Experimental Investigations on The Effect of Inverted Cone Condenser Plate Material and Tilt Angle on The Solar Still Production Under Malaysia Conditions

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Abstract*: Due to population growth, the demand for fresh water continues to increase in both developed and under developed countries. One way of meeting this demand is through desalination of sea water. A simple solar still that makes use of solar energy which is renewable and clean is the most widely used solar desalination system to supply potable water. The still's design parameters such as the cover angle and material can influence productivity. This paper aims to investigate the effect of the inverted cone condenser plate material and tilt angle on the solar still production under Malaysian conditions. Results showed that the still with Polyvinylchloride condenser plate will produce a higher amount of condensation as compared to Polypropylene and the steepest tilt angle (30o) bore the highest yield of fresh water.

***Keywords*: Condenser plate, Desalination, Solar energy, Solar still.**

I. INTRODUCTION

Seawater is abundant and yet potable water is not available in many areas by the coast. [1]. The high salt content in seawater at 35,000 parts per million (ppm) as compared to freshwater of less than 1,000 ppm makes it unsuitable for human consumption. Removal of salt in seawater can be carried out through desalination but large amounts of energy is required [2]. However, solar energy which is renewable can be utilised for the desalination process in areas where solar radiation and seawater are plentiful [3].

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Similar to the natural hydrologic cycle of evaporation and condensation, the solar still allows the sun's rays to pass through the still's glass cover and heat up the seawater placed in the basin which will then evaporate. Subsequently, the water vapour will then condense on the inner surface of the glass cover and trickle down into the collector basin [4].Climate factors such as solar intensity, wind velocity, and ambient temperature affect the productivity of a solar still. The cover angle, material coating on the basin, water depth, temperature difference between the water and the cover, and the insulation can also influence production [5].

Aluminium or steel are normally used in the fabrication of the evaporator basin [6]. The thermal conductivity of the metal controls the capability of the material to transfer heat. For aluminium and copper, the thermal conductivity 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 price of copper and aluminium is almost twice the cost of galvanized steel [7].

Glass cover is more suitable as compared to plastic for long term applications [8]. However, glass is difficult to fabricate into an inverted cone shape condenser plate as compared to plastic-like materials [9]. The cover tilt angle of the still should also be increased for maximum output as the latitude angle of the test site grows larger [10].

There are two categories of solar stills; passive and active. In passive stills, solar radiation is the only source of energy used to raise the water temperature in the evaporator basin [11]. However, for active stills, additional thermal energy is supplied to the water through external means such as a solar collector, solar pond, parabolic concentrator or other devices [12].

In this work, passive solar stills of different inverted cone condenser plate material and tilt angles were fabricated utilising available local materials. The experiments were conducted to study the effects of the material and tilt angle on the solar still performance under the Malaysian climate.

II. METHOD

For the solar still, aluminium metal sheet of 0.5 mm thickness is molded into the evaporator basin and painted black throughout to improve the radiation absorption [8]. As shown in Fig. 1, the basin is 280 mm in diameter with a height of 20 mm and accommodates 1 litre of saline water (35,000 ppm) at a depth of 16 mm.

Polystyrene of 35 mm thickness is placed underneath the basin as an insulator and the still is then mounted on a plywood stand.

The evaporated water will condense on the inner surface of the inverted cone condenser plate, flow into the conical funnel and collected in a bottle underneath.

Two stills, of which the condenser plates and walls are made of 0.5 mm thick Polyvinylchloride (PVC) and Polypropylene (PP) respectively with a tilt angle of 10^{o} is tested to study the effect of the condenser plate material on the still productivity (Fig. 2). Subsequently, four stills with different inverted cone tilt angles utilising the best condenser plate material were constructed and tested (Fig. 3).

Experiments were conducted in Shah Alam, Malaysia (3.0733° N) for a period of 12 hours (7 am to 7 pm) 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.

