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Condensation Rate Enhancement of the Inclined Condenser in the Solar Still Connected With a Solar Water Heater

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Abstract: One method to increase the fresh water productivity of the basin type stills is to increase the condensation rate of their condensing surfaces. A basin type still with an aluminum condenser was fabricated and tested in the Department of Mechanical Engineering at Texas Tech University. To increase the condensation rate the outer surface of the condenser was cooled with cooling water at different flow rates with and without woven jute material above it. For the same reason, cotton wick material was installed inside the basin of the still. It was found that the higher the flow rates of the cooling water across the condenser, the greater the condensation rate. Installation of cotton wick material inside the basin of the still and using jute material above the outer side of the condenser also caused an increase in the condensation rate thereby an increase in fresh water productivity of the still. Further, it was found that the maximum fresh water productivity was achieved when both the jute and the wick materials were installed during the experiment and when the condenser was cooled by water at 10 L/hr flow rate.

Keywords: Desalination; Condensation; Condenser; Solar Still; Solar Heater; Fresh water

1. INTRODUCTION

Along with the dramatic population growth and improved living standards, existing fresh water supplies are deteriorating [1], [2] and [3]. The rising of the world's population leads to the rising of water demand. As a consequence, there is a lack of pure water for drinking, agricultural and industrial use. There are 26 countries that do not have sufficient water resources to sustain agriculture and economic development, and approximately one billion people lack access to safe drinking water. With nearly 98% of the world's available water supply being sea or brackish water, desalination has become an important alternative source of clean water [4]. The condenser is a heat transfer device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In doing so, the latent heat is given up by the substance, and will transfer to the coolant of the condenser [5], [6]. One method to increase the fresh water productivity of the basin type stills is to increase the condensation rate of their condensers. The use of surrounding air or water in order to cool the condenser will lead to this result. Several approaches have been used to increase the efficiency of such stills by cooling their condensers [7], [8], [9], [10] and [11]. Another way to increase the still fresh water productivity is by increasing the evaporation rate of the water inside the basin. Several researchers were used different materials inside the basin in order to increase the fresh water productivity of such stills [12]. [13], [14], [15], [16] and [17].

Because the main drawback of the conventional solar stills is the low productivity so there is a need to enhance their fresh water productivity. One way to achieve that is to improve the condensation rate inside the solar still.

The objectives of this study are to:

- Enhance of a basin type solar still performance and improve its productivity by using a specially designed condenser.
- Define the effect of cold water stream flowing over the condenser at different flow rates, with and without jute wicking material on the productivity of the solar still.
- Define the effect of the cotton wicking material inside the basin of the solar still productivity.

2. EXPERIMENTAL SETUP

Basin type solar still (Figure 1) was constructed using aluminum for the condenser. The dimensions of the still's basin were 0.50 m x 0.50 m x 0.15 m and the bottom side of the basin was coated with black paint for good solar absorption. Transparent acrylic (Plexiglass) sheets were used for the sidewalls, which allowed sunlight to entry to the solar still during the experiment. In order to minimize the heat losses the outer lower side of the basin was insulated with 18mm thick expanded polystyrene boards with R-4 Value.

