Experimental Investigations on the Performance of a Single Slope Solar Still Coupled With Flat Plate Solar Collector under Malaysian Conditions

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ABSTRACT

The high salinity level of seawater prevents it from being ingested by humans. Desalination using solar energy is a cheaper alternative compared to fossil fuels and it is also renewable and environmentally friendly. The productivity of passive solar stills however is relatively low. Active stills where extra thermal energy is supplied to the water in the evaporator basin using various devices tend to have higher levels of productivity. This paper aims to investigate the performance of a single slope solar still coupled with flat plate solar collector of different design parameters under Malaysian conditions. Results of the experiments showed that the performance of stills coupled with the solar collector is better than the one without. The still with 5 mm copper rods solar collector yielded the highest volume of fresh water (12.5 percent) which is twice the amount produced by the passive still (6.25 percent).

Keywords: *Desalination, Solar energy, Solar still, Solar collector*

Introduction

Oceans provide a limitless source of water but their high salinity makes it unsuitable for consumption [1]. Seawater contain around 35,000 parts per million (ppm) of dissolved salts and for fresh water, the concentration of salt has to be less than 1,000 ppm in order for it to be ingested safely.

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Desalination in general means to remove salt from seawater or generally saline water [2].

With the abundance of solar energy, it can be used as an alternative energy source to desalinate the seawater into potable water. The solar still operation is similar to the natural hydrologic cycle of evaporation and condensation. The basin is filled with seawater and the sun's rays that pass through the glass cover will heat up the water which will then evaporate. The resultant water vapour then condenses on the inner surface of the glass cover, and trickle down the into the collector basin [3].

The productivity of a solar still is affected by climate parameters that include solar intensity, wind velocity, and ambient temperature. The cover angle, material coating on the basin, water depth, temperature difference between the water and the cover, and the insulation are also factors that influence productivity [4].

Copper, aluminium and steel are usually used for the evaporator basin [5]. The thermal conductivity of the metal is an important property as it will determine the capability of the material to transfer heat. The thermal conductivity for aluminium and copper are high at 200 W/m.K and 390 W/m.K respectively as compared to steel which is 48 W/m.K. However, the cost for copper and aluminium when compared to that of galvanized steel is more expensive, that is almost two times the cost of galvanized steel [6].

Glass is more suitable for long term applications as compared to plastic which is used for short term applications [7]. The cover tilt angle of a simple solar still should be increased as the latitude angle of the test site becomes large for maximum productivity [8].

Solar stills can be divided into two categories, passive and active. For passive solar stills, solar radiation is the only source of energy used to raise the water temperature in the evaporator basin, leading to a lower productivity [3].

For active systems however, extra thermal energy is supplied to the water in the evaporator basin through an external mode such as a solar collector, solar pond, parabolic concentrator or other devices to increase the evaporation rate and in turn improve its productivity [9]. The performance of a single basin solar still coupled with flat plate collector trough heat exchanger was theoretically investigated by Lawrence and Tiwari [10] and their results showed increase in productivity as compared to the passive mode.

The heat transfer through the flat plate solar collector is via conduction and can be formulated using Equation (1) [11]

$$Q = kA\frac{\Delta T}{d} \tag{1}$$

where;

Q is the heat transfer (W)

k is the thermal conductivity (W/m K)
A is the area (m^2)
ΔT is the temperature gradient (K)
d is the thickness (m)

In this work, single slope solar stills coupled with flat plate solar collector of different design parameters were fabricated utilising available local materials. The experiments were conducted to study the effects of the solar collector design parameters on single slope solar still performance under Malaysian climate.

Experimental Method

Aluminium metal sheet of 1.0 mm thickness was molded into the evaporator basin and painted black throughout to improve the radiation absorption [12]. As shown in Figure 1, the basin of the solar still consists of two sections: evaporator basin and collector basin. The measurements are 250 mm x 250 mm and 40 mm x 250 mm for the evaporator basin and collector basin respectively. The evaporator basin height is 55 mm and accommodates 1 litre of saline water (35,000 ppm) at a depth of 16 mm.

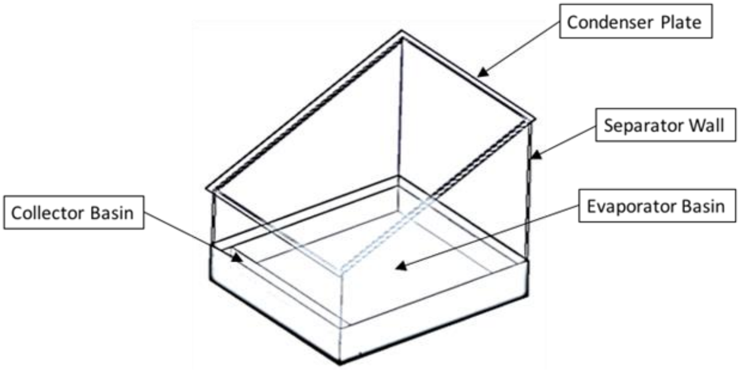

Figure 1: Schematic model of the solar still

The evaporated water will condense at the condenser plate surface and flow into the collector basin and measured. The glass condenser plate of 2 mm thickness is inclined at a 30^o angle to increase the speed of the water droplets moving along the inner surface of the condenser plate as compared to a lower angle which might cause it to fall back into the basin [8]. The shortest height of the separator wall is 200 mm and the walls are also made of 2 mm thick glass.

