Enhancing the performance of solar stills for desalination of the sea water

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Abstract. The purpose of this research is to determine whether the production output of distilled water from desalination by distillation using a hybrid solar still coupled with Photovoltaic panels can enhance the overall efficiency of the system for desalinating the seawater. Desalination by distillation has not yet reached the global market as the output rate is significantly less compared to other methods such as reverse osmosis (RO). This research developed a working hybrid prototype solar still that utilized both passive and active heating sources to assess its performance and competitiveness with other solar stills in the market. The outcome of this research indicates that a solar still on its own is efficient enough in removing Total Dissolved Salts (TDS) for safe drinking water. However, it cannot compete with the performance of alternatives such as RO desalination units and is highly dependent on solar energy. Although, the results from this study show that the use of solar reflectors can increase the performance by 21%. This study concludes that a new technology/concept is needed to fill in the gap between solar stills and RO units whereby it can match the performance of a typical RO desalination unit and maintain the same capital and running costs of a typical solar still.

1. Introduction

Water is the key element to support all life on earth and essential to sustain continuous development and economic activities. Water is available as surface water or groundwater and has been extensively used for domestic, industrial, and agricultural purposes. About 71% of the earth’s surface is covered by water. Almost 97% of the earth’s water is present in the oceans, which are saline in nature and the remaining 3% of water is from freshwater sources. The fresh potable water is distributed amongst glaciers and ice caps located in the Arctic and Antarctic region (68.7%), surface water (0.3%), and groundwater (30.1%). Out of surface water, 87% is contained in lakes and rest in rivers and swamps [1], which means that only 1% of total water found on earth is easily accessible to humans. The scarcity of fresh potable water is affecting one fifth of the world's population and a quarter of the world’s population faces a shortage of technology to retrieve fresh water from rivers and ponds [2]. Water demand is continuously increasing due to the increase in the global population with demand for food production, urbanization, and industrialization. The United Nations World Water Development Report (UNWDR) released in 2015 forecasts that there will be a 40% shortage of fresh potable water in the world by 2030 [3], which is only 10 years from now. Therefore, this study aims to come up with a solution to combat the global water crisis by improving existing designs of solar stills to produce clean potable water for people living in coastal areas that are experiencing water shortages.
Desalination is the process that separates mineral components from saline water. Specifically, this process is used to remove the salt content in seawater for it to be used for either human consumption and or other purposes such as irrigation for agricultural crops [4]. Desalination can be categorized into two main processes, by thermal phase change whereby the seawater changes its state e.g. from liquid to gas, and then back to the liquid via evaporation and condensation. A second process involves the seawater passing through a membrane. Depending on which method, the membrane can act as a filter. Take reverse osmosis, for example, here seawater is pumped through a membrane filter at a pressure of 800 PSI, the membrane filters out the nanoparticles and salt producing output water of less salinity. Table 1 shows the different materials used of desalination. This research, however, will only be focusing on distillation using a solar still. The solar humidification method uses the concept of heating and cooling (evaporation and condensation) when the seawater evaporates and condenses back into the water, the salt is left behind. The process behind solar stills is based on the Humidification and Dehumidification (HDH) process, it is just like the natural hydrological process whereby the heat radiation produced from the sun heats the ocean, and then the seawater evaporates into the atmosphere to form clouds. These newly formed clouds, then condense back to liquid resulting in rainfall. The HDH process in a solar still replicates this natural hydrological cycle.

Desalination by distillation using solar stills is out of favour as it is considered inefficient, especially for large scale purposes whereby the production output rate compared to other methods of desalination is nowhere close to being competitive. Having said that, distillation does come with its benefits such as low capital cost, low maintenance, and relatively lower energy demand [5]. It was estimated that the production of 1 million cubic meters of water per day requires at least 10 million tons of oil per year [6, 7], this by no means is sustainable. By enhancing the performance of solar stills, to the extent where it is capable of producing the daily average water consumption of a person can reduce water scarcity/shortages in coastal areas worldwide. It can be deployed for natural disaster aid response and possibly introduce a competitive cost-effective alternative for commercial seawater desalination. Seawater desalination has the potential to solve the global water scarcity issue, it can also diversify a country’s source of water supply and reduce its vulnerability on water shortage during dry long periods such as draughts, and possibly remote coastal areas. The objective of this research is to determine whether the production output of distilled water from desalination by distillation using a hybrid solar still coupled with Photovoltaic panels can improve the overall efficiency of the system for desalinating the seawater.

