMs can produce more potable water. The average water output of the machine without an organic PCM setup is 30.8 mL, and on average, it converts 2.056% of the total input water volume. On the other hand, the average water output for the machine with organic PCM setup is 68.9 mL; on average, it converts 4.6% of the total input water volume, which is 1500mL. The highest recorded output was 48.5 mL and 104.5 mL without organic PCM and with organic PCM setups, respectively. Thus, the setup with organic PCM can produce

123.7% more than the without PCM setup. Results show that a mixture of 1:1.2 of beeswax and palm wax effectively increases the desalination machine's productivity by 123.7%. Thus, organic Phase change materials can be effectively used as thermal energy storage for the seawater desalination system [24]. Moreover, the presence of organic phase change materials (beeswax and palm wax) in desalination system as heat storage can increase the systems, efficiency.

4. Conclusions

A prototype of a solar seawater desalination system equipped with a solar tracking Fresnel lens and thermal energy storage tank that uses organic phase change materials (palm wax and beeswax) was designed and developed. The machine is an automatic solar tracking device that operates during daylight and captures sunlight, reconcentrated to a mini- boiler/solar still. The heat stored in the organic PCMs maintains the temperature of the basin saline water. The temperature drops down slowly overnight. The prototype has two setups. The first setup has organic-phase-change materials (PCM) with thermal energy storage. The PCM design can produce.

The average daily water production of 68.9 mL converts to 4.6% of the input water volume based on the average daily water produced, with the highest record output of 104.5 mL. In contrast, the without PCM setup can make an average of 30.8mL and converts 2.056% of the total input water volume and peak of 48.5mL using the sun's energy. The average 4.6% volume conversion of input water to potable water was affected by unstable weather conditions and output loss due to draining failure. Generally, on average, a 1:1.2 mixture of beeswax and palm wax can increase water production by 123.7%.

Acknowledgement
We want to acknowledge the DOST-SEI Region XI for helping us in our research. Our statistician, Engr. Elena Mantillano, our laboratory custodian, Engr. Paulo Gavino, to our professors Engr. Delan Bacus and Engr. Jetron Adtoon and to our family and friends who were there to support us.

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