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Solar Desalination by Indirect Heating

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Abstract
A solar unit to produce desalinated water and hot water from saline feed water was designed and tested. The unit consists of a solar collector (5 evacuated tubes) that heats a thermal fluid circulating in a closed loop due to thermo siphoning effect. The hot thermal fluid passes through a water bath giving its thermal energy and causes some of the water in the bath to evaporate. The vapor generated condenses on an inclined glass plate and withdrawn as desalinated water. The effect of the ambient temperature, the solar irradiation, and the other weather conditions on the productivity of the unit (liters of desalinated water produced/hr) was investigated. The results showed that the unit was capable of producing 0.15 L of desalinated water/hr. The experiments showed that the unit productivity was improved by cooling the glass cover on which the water vapor condenses. Two types of thermal fluids were used namely; jojoba oil and water. Water as a thermal fluid gave better productivity. The effect of feed water salinity on the unit productivity was tested by feeding water of salinity ranging between 0.5 g/L (tap water) to 25 g/L. The productivity decreased as the feed water salinity was increased.

Keywords: *Desalination, Solar, Hot Water, Productivity*

1. Introduction

The search for a clean and cheap source of energy to produce potable water from either sea water or brackish water has received lots of attention. Many methods have been proposed to use solar energy to produce potable water. These methods can be classified into three main categories. The first method is the solar still basin which is based on heating a black surface on the bottom of the basin that in turn transfers its energy to still water on top of it. Accordingly the water temperature rises and hence faster evaporation takes place. The vapor condenses on a glass cover placed on top of the basin and then withdrawn as desalinated water. Although this technique is simple and the cost involved is low, the productivity is low. The second technique is based on concentrating the solar energy on the focal line of a parabolic trough. The line is usually a pipe that contains a thermal fluid which heats it up to high temperature. The fluid is pumped to a heat exchanger where it heats water causing vapors to form which are condensed and withdrawn as desalinated water. The productivity of such units is high however the cost is also high. The third technique is the single or multiple effect falling film solar desalination methods. This method is based on allowing a thin water film to flow over an inclined plate acting as a solar collector. The low amount of water on the plate and the movement of water over it results in higher productivity compared to the solar still. Such system is easy to construct however it requires continuous observation to ensure complete wetting of the surface. Abu Arabi et al [1] have designed a solar desalination unit with falling film that was capable of producing 0.6 L/hr of potable water of ionic conductivity of 23 μs. The productivity of such unit was improved by 30% upon cooling the upper glass cover on which condensation takes place. The unit was tested with tap water and saline water of variable salinity up to 20 g/L. The results showed that the productivity of the unit decreases as the salinity of water increases. Moreover they showed that such unit can also produce hot water of temperature up to 60 ^oC. Mousa and Abu Arabi [2] theoretically modeled the above unit and they found a good agreement between the theoretical and the experimental results. Al-Hinai et al [3] studied the performance of a double and a single effect solar still and found that such unit can produce in average 6 kg/m^2-d and 4.5 kg/m^2-d, respectively. Tanaka [4] showed that the productivity of a solar still can be improved up to 12% by changing its inclination in summer and no significant improvement was achieved in winter. Schwarzer et al [5] presented a numerical and experimental work on a solar unit consisting of a solar collector and a desalination tower. The solar collector heats a thermal fluid that moves to a heat exchanger and releases its heat to water. The hot water enters a desalination tower having several stages where the vapor from one stage is used to heat the liquid falling on it from the previous stage. The condensing vapors on each stage are collected as a product. Schwarzer et al [5] showed that up to 25 L/m^2-day can be produced from such system. Aybar et al [6, 7] investigated both experimentally and theoretically the productivity of a falling film unit and showed that nearly 0.2 L/m^2-hr of desalinated water can be produced. They also tested the effect of various collecting materials on the unit productivity and showed that using black fleece can improve the productivity of the unit to ~ 0.4 L/m^2-hr. Abdallah