2. Materials and methods
For this study, a prototype hybrid solar still incorporating both passive and active designs have been considered. The prototype for this project was based on the design of a basic single sloped solar still as shown in figure 1. The various components of the solar still with the types of materials selected are given in table 1. The performance of the designed solar still was evaluated based on six individual tests on different set up as shown in table 2. The seawater samples were collected for desalination. The samples were measured for Total Dissolved Solid (TDS) using TDS meter before and after distillation. The solar intensity or illuminance on distilled output was measured using ET 250 Solar Module Measurement equipment of Petroleum and Chemical Engineering Laboratory of Universiti Teknologi Brunei. The wind speed and air temperature were measured using the BENETECH GM8908 Pocket wind speed gauge anemometer. The glass surface temperature of the solar still was measured using LCD Thermometer.
Table 1. Material selected for the prototype.

| Component                  | Material                                      |
|----------------------------|-----------------------------------------------|
| Top cover plate            | Glass                                         |
| Still basin                | Glass                                         |
| Insulation                 | Plywood (optional)                            |
| Collection pipe            | PVC pipe                                      |
| Distilled water storage    | 1.5 L plastic bottle                          |
| Cover for electrical       | Plywood                                       |
| components                 |                                               |
| Solar reflector            | Plywood wrapped in the solar reflective aluminum film |

Figure 1. Isometric and real view of the still basin.

Table 2. Types of tests carried out in this study and its description.

| Test           | Type                           | Description                                                                 |
|----------------|-------------------------------|-----------------------------------------------------------------------------|
| Test 1         | Just the glass box (5°)       | Just the glass box on its own without any active heating sources. This test is to get a baseline performance of the solar still without any alterations. |
| Test 2         | With heating element          | A silicone heating element (10W) capable of producing a heat output of 100°C is placed in the basin of the solar still. |
| Test 3         | Solar reflector with the heating element | It involves the use of both heating element and solar reflectors. |
| Test 4         | Heating element with solar reflector and fan | It includes the use of the heating element and solar reflectors. Solar reflectors are used to identify the performance of direct sunlight onto the solar still (45°). A fan is also used which blows cool air onto the top surface of the cover glass. |
| Test 5         | Heating element with insulation and fan | It is similar to Test.4, the only difference here is instead of utilizing the solar reflectors, they are tilted up (90°) which converts the reflectors into 150mm plywood insulation |
| Test 6         | Just the glass box (9°)       | It is similar to Test.1 whereby there are no additional added elements. The only difference is the angle of the glass cover has been changed from 5° to 9°. |

3. Results and discussions

In this study, a total of six individual tests were carried out. The six tests are all different from one another. For example, test 2 was carried out with a heating element and in test 3 heating element as well as the use of solar reflectors. This is to identify the difference in performance from the prototypes based
on test types. All tests carried out are described in Table 2. Table 3 is a summary of all the readings and averages taken from each test carried out in this study.

**Table 3. Results for a various test carried out.**

| Type                        | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 |
|-----------------------------|--------|--------|--------|--------|--------|--------|
| Initial water temperature (°C) | 32.3   | 31.8   | 31.1   | 32.3   | 30.4   | 29.3   |
| Initial TDS (ppm)           | 6900   | 6900   | 6900   | 9940   | 9870   | 9960   |
| Final TDS (ppm)             | 19     | 13     | 10     | 333    | 799    | 43     |
| Distilled output (ml)       | 258    | 274    | 331    | 260    | 205.5  | 272    |
| TDS removal (%)             | 99.72  | 99.81  | 99.86  | 96.68  | 91.9   | 99.6   |
| Average air temperature (°C) | 29.84  | 29.71  | 30.46  | 30.2   | 29.54  | 29.97  |
| Average surface glass temperature (°C) | 46.1  | 46.06  | 50.17  | 42     | 45.87  | 45.17  |
| Average illuminance (KW/m²) | 0.7    | 0.75   | 0.53   | 0.38   | 0.27   | 0.64   |
| Average wind speed (m/s)    | 1.59   | 1.49   | 0.91   | 1.29   | 1.34   | 1.4    |

