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SOLAR WATER DISTILLATION BY USING WATER IN THE INNER GLASS EVACUATED TUBES

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ABSTRACT

Evacuated tubes are made from two layers of glasses. The inside glass is coated and the space between the glasses is evacuated. When sun radiations pass through the first layer and transfer heat to the inner side, since the space between them is evacuated it cannot cool down with convection or conduction. The common way of using an evacuated tube is to put an evacuated copper rod inside it to heat up and make contact with a water container to let the water boil. In the current study water is directly inside the inner evacuated tubes. Thus, the evaporation happens in these tubes and there is no need to use a water container or copper rods. Results show that when the amount of water is increased in the tubes the production raises significantly. Result for two values of volume of water in two days with acceptable similar solar radiation and ambient temperature are reported.

INTRODUCTION

Fresh water has a vast usage in both industry and civil areas hence supplying enough fresh water is a matter that always must be considered. In so many cases water desalination devices are reasonable choices. For example in the areas near the sea because of accessibility to sea water it is logical to desalinate this water to supply fresh water. The solar powered desalination process is one of the simplest but efficient methods specially for small capacity of fresh water production [1]. Solar energy is one of the most promising applications of renewable energies to sea water desalination [2]. In this manner enhancement of solar desalination devices are important.

NOMENCLATURE

l	[m]	Length
r	[m]	Radius
T	[^{0}C]	Temperature
V	[L]	Volume
x	[m]	Cartesian axis direction
y	[m]	Cartesian axis direction
z	[m]	Cartesian axis direction
Special characters		
Θ	[degree]	Tilt angle with horizon
Subscripts		
i		Inside
m		Metal box
o		Outside
t		Evacuated tube

Several studies have been reported on the performance of the evacuated tubes [3]. An experimental investigation by Chen et al. [4] on the long-term thermal performance of a two-phase thermosyphon solar water heater shows that the two-phase closed thermosyphon gave better efficiency, followed by the single-phase thermosyphon one. These two evacuated tube collectors showed better thermal performance than the three flat plate collectors.

Zambolin and Del Col [5] compared the performance of a flat plate collector and an evacuated tube collector for steady state and for daily operations. A single-glazed flat plate collector and an evacuated tube collector were installed side by side and tested at the same working conditions; the evacuated tube collector was a single-phase thermosyphon type with external compound parabolic concentrator reflectors. It was found that flat plate collector has better steady- state efficiency and daily efficiency at low working temperature level. The situation is reversed when the collector temperature is on average much higher than the ambient temperature.

Shariah et al. [6] carried out research on the optimized tilt angle of flat plate collector. A computational model in TRNSYS was applied to study the long-term performance of thermosyphon flat plate system. The systems simulated were located in two cities in northern and southern Jordan respectively. It was found that the optimum tilt angle is in the range of 0-20° larger than the location latitude.

Tang et al. [7] investigated numerically the optimal tilt-angles of all-glass evacuated tube solar collectors. They suggested that for most areas in China with site latitude larger than 30 °, around 10° less than the site latitude is the optimal tilt angle.

In common solar stills which are using for desalination the copper rods inside the evacuated tubes make contact with a water container to let the water boil. In the current study water has poured directly inside the inner evacuated tubes.

THEORY AND PRINCIPLES

The principle of vaporization of water in the system lies on the properties of evacuated tubes. Air is removed from each tube (evacuated) to eliminate heat loss by convection. Inside the glass tube, a flat or curved aluminum or copper fin is usually attached to a metal pipe [8]. However, in the current study, by removing the aluminum/copper fin and pouring water directly in the evacuated tubes we let the heat transfer directly from the inner wall of the evacuated tube to the water, and from the solar radiation. Water is heated until it reaches to its saturation temperature, then it starts boiling inside the tubes and vaporizes, vaporized water (superheated vapor) enters the condensation box to lose heat to its cold walls which are at the ambient temperature and condenses, condensed water which is fresh water is produced and will be collected through the bottom of the condenser.