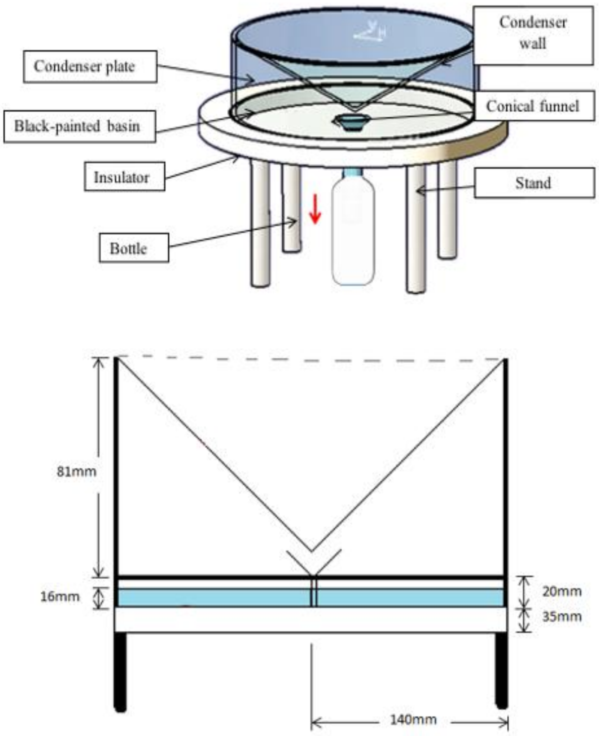

Fig. 1 Solar still construction

Fig. 2 Solar stills with PVC (left) and PP (right) condenser plates

Fig. 3 Solar stills of 15^{o}, 20^{o}, 25^{o}, and 30^{o} condenser plate tilt angle

III. RESULTS AND DISCUSSION

Nomenclature	
PVC	Polyvinylchloride
PP	Polypropylene
A	Solar still with 15^{o} condenser plate
B	Solar still with 20^{o} condenser plate
C	Solar still with 25^{o} condenser plate
D	Solar still with 30^{o} condenser plate

Large water droplets were formed on the inner surfaces of both the PVC and PP 10o tilt angle condenser plates during the experiment. However, there were no condensed water in the bottles as the gentle incline does not increase the droplets speed to enable them to travel along the inner surface and into the funnel and this is concurred by Khalifa [10]. As a result, the droplets will grow as condensation continue to occur and fall back into the basin under gravity [13].

Table 1 shows that the total amount of water collected on the inner surface of the PVC plate (13.5 ml) is higher than the PP plate (11.0 ml) over the 12-hour period as the higher thermal conductivity of PVC (0.19 W/m.K) will condense more water vapour as compared to PP (0.16 W/m.K) and is corroborated by Kabeel and El-Agouz [14].

Table 1 Solar stills productivity based on condenser plate material

Solar Still Condenser Plate Material	Condensation (ml)
PVC	13.5
PP	11.0

As such, PVC was chosen as the condenser plate material in the investigation on the effect of tilt angle on the still production. Since the 10^{o} condenser plate tilt angle did not yield any collected water in the bottle, the tilt angles of the four stills fabricated have been increased to 15^{o}, 20^{o}, 25^{o}, and 30^{o} respectively.

Fig. 4 shows the comparison between the ambient temperature and water temperatures in the evaporator basins of the solar stills. From the graph, water temperatures in all the evaporator basins showed a steady increase from 9 am until peaking at 1 pm.

The highest water temperature recorded was in solar still C at 57.4 ^{o}C and the lowest is still B at 54.6 ^{o}C. A gradual decline in water temperatures in all the basins were recorded from 1 pm until 7 pm and is validated with the finding by Ahsan et al. [15] that solar energy is highest at midday and begin to decrease after that.

Fig. 5 shows the volume of condensed water over time for all four solar stills. The salinity of the condensed water for all the stills are less than 1,000 ppm (Table 3) and can thus be safely ingested by humans.

The condensation rate in the stills showed a measured increase from 11 am until cresting at 3 pm before gradually declining subsequently. Solar still D with the steepest condenser plate tilt angle of 30o recorded the highest condensation of 32 ml at 3 pm while still a (15o tilt angle) recorded the lowest amount. These values seem to correlate with the water temperatures in the basins shown in Fig. 4 as higher temperatures would increase the evaporation rate which may in turn intensify the condensation rate and is supported by Manokar et al. [7]. Table 2 shows the productivity of the solar stills.

