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The Effect of Condenser Plate Material on Single Slope Solar Still Productivity under Malaysian Climate

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Abstract: *Access to fresh water is a problem faced by both developed and under developed nations. Although seawater is plentiful, large amounts of energy is required to separate the potable water from the salts. Compared to other desalination processes utilising fossil fuels, solar distillation is inexpensive, environmentally friendly and employs clean and renewable energy. This paper seeks to explore the effect of the single slope solar still condenser plate material on the still production under Malaysian climate. 5 mm thick extra clear float glass condenser plate produced the highest amount of fresh water (63.5 ml) compared to 2 mm thick clear float glass and 5 mm thick bronze glass.*

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

I. INTRODUCTION

Seawater is not suitable for ingestion as it comprises about 35,000 parts per million (ppm) of dissolved salts compared to fresh water which is less than 1,000 ppm [1]. Removing salt from seawater can be achieved through the process of desalination [2]. In a solar still, the sun's rays will pass through the glass cover, heating the seawater inside the basin and causes it to evaporate. The water vapour will condense on the cover's inner surface before dripping into the the collector basin. The process is akin to the natural hydrologic cycle [4].

The output of a solar still can be influenced by the environment and working surroundings. Environmental factors include solar concentration, ambient temperature, and wind velocity. Temperature difference between the water and the cover, insulation, basin material coating, and the cover angle encompass the working surroundings that can influence the yield [4].

The ability to transfer heat is determined by the thermal conductivity of a material. Normally, the evaporator basin is constructed of metals such as steel, copper or aluminium [5].

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Compared to the thermal conductivity of steel (48 W/m.K), both copper and aluminium have higher values; 390 W/m.K and 200 W/m.K respectively. Nonetheless, the price for copper and aluminium are more costly, approximately twice the price of steel [6].

Glass or plastic can be used for the still's transparent cover while for long term use glass is considered to be more appropriate [7]. As the latitude angle of the test location becomes higher, the still's cover tilt angle ought to be enlarged for maximum throughput [8]. As affirmed by Kabeel et al., increase in thermal conductivity and a decrease in the thickness of the cover plate will result in an increase in the heat transfer through the plate [9]. The still's yield can also be increased by minimizing the gap between the surface of the water and the still condenser plate [10].

The intrinsic green tinge on clear float glass is due to the iron content in the silicate. Extra Clear float glass on the other hand comprises about one quarter of the iron content of clear float glass, providing an extra clear glass appearance [11]. Bronze glass is produced by adding iron, cobalt and selenium to the glass composition [12].

There are two categories of solar stills which are passive and active. In passive stills, the rise in water temperature in the evaporator basin is generated solely by solar radiation as the energy source [3]. Conversely, active stills receive additional energy from external sources such as a solar pond, solar collector, or other mechanisms to heat up the water in the basin [13].

For this research, passive single slope solar stills utilising different condenser plate materials sourced locally were constructed and tested to investigate the effects of the material on the still production under Malaysian conditions.

II. METHOD

The 250 mm x 250 mm evaporator basin was constructed of 0.5 mm thick aluminium metal sheet with a height of 20 mm (Fig. 1). It contains 1 litre of saline water at 35,000 ppm with a depth of 16 mm. To enhance radiation absorption, the basin is painted black all over [14]. For insulation, 35 mm thick polystyrene was applied to the bottom and the sides of the basin. The still is then affixed to a plywood stand. Condensation of the evaporated water from the basin will occur on the inner surface of the condenser plate where it will stream into the inclined gutter and accumulated in a bottle by a tube.

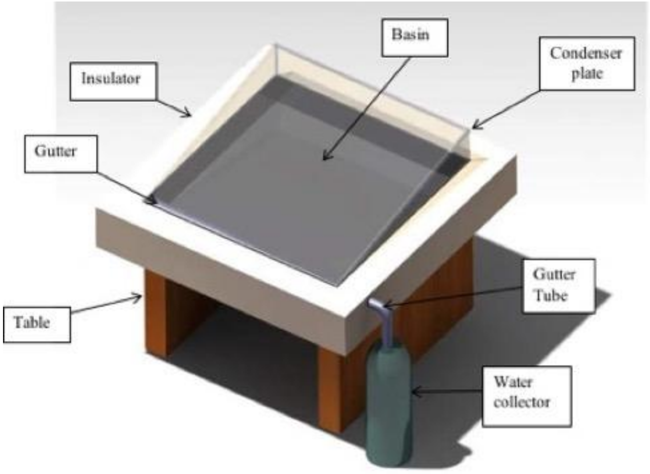

Fig. 1. Solar still construction

For the condenser plate material, three types of glass; extra clear float, clear float and bronze were sourced locally based on their minimum available thickness and is shown in Fig. 2.