EXPERIMENTAL SETUP

The system consists of two evacuated tubes which made an angle of 60 degree with the horizon. These two tubes are attached to a metal box where the condensation happens. The metal box is made of galvanized metal with the thickness of 2 millimeters. To enhance the heat transfer, top and sides of this metal box are covered by 20 heat sinks, 5 on each side. A sunshade prevents heating the system by sun radiation while the airflow through heat sinks enhances the condensation. Figure 1 shows the experimental setup.

Figure 1 Experimental setup

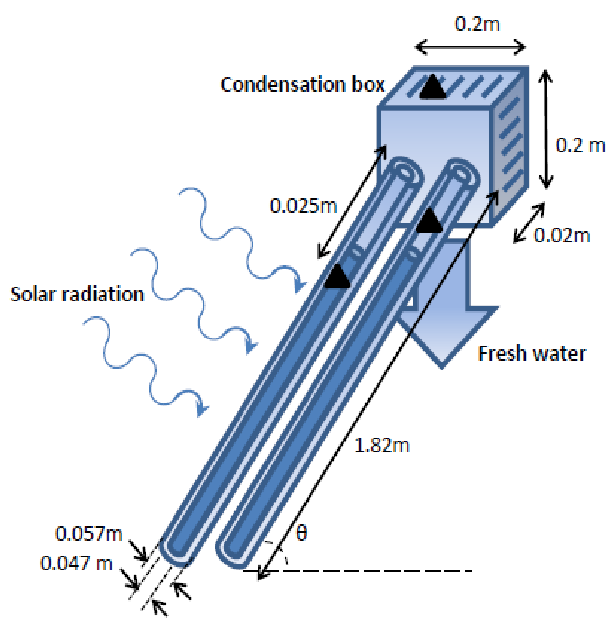

Figure 2 Schematic of the setup. Location of the thermocouples are shown by the symbol ▲

Figure 2 shows the system and location of thermocouples schematically. In this figure dimensions of the condensation box, $\boldsymbol{x_m} = \boldsymbol{y_m} = \boldsymbol{z_m} = 20\ cm$, length of the tubes $\boldsymbol{l_t}$ =182 cm, and the angle of the tubes with the horizon, $\theta = 60^0$ are given. Tube inner radius, $\boldsymbol{r_i}$, is 47 mm and outer radius , $\boldsymbol{r_o}$, is 57 mm. Water has poured inside the tubes manually at the beginning of each day. To clarify the arrangement of heat sinks on the condensation box, it is presented in figure 3. One side of condensation box and heat sinks can be seen in this picture. Except the front side which the evacuated tubes are connected and the bottom of the box other four sides have same arrangement of heat sinks.

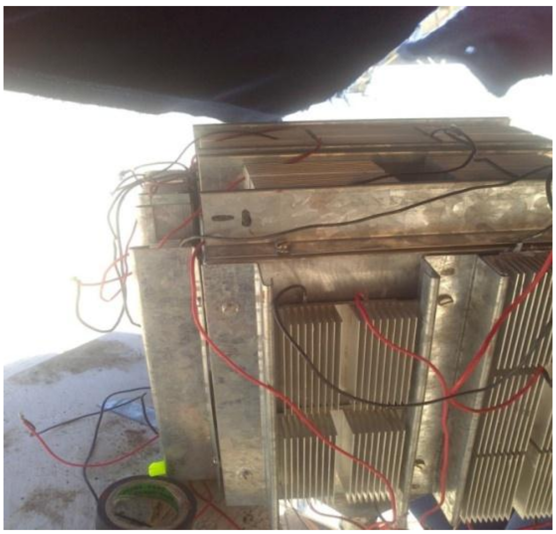

Figure 3 Arrangement of heat sinks on condensation box

RESULTS AND DISCUSSIONS

To investigate the effect of water head in the evacuated tubes the system has tested for two days in row. In the first day the tubes are completely full of water which means 2.5 liters of water in each tube. On the other day tubes were containing 1.5 liter of water. Another test is performed in which the sunshade is removed to investigate the effect of shading.