The flat plate solar collector is located on both sides of the solar still and consists of two 250 mm x 80 mm black painted aluminium sheet of 1 mm thickness and five 420 mm long solid copper rods as shown in Figure 2. Of the four stills fabricated, three were coupled to solar collectors with different copper rod diameters (3, 4 and 5 mm) while the last still has no solar collector attached.

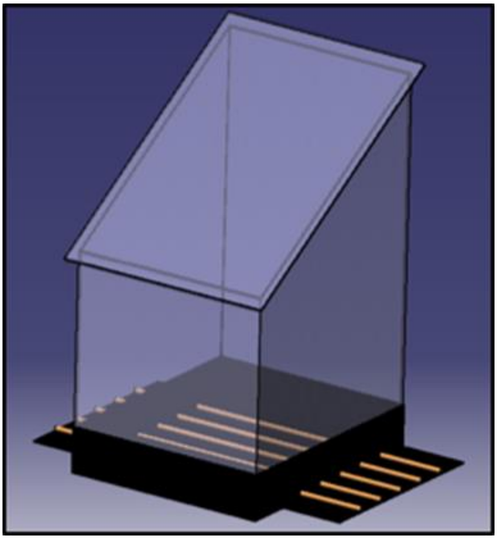

Figure 2: Schematic model of the solar still coupled with flat plate solar collector

Experiments were conducted in Shah Alam, Malaysia (3.0733° N) for a period of 24 hours (7 AM to 7 AM the next day) and the stills output were measured at 2 h intervals. The stills were also positioned in the East-West direction (elevation angle) to study its effect on the stills performance.

The ambient temperature and relative humidity were measured with a Sunleaves Hygro-Thermometer and Type K thermocouples (chromel-alumel) were attached to specific points on the still to record the temperatures. Water salinity values were determined using a SENSION 7 Benchtop Conductivity Meter.

Results and Discussion

Figure 3 shows the volume of evaporated water over time for the four solar stills. Evaporation rates are highest during the daylight hours between 9 am until 7 pm. After that, evaporation occurred at a much slower rate and could not be recorded.

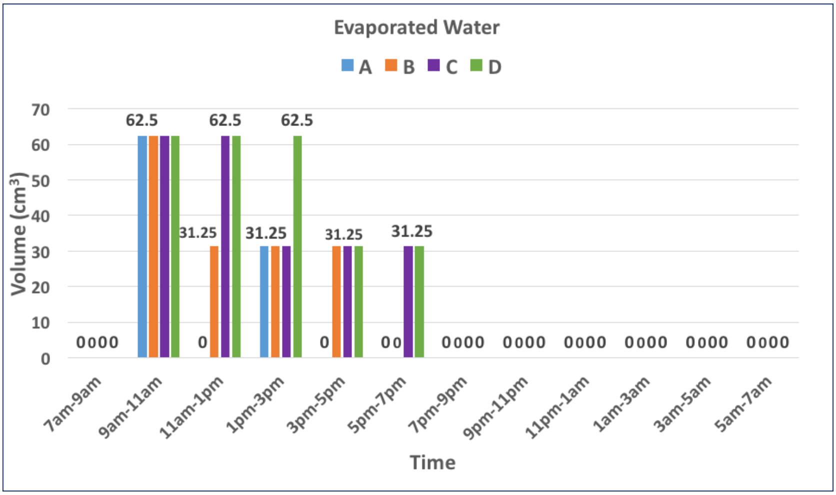

Figure 3: Volume of evaporated water in the solar stills over time

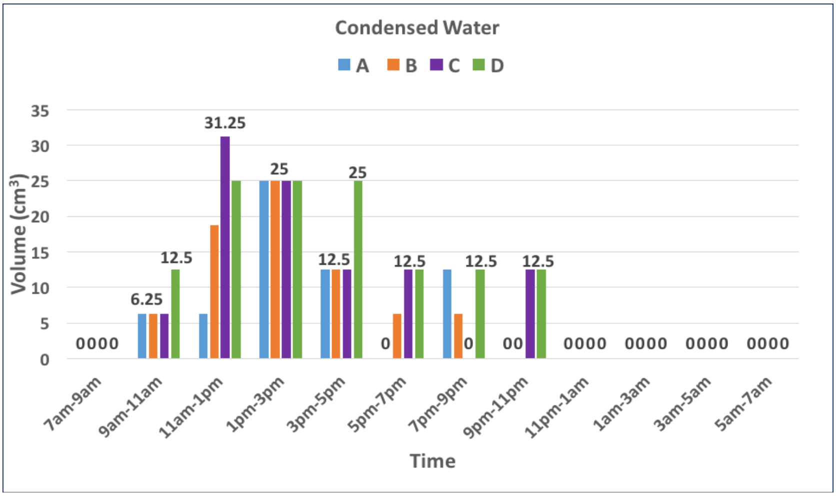

Figure 4: Volume of condensed water in the solar stills over time

Legend

A Solar still without solar collector

B Solar still coupled with five 3 mm diameter solid copper rods solar collector

C Solar still coupled with five 4 mm diameter solid copper rods solar collector

D Solar still coupled with five 5 mm diameter solid copper rods solar collector

This correlates with the fact that solar energy is highest during daytime and the findings by Ahsan et al [13]. The rate of evaporation in solar still D is the highest as compared to the other stills and passive still A recorded the lowest.