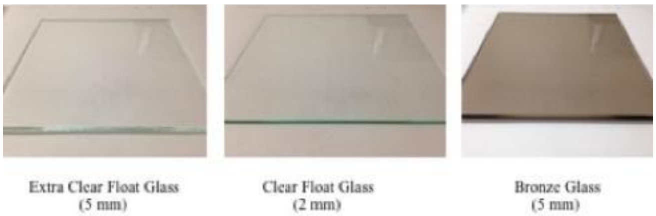

Fig. 2. Condenser plate material

The plates are successively placed over a basin filled with water heated at constant boiling temperature at varying tilt angles and time is recorded when the initial flow of the condensed water droplets reaches the edge of the glass (Fig. 3).

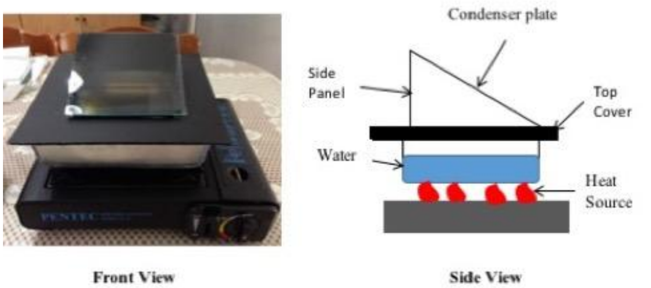

Fig. 3. Tilt test setup

Subsequently, three single slope stills, each of which the condenser plates and walls are made of the respective glass materials incorporating the best tilt angle are tested for their productivity (Fig. 4).

The trials were performed in Shah Alam, Malaysia (3.0733° N) where the stills were placed in the East-West direction in order to examine the influence of the elevation angle on the yield. The duration of the test is from 7 am to 3 pm (8 hours) and measurements were made every two hours.

A KIMO SL200 Solarimeter was utilised to measure the solar irradiance and temperatures at different locations on the still was captured using Type K (chromel-alumel) thermocouples. A Sunleaves Hygro-Thermometer was employed to gauge the ambient temperature and relative humidity. A SENSION 7 Benchtop Conductivity Meter was used to determine water salinity.

Fig. 4. Single slope solar still

III. RESULT AND DISCUSSION

Nomenclature	
A	5 mm thick Extra Clear Float Glass condenser plate solar still
B	2 mm thick Clear Float Glass condenser plate solar still
C	5 mm thick Bronze Glass condenser plate solar still

As shown in Table I, 21.20 seconds was the swiftest time for the condensed water droplets to reach the edge of the condenser plate at a 10-degree tilt angle while 3 degrees tilt angle registered the slowest times. Even though the condensation pace can be increased with a smaller gap between the water surface and the condenser plate [10], the gentle incline causes the droplets to flow at a slower rate [8]. The time taken for the droplets to reach the edge of the plate continue to rise at 15 degrees tilt angle but falls at 20 degrees as a higher angle increases the droplets speed. However, in order to have a good balance concerning the minimum space between the plate and water surface and the tilt angle for optimal throughput, the 10-degree tilt angle was chosen and incorporated in the stills used for the productivity test.

Table I: Condenser plate tilt angle versus time

Tilt Angle (deg)	Time (s) A	B	C
3	50.50	187.26	78.70
10	21.20	27.00	46.89
15	38.95	28.33	53.70
20	23.20	25.56	31.06

The ambient temperature and water temperatures in the solar still's evaporator basins is presented in Fig. 5.