Water production on each day is measured every half an hour from 9 am to 5 pm and three thermocouples are installed to detect temperature at different locations. One thermocouple is installed about 5 cm of the open head of evacuated tube adjacent to the inner wall to indicate the inner wall temperature of tubes. The other thermocouple is hanging inside one of the evacuated tubes and is showing the temperature of water inside tubes. The last thermocouple is adjacent to the outer side of the metal box and is exploring the metal box wall temperature. Temperatures are measured every half an hour. Solar radiation also is measured during the days of test.

Figures 4- 9 present data taken in September 21st, 23rd, and 24th, 2014, respectively. All temperatures are in degrees centigrade (Celsius) and produced water are the amount of water in milliliters produced in every half an hour.

As it can be seen in Figure 4, in which the tubes were full of water the production is way better than Figure 7 where the tubes were half empty.

Although at the latter day (Figure 8 and 9) the production and water temperature and inner wall temperature were higher, the overall production of the first day was better. That is due to some situations of the experiment because in the first day the water poured at 9 o'clock and it takes a while for water temperature to raise enough. However, on the other day water had been in the tubes from the day before and so it was warmer at 9:30 in the morning when the test began. Even with such situation yet the production of the tubes with 2.5 litters was better.

In all three cases the water temperature rises gradually until it reaches to around 97 degrees and after that it faces not noticeable changes. But the temperature of inner side of the tubes increases constantly except the day of half full tubes. At this day determining the temperature of water was not possible since head of water was below the thermocouple after 11:30.

Total production at the day in which tubes were full was 990 milliliters while on the day with half empty tubes it was about 800 milliliters. It shows that the production decreased about 19 percent when the water head in the tubes has decreased to half. In Figure 5 which shows the day with tubes full of water but without shading the total production is 1000 milliliters which shows not a significant change but it has to be considered that in this day the ambient temperature is lower and solar radiation is noticeably higher than the day with full tubes and sunshade. The production expected to be higher due to cooler ambient and higher radiation which is not the case and it may caused by absence of sun shade.

The water production rate of all three cases rises and reaches its peak at about 12 o'clock and then start to drop constantly. It is the same about the metal box wall temperature and it happens because reduction in water production rate is resulted from reduction in vapor entering rate to the metal box and so the reduction of wall temperature.