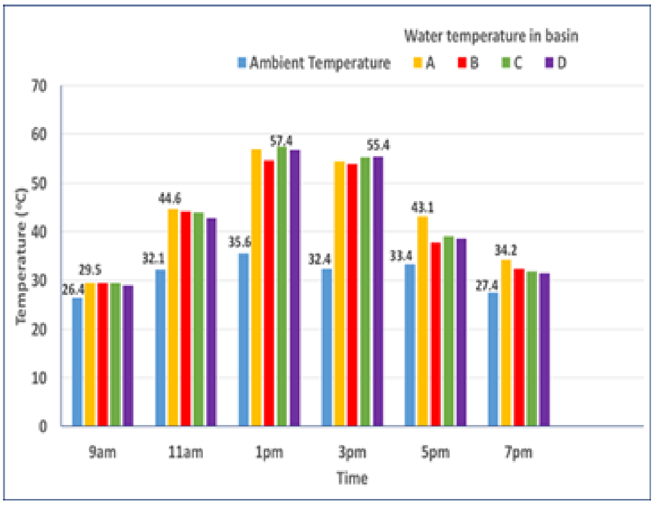

Fig. 4 Ambient and water temperature in evaporator basin

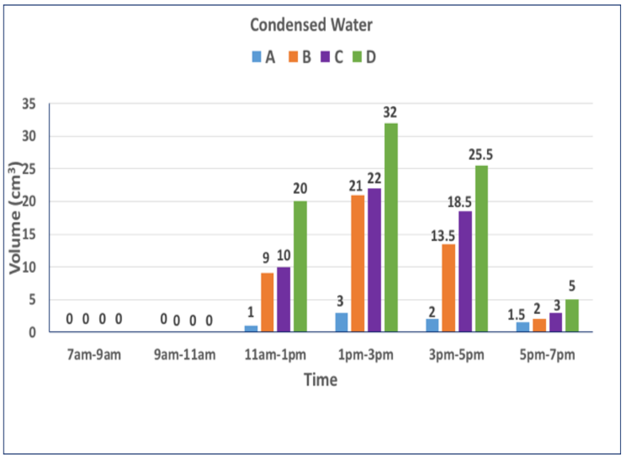

Fig. 5 Volume of condensed water in the solar stills over time

Total evaporation volume for solar still D is highest at 630 ml and still A is lowest at 390 ml. In terms of total volume of condensed water collected, still D again produced the highest amount at 82.0 ml while still A yielded the lowest (7.5 ml). Similarly, still D with the steepest condenser plate tilt angle (30o) displayed high condensation versus evaporation ratios. It is likely that the steeper incline increases the droplets speed travelling along the interior surface of the condenser plate into the water channel instead of falling back into the basin as compared to the other stills and this is concurred by Khalifa [10].

A higher evaporation volume in still D also leads to a higher condensation/evaporation ratio and is corroborated by Kabeel and El-Agouz [14].

Table 2 Solar stills productivity

Solar Still	Evaporation (ml)	Condensation (ml)	Condensation/Evaporation (%)
A	390	7.5	1.92
B	450	45.5	10.11
C	510	53.5	10.49
D	630	82.0	13.02

Table 3 Salinity of water in the evaporator basin and condensed water

Solar Still	Evaporator Basin		Condensed Water (ppm)
	Before (ppm)	After (ppm)	
A	35000	39100	711
B	35000	38700	643
C	35000	37300	510
D	35000	36800	580

IV. CONCLUSION

The performance of passive solar stills of different inverted cone condenser plate material and tilt angles were experimentally studied under Malaysian conditions. Condenser plate constructed of Polyvinylchloride (PVC) will produce a higher amount of condensation as compared to Polypropylene (PP). The still with the steepest condenser tilt angle (30^{o}) yielded the highest productivity of 82 ml of water as compared to the 15^{o} tilt angle still (7.5 ml). Higher temperatures inside the stills will generate higher evaporation rates. The processed water salinity of less than 1,000 ppm also makes it safe for human consumption. From this investigation, it can therefore be concluded that a still with a 30^{o} inverted PVC cone condenser plate tilt angle will give the best production rate of fresh water.

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