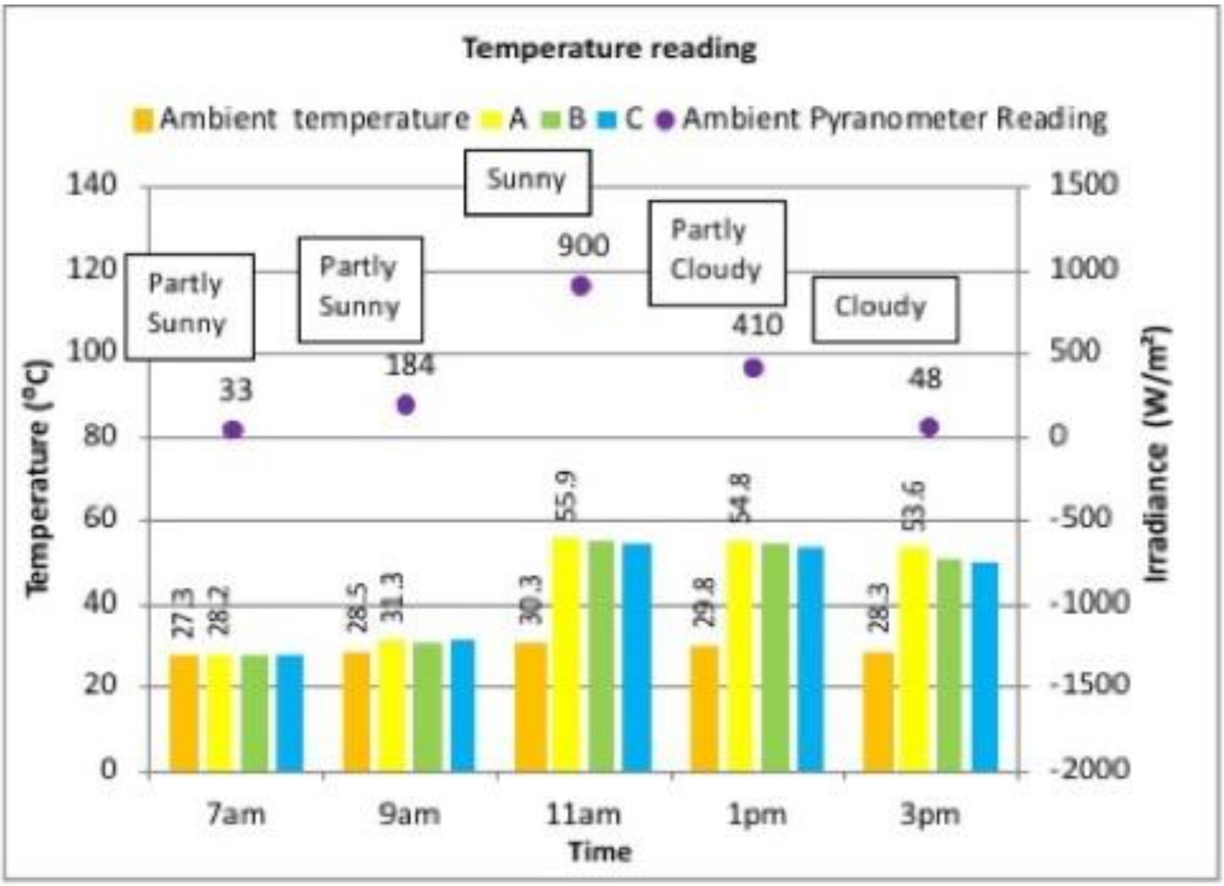

Fig. 5. Ambient and water temperature in evaporator basin

Table II: Solar irradiance through the condenser plates

Time	Ambient (W/m^2)	Extra Clear Float Glass (5 mm thickness) (W/m^2)	Clear Float Glass (2 mm thickness) (W/m^2)	Bronze Glass (5 mm thickness) (W/m^2)
7 am	33	25	23	18
9 am	184	178	170	101
11 am	900	848	754	410
1 pm	410	341	330	205
3 pm	48	39	35	23

Ambient pyranometer readings display a rise in solar irradiance from 7 am, cresting at 11 am and gradually waning after that. This flux in solar irradiation also correlates with the ascent and descent in the ambient temperature and water temperatures in the basins and is concurred by Ahsan et al [15]. In all the basins, the water temperatures are higher than that of the ambient. This is probably due to absorption of the solar energy transmitted through the condenser plates thus heating up the water [16]. The highest recorded water temperature was at 11 am in solar still A at 55.9 ^{o}C.

As shown in Table II, the solar irradiance through all three condenser plates is less than the ambient as part of it is reflected, absorbed in the thickness of the glass and the remainder transmitted [11]. Extra clear float glass permits the most solar transmittance compared to clear float glass and bronze glass.

Although the thickness of clear float glass (2 mm) is less than extra clear float glass (5 mm), its solar transmittance is less than extra clear float as this may be due to its higher iron content in the silicate [11].

The volume of condensed water over time for the three solar stills is displayed in Fig. 6. The quantity of water in each still is nearly proportional to the amount of solar transmissivity through the condenser plates and is supported by Ahsan et al. [17]. The highest condensation registered is 30.0 ml at 11 am in still A and the lowest condensation is in still C.