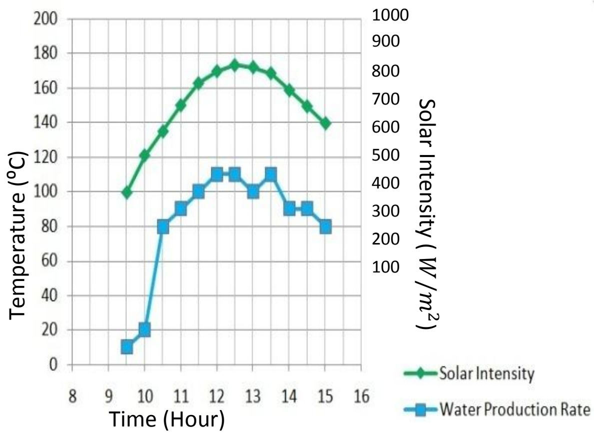

Figure 4 Full tubes with shading; production rate

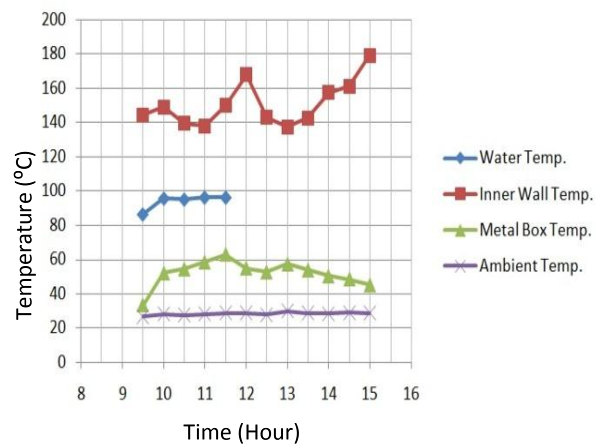

Figure 7 Half tubes with shading; temperatures

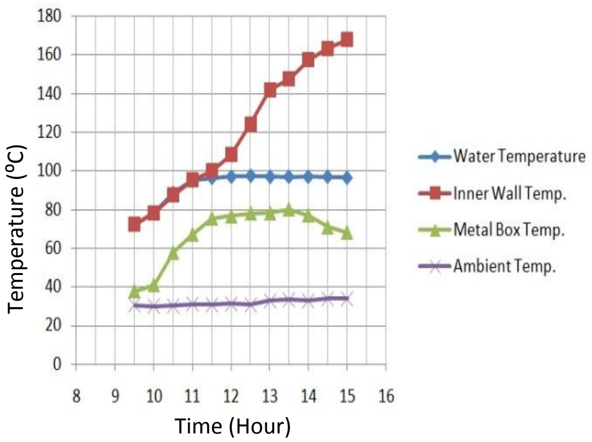

Figure 5 Full tubes with shading; temperatures

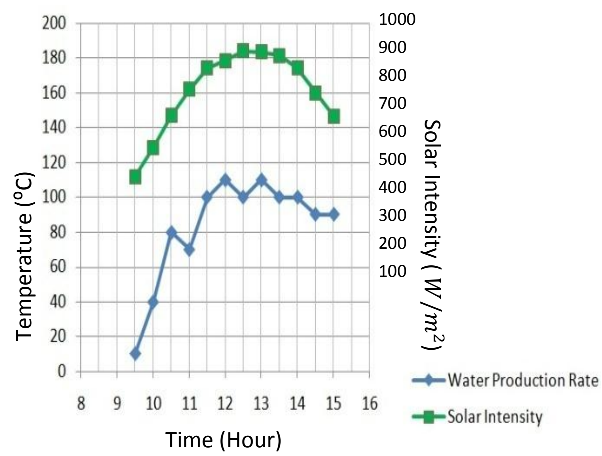

Figure 8 Full tubes without shading; production rate

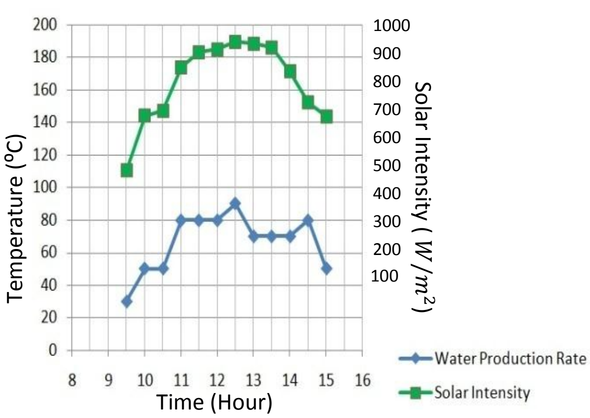

Figure 6 Half tubes with shading; production rate

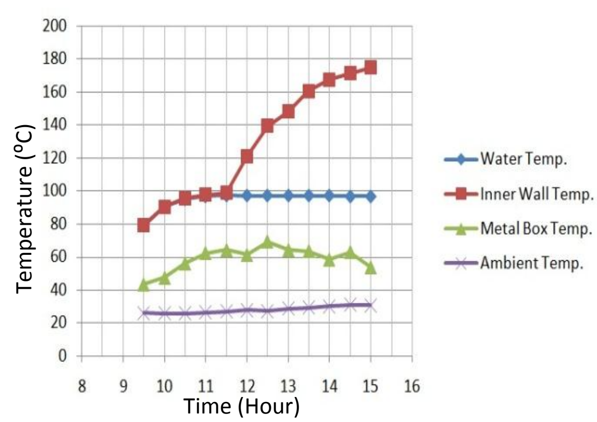

Figure 9 Full tubes without shading; temperatures

CONCLUSION

Data from three days experiments show that evacuated tubes have better water production when they are full of water in comparison with the case in which they are half empty. At the beginning of the day the production of half empty tubes were better but the overall production of them is about 19 percent lower than full pipes. The temperature in the inner wall of half empty evacuated tubes were a bit higher but it seems that at the last hours of the test when the water head in the tubes drops dramatically the vaporization rate decreases. It is also the case in the day with full tubes but the production reduction at this situation is slighter.

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