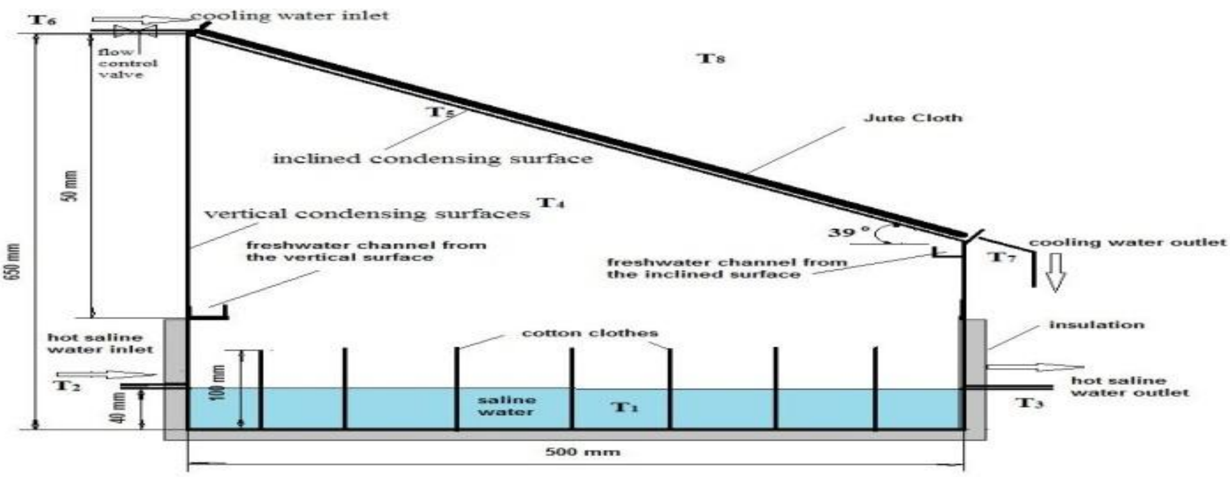

Figure1. Experimental Still Schematic.

Where: T1, T2, T3, T4, T5 and T6 are the ambient, hot water inlet, hot water outlet, vapor, condenser and cooling water inlet temperatures.

During the experiment the brackish water in the solar water heater was heated up to 50°C and that temperature was controlled by thermostat then pumped to the solar still. This gave consistency to the experiment, and allowed for a better understanding of how the other treatments will affect the fresh water productivity with constant temperature.

Since lowering the temperature of the condenser helps to increase the vapor condensation, a plastic distributor with 24 small slots at the top of the condenser was installed to distribute the cooling water at temperature of 22°C evenly over its outer surface. A thin layer of woven jute material was applied to the outer surface of the condenser then cooling water was distributed over it evenly. The still was also run without jute and without cooling water as a control case. The flow rate of the cooling water was controlled by a flow control valve and during the experiments the flow rate was either 2L/hr or 10L/hr.

Eight rows of cotton wick material with 0.48 m^2 total area were installed in the basin as shown in figure 2 to define if that can affect the water productivity of the still.

Fig. 2.Eight rows of the wick material used to increase the area of evaporating surface inside the basin of the still.

Water produced by vapor condensation on the surfaces of the condenser and sidewalls were collected by two plastic channels then transported by plastic tubes to collection jars.

3. RESULTS AND DISCUSSION

Temperatures and fresh water productivity first measured when the condenser was cooled by the surrounding air only as a control case. In this case measured temperatures are given in Table 1 and the total fresh water productivity of the still, which consisted of the productivity of the condenser and sidewalls, is shown in Figure 3.

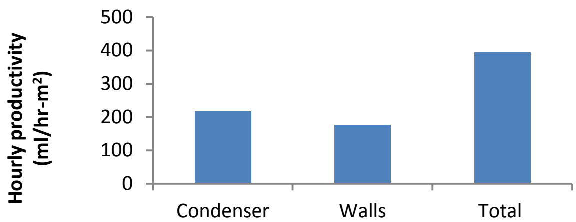

Figure 3. Condenser, walls and total fresh water productivity when the condenser was cooled by surrounding air (The control case).

Table 1. Temperatures (°C) when the condenser was cooled by the surrounding air only (The control case).

Hot water inlet	Hot water in the still	Hot water inlet	Vapor	Condenser	Ambient
T_1	T_2	T_3	T_4	T_5	T_6
51	50	49	41	38	22

The aluminum condenser was produced more fresh water than the sidewalls and this is due to the high thermal conductivity of the aluminum compared to the acrylic. Here the condenser was produced 218 ml/hr-m^2 which was the minimum amount of fresh water during the experiment, while the total productivity of the still was 395 ml/hr-m^2.

Table 1, Figure 4 and Figure 5 show that the temperature of the condenser reached 38^{o}C during the experiment, which is relatively high. This can be explained because the condenser has been cooled by the free convection of the surrounding air only.