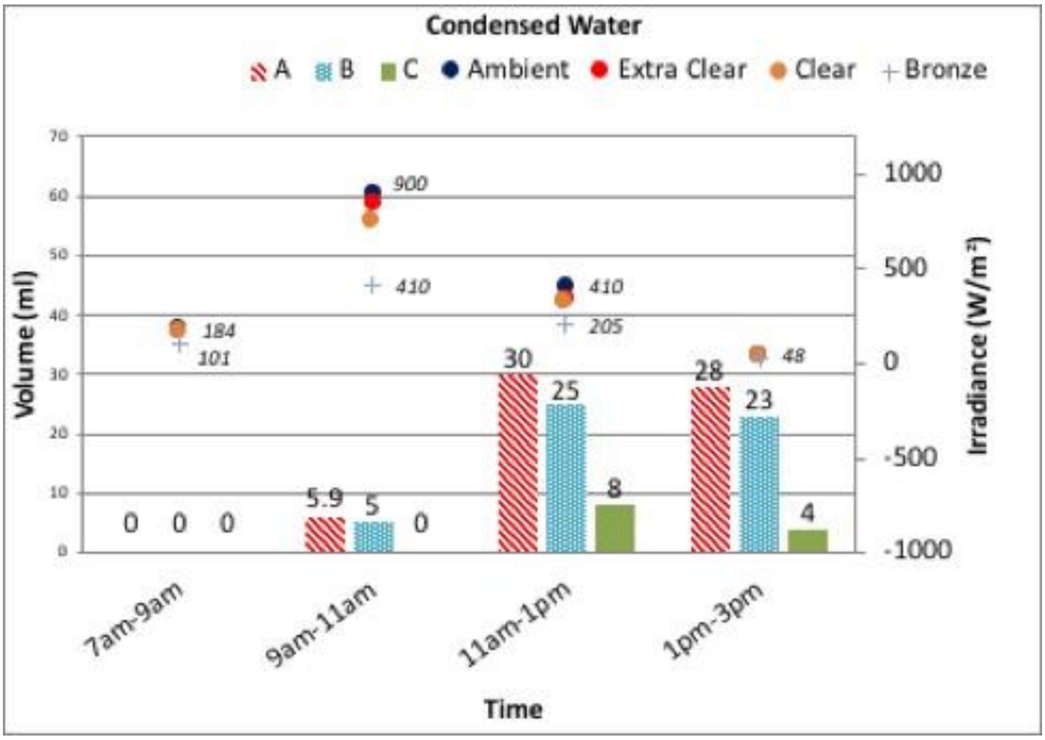

Fig. 6. Condensed water volume in the solar stills over time

Table III: Solar stills productivity

Solar Still	Evaporation (ml)	Condensation (ml)	Condensation/Evaporation (%)
A	336.1	63.9	19.0
B	327.0	53.0	16.2
C	288.0	12.0	4.2

Table IV: Water salinity of condensed water and in the evaporator basin

Solar Still	Evaporator Basin		Condensed Water (ppm)
	Before (ppm)	After (ppm)	
A	35000	41100	200
B	35000	39200	400
C	35000	37700	200

Table III shows the overall productivity of the stills. Total evaporation volume is highest in still A at 336.1 ml and lowest in still C (288.0 ml). Still A also yielded the most amount of condensed water (63.9 ml) and still C the least (12.0 ml). From Fig. 5, it can be deduced that the intensification of the condensation rate in still A compared to the other stills can be attributed to the increase in the evaporation rate due to higher basin water temperature and this is supported by Manokar et al [6]. This was also bolstered by Kabeel and El-Agouz who affirmed that a higher evaporation volume will steer to a higher condensation/evaporation quotient [9].

Table IV discloses that the condensed water in all the stills can be safely ingested by humans as the salinity values are less than 1,000 ppm.

IV. CONCLUSION

The effect of single slope solar stills with different condenser plate materials were experimentally examined under Malaysian climate. The 5 mm thick extra clear float glass condenser plate still bore the highest throughput of 63.9 ml of water as compared to 2 mm thick clear float glass (53.0 ml) and 5 mm thick bronze glass (12.0 ml). Although Kabeel et al. [9] expressed that heat transferred through the cover plate will increase with a decrease in thickness, the extra clear float glass composition allows more solar transmittance even though it is thicker than clear float glass. The amount of solar irradiance heating up the water in the basin is more likely the dominant factor as compared to the heat transferred through the condenser plate. Water generated by the solar still is also safe for human consumption as the salinity is less than 1,000 ppm.

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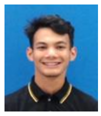

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