Figure 4 shows the volume of condensed water over time in the four solar stills.

Similar to the evaporation rate, condensation rates are also highest between 9 am and 7 pm. However, condensation inside stills coupled to solar collectors can still be recorded until 11 pm as compared to the evaporation. This is because the energy stored in the water will be released in the absence of sunshine and desalinated water production will continue [14]. Solar still D recorded the highest condensation of 31.25 ml at 1 pm while passive still A continue to display the lowest condensation rates.

Table 1 shows the productivity of the solar stills.

Table 1: Solar stills productivity

Solar Still	Evaporation (ml)	Condensation (ml)	Condensation/Evaporation (%)
A	93.75	62.50	67
B	156.25	75.00	48
C	218.75	100.00	46
D	250.00	125.00	50

Table 2: Salinity of water in the evaporator basin and condensed water

Solar Still	Evaporator Basin		Condensed Water (ppm)
	Before (ppm)	After (ppm)	
A	35000	36200	100
B	35500	37600	200
C	35800	38900	800
D	36200	39600	800

Total evaporation volume for solar still D is the highest at 250 ml and the passive still A is the lowest at 93.75 ml. This concurs with the evaporation rates shown in Figure 3. In terms of total volume of condensed water collected, solar still D again produced the highest amount at 125 ml. However, this is half the amount of the water evaporated (250 ml). The condensation versus evaporation ratios for the other stills coupled with flat plate solar collectors (C and D) were also about 50 percent as compared to the ratio of solar still A (without solar collector) which is 67 percent.

The salinity of the condensed water for all the stills are less than 1,000 ppm (Table 2) and can be safely ingested by humans.

Figure 5 shows the comparison between ambient temperature and water temperatures in the evaporator basins of the solar stills.

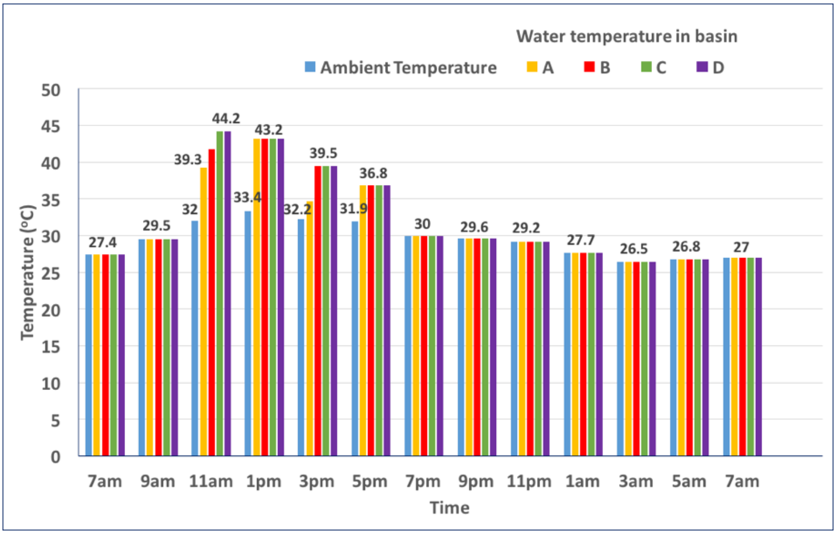

Figure 5: Ambient and water temperature in evaporator basin

From the graph, water temperatures in all the basins exceeded the ambient temperature from 11 am to 5 pm, correlating with the rate of evaporation in Figure 3 as higher water temperature will cause a higher rate of evaporation [15]. Peak water temperatures in all the basins were attained at 11 am. The highest temperature recorded was in solar still D at 44.2 °C and the lowest is passive still A at 32 °C. It can be established that the active solar stills are able to heat the water in the evaporator basin to a higher temperature with the extra thermal energy supplied by the flat plate solar collector and this is supported by Shafii et al [9].

In contrast, higher temperatures inside the stills coupled to solar collectors lead to a lower condensation/evaporation ratio as compared to the passive still A and is corroborated by Kabeel and El-Agouz [16]. A lower cover temperature will help to increase the condensation.

Conclusion

The performance of single slope solar still coupled with flat plate solar collector was experimentally studied and compared to a passive solar still under Malaysian conditions. The active still with the biggest diameter solid copper rods (5 mm) yielded the highest productivity of 125 ml of water as compared to the passive still (62.5 ml). Higher temperatures inside the stills will generate higher evaporation rates but will lower the condensation rate at the inner cover surface. The processed water salinity of less than 1,000 ppm also makes it safe for human consumption.

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