3.1. **Effect of average glass surface temperature on distilled output**

This experimental study investigated whether changes made to the solar still would have an impact on its ability in removing the total dissolved salts in seawater. The average glass temperature for all the tests carried in the range of 45-46°C (figure 2). As expected, the combination graph shown in figure 2 shows the relation between the glass surface temperature and distilled out. The only outlier in this analysis is test 3 where it produced the most output and has the highest average glass surface temperature of 50.17°C.

![Figure 2. Effect of average glass surface temperature on distilled output.](image-url)
3.2. Effect of average illuminance on distilled output

Figure 3 shows the average illuminance for each test in the form of bar charts and lines to represent the distilled output for each test. After analyzing the graph, there is a strong relationship between the average illuminance and distilled output. This is as expected, from previous studies and theoretical perspective, solar stills are highly dependent on solar energy. The tests carried out in this study is the strong pattern between tests 1, 2 & 3; whereby the average illuminance increases in the ranges 0.5-0.75 (KW/m$^2$) and the distilled output increases 258, 274 & 331 (ml) respectively.

![Figure 3. Effect of average illuminance on distilled output.](image)

After further analysis, test 3 produced the most distilled output, however had the third lowest average illuminance amongst the six tests carried out in this study. Besides, the day Test 3 was carried out was majorly cloudy. This indicates that solar reflectors can significantly enhance the performance of a solar still even during cloudy days. Traditional single sloped solar stills do not utilize solar reflectors or have it incorporated into the design. Test 3 demonstrates the effectiveness of utilizing solar reflectors.

3.3. Effect of average wind speed on distilled output

Figure 4 shows the relationship between the average wind speed and distilled output. The results for average wind speed are similar to the relationship between the average surface glass temperature and distilled output whereby the range is too small to compare. Here the range for the average wind speed for all tests is very small and insignificant.
Test 3’s average wind speed on the other hand is significantly less than the other 5 tests with an average of 0.91 m/s. Especially when findings from past studies suggesting that the performance of solar stills increases with an increase in wind speed [8,9].

3.4. **Effect of angle of inclination of the glass cover on distilled output**

Figure 5 shows the distilled output and average illuminance of both Test 1 & Test 6 at the angle of inclination to 5° from 9°. Test 1 produced a distillate amount of 258 ml and received an average illuminance of 0.64 KW/m². Test 6 on the other hand managed to produce 272 ml despite receiving an average illuminance of 0.7 KW/m². A test was carried out to see the relationship between the angle of inclination of the glass cover and distillate output. The inclination angle for the glass cover of solar stills performs best when the angle is equal to the location’s latitude. Due to that reason, the prototype has a 5° angle of inclination, to match Brunei Darussalam’s latitude.

The test also utilized a heating element which helped kept its average water temperature to be 53.66°C. The test did not utilize a heating element and has an average water temperature of 52.74°C. As previously discussed both parameters (average water temperature and illuminance) can have a significant impact on the performance of the prototype. Test 6’s results have shown that the angle of inclination too can significantly affect the performance of the system.
4. Conclusion
The performance of prototype solar stills for desalination is highly dependent on the sun's illuminance (KW/m²). Based on the results from the experimental tests carried out in this study shows that the dependency can be reduced drastically with the introduction of solar reflectors. Using the results from Test 2 (without reflector) and Test 3 (with reflector), solar reflectors can increase the performance of solar stills by 21%. It should be noted that Test 3 received an average illuminance of 0.53 KW/m² less than test 2 is 0.22 KW/m². This indicates that the performance could most definitely surpass the 21% mark if both tests received the same amount of illuminance. Is it recommended that the solar reflector surface area and angle should be designed accordingly so that it can meet the demand of the solar still.

As mentioned in the analysis of the results; air temperature, glass surface temperature, and wind speed did not have impact on the performance of the system.

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