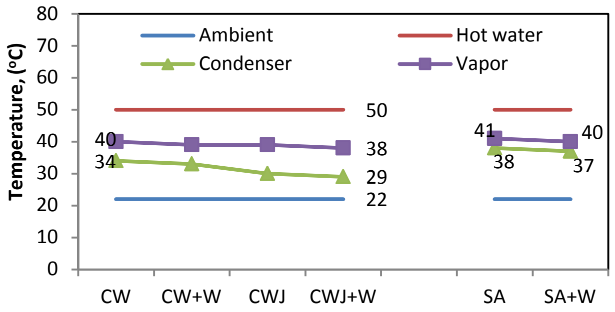

Figure 4.* Temperatures when the condenser was cooled by a current of water at 2L/hr flow rate and when the condenser cooled by the surrounding air only.

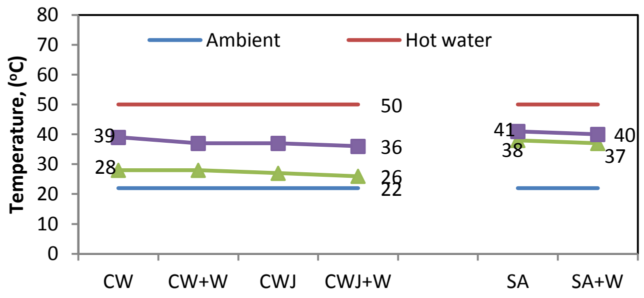

Figure 5.* The measured temperatures during the experiment when the condenser was cooled by a current of water at 10L/hr flow rate and when the condenser cooled by the surrounding air.

***Where:** CW- Condenser cooled by water, CW+W- Condenser cooled by water + wick material in the basin, CWJ- Condenser cooled by water with jute material, CWJ+W- Condenser cooled by water with jute material + wick material in the basin, SA- Condenser cooled by surrounding air, SA+W- Condenser cooled by surrounding air + wick material in the basin.

Figure 6 and 7 show how the fresh water productivity affected by the wick material which installed inside the basin of the still. As shown in figure 6 when the condenser cooled by the surrounding air only with wick material inside the basin of the still fresh water productivity reached to 268 ml/hr-m^2 from the condenser, from the side wall up to 177 ml/hr-m^2 and consequently the total fresh water productivity was 455ml/hr-m^2. When compared to the control case the total fresh water productivity of the still increased about 12%.

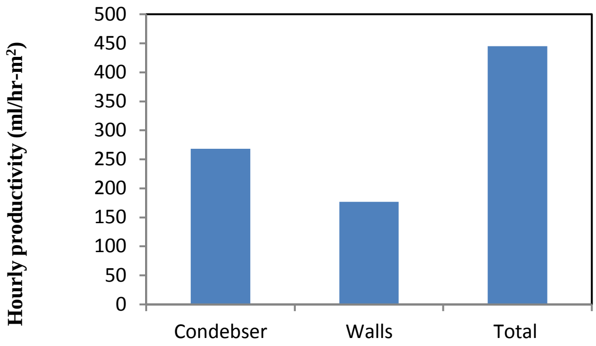

Figure 6. The effect of wick material inside the basin on the condenser, walls and total fresh water productivity when the condenser was cooled by surrounding air only.

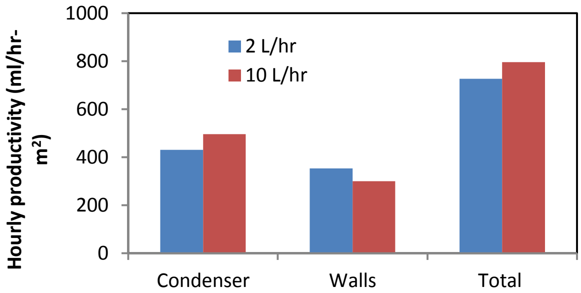

Figure 7. Effect of the wick material inside the basin on the condenser, walls and total fresh water productivity when the condenser was cooled by a current of water at different flow rates.

As shown in figure 7 when the bare condenser was cooled by a current of water at 2L/hr flow rate the total productivity was 727 ml/hr-m^2 then became 796 ml/hr-m^2 when it was cooled at 10 L/hr flow rate. Compared to figure 6 the productivity increased about 63 % and 79 % respectively.
The increment in productivity in figure 6 was due to the increment in evaporating area inside the basin which increased from 0.25 m^2 to 0.49 m^2 when the wick material was used. While the increment in productivity as shown in figure 7 was due to the condenser cooling effect in addition to the increment in evaporation area.

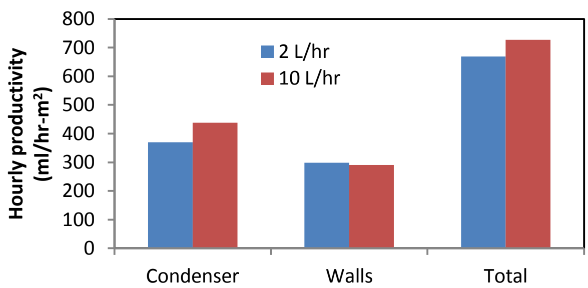

Figure 8. Effect of the different flow rates of the condenser cooling water on condenser, walls and total fresh water productivity.

As shown in Fig. 8, the total fresh water productivity was 669 ml/hr-m2 then was 727 ml/hr-m^2 when the bare condenser was cooled by a current of water at 2L/hr and at 10 L/hr flow rate, respectively. Compared to the control case the condenser productivity increased about 70% and about 100% when the condenser was cooled by a current of water at 2 L/h and 10 L/h flow rate respectively. This is a consequence of the increased difference between the vapor temperature inside the still and the condenser temperature as it shown in Fig.4 and 5. But compared to figure 7 the condenser productivity decreased about 14% and 12% when it was cooled by a current of water at 2 L/h and 10 L/h flow rate respectively. The reason of fresh water productivity decrease here is due to the absence of wick material inside the still basin.

When the woven jute material was placed on the outer side of the condenser as in Figure 9 the total hourly fresh water productivity increased to 664ml/hr-m^2 then to 822 ml/hr-m^2 when condenser was cooled by 2L/hr and 10L/hr flow rate, respectively. Compared to figure 8 the addition of jute material increased the hourly fresh water productivity from the condenser about 11% then about 20% when it was cooled by 2 L/hr and by 10 L/hr flow rate, respectively. When the condenser was cooled by 2 L/hr and by 10 L/hr flow rate the temperature difference between the vapor inside the still and the condenser where 9°C and 10°C respectively as it shown in Figure 4 and 5. So the fresh water productivity positively affected by these differences. The addition of the jute wick on the outer side of condenser increased the hourly fresh water productivity because the thin layer of the jute evenly distributed the water on the surface and retained the water on the condenser. Heat transfer from the condenser was then increased because of the evaporation from the jute wick material.

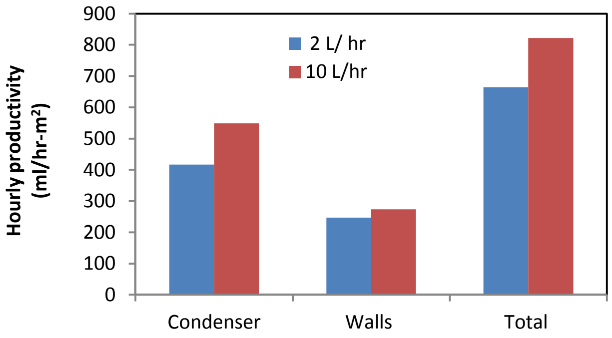

Figure 9. Effect of jute material on the outer side of the condenser on the condenser, walls and total fresh water productivity when the condenser was cooled by a current of water at different flow rates.

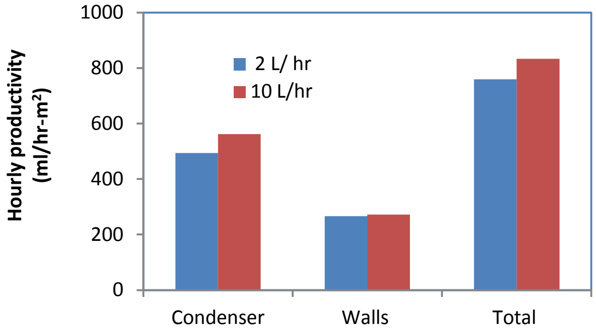

Figure10. Effect of jute material on the outer side of the condenser with wick material in the basin on the condenser, walls and total fresh water productivity when the condenser was cooled by a current of brackish water at different flow rates.

For the still with the cotton wick material placed inside the basin and with the jute material placed on the outer side of the condenser as shown in Figure 10 the total hourly fresh water productivity reached to 760 ml/hr-m^2 then to the maximum productivity during this study (834 ml/hr-m^2) when the condenser was cooled by 2 L/hr and by a 10 L/hr flow rate, respectively, while fresh water productivity from the condenser reached to 494 ml/hr-m^2 then to 562 ml/hr-m^2 when the condenser was cooled by 2 L/hr and by a 10 L/hr flow rate, respectively. In this case the vapor temperature inside the basin condenser and the condenser temperature were about 9°C and 10°C respectively as shown in Figures 4 and 5.

Compared to the control case figure 11 and 12 show the percentage increment of fresh water productivity during the experiment from the condenser and from the side walls when the condenser was cooled by a current of water at 2 L/hr then at 10 L/hr. When the condenser was cooled by water only the fresh water productivity from the condenser was affected positively, while the productivity from the side walls was negatively affected. Condenser fresh water productivity was obtained at the expense of the side wall fresh water productivity. The largest proportion of the vapor inside the still was condensed on the cooled aluminum plate (the condenser).

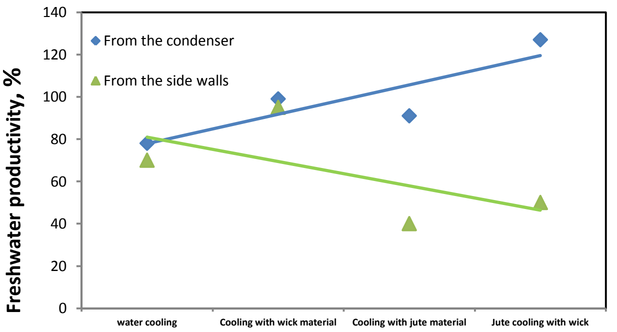

Figure 11. Percentage of fresh water productivity from the condenser and side walls when the condenser is cooled by water at 2L/hr flow rate compared to the control case.

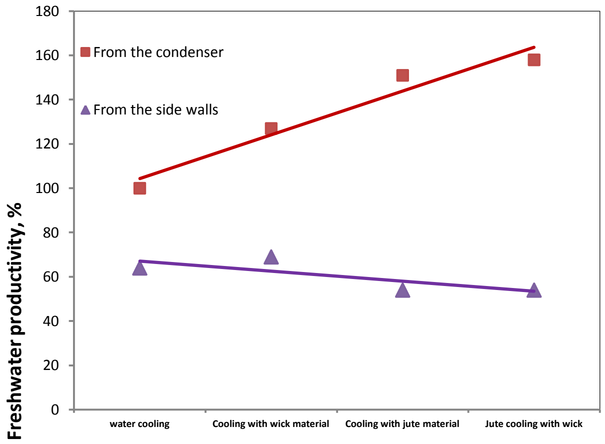

Figure12. Percentage of fresh water productivity from the condenser and side walls when the condenser was cooled by water at 10L/hr flow rate compared to the control case.

4. CONCLUSIONS

The following conclusions can be drawn from the experimental results:

1. Cooling the condenser by water led to an increase in the still fresh water productivity. The higher the flow rate of the cooling water, the greater the fresh water productivity.
2. Woven jute material evenly distributed the water on the outer side of the condenser and thus led to an increase in fresh water productivity of the still.
3. Cotton wick material installation inside the basin also increased the fresh water productivity.
4. The maximum fresh water productivity achieved when both the jute and the wick materials were installed during the experiment and when the condenser was cooled by water at 10 L/hr flow rate.

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