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et al [8] investigated the effect of various absorbing material on thermal performance of solar stills and showed that using black rocks has resulted in the highest productivity with an improvement of 20% over the regular black painted basin. Valsaraj [9] concentrated the solar energy using floating perforated, coated and folded aluminum sheets over the water surface in a solar still. They showed that such design improved the productivity by 43% compared to regular solar stills. Khaydarov et al [10] used solar powered direct osmosis unit to produce desalinated water from saline one. They showed that such unit can reduce the water salinity from 17 g/L to 50 mg/L. Hongfei et al [11] used three effects falling film indoor unit heated by an electric heater. They claimed to produce about 135 kg/h. Chaouchi et al [12] desalinated brackish water by means of parabolic solar concentrator. They showed that about 0.7 L/hr can be produced from such unit. They also modeled the unit theoretically and found that an average relative error of 43% exists between the experimental and the theoretical results. Zhang [13] studied experimentally water desalination from a horizontal tube falling film evaporator with closed circulation system. They showed that the productivity of such unit can produce nearly 9 L/m^2-day which is 2 – 3 times the regular solar still unit. Abdel-Rehim [14] used a parabolic trough solar collector that heats a thermal fluid which in turns is used to evaporate water. They found that such system is capable of producing about 2.5 L/day.

In this paper solar desalination by indirectly heating the feed water is presented. The effect of ambient conditions, type of the thermal fluid, cooling of the cover glass will be investigated. Such unit has many advantages over other systems due to its low cost, self running and needs no observation and maintenance.

2. Experimental Setup

The unit consists of two main components namely a solar collector and an evaporator. The solar collector consists of 6 or 5 vacuum tubes of length of 1.43 m. The tube has two pipes; the inner one is coated with black material and has a diameter of 1.9 cm. The outer pipe has a diameter of 4.8 cm with vacuum in the annulus space. The evaporator is a rectangular basin (0.6 m x 0.2 m) that has 24 tubes (each has an inner diameter of 4.8 mm and 0.5 m length) in which the hot water generated in the solar collector pass through to heat the water in the basin. The height of the front side of the basin is 0.22 m and gradually increasing at an angle of 22^o. The top side of the basin is covered with glass to condense the vapor generated in the evaporator basin. The level of water in the basin is kept constant via a feed tank of diameter of 0.25 m and height of 0.4 m connected directly to the basin. Hence by keeping the level of water constant in the feed tank the water level in the basin is also kept constant. A schematic diagram of the unit is shown in Fig. 1

The thermal fluid enters the solar collector's tube at the bottom and as it gets heated it rises to the top passing through the tubes in the evaporator releasing its sensible heat to the water in the basin. As the thermal fluid gives off its energy it cools down and becomes denser than the hot part in the collector's tubes. Hence it falls down allowing the hot part to rise to the top (thermo-siphoning).

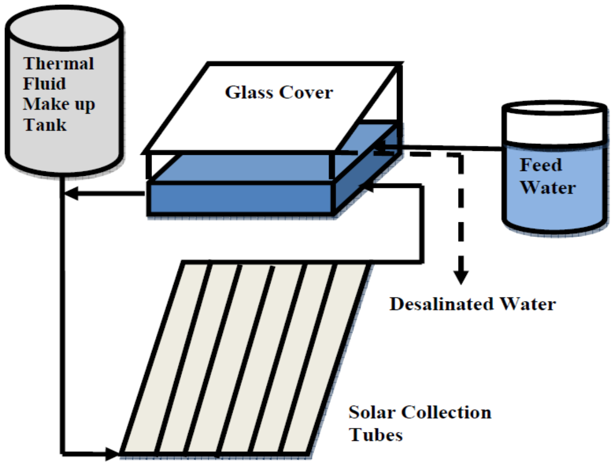

Fig. 1: A schematic diagram of the experimental setup.

Two types of thermal fluids were used; water and jojoba oil. The effect of the feed water salinity on the productivity of the unit was tested by using feed water of salinity equals to 5 g/L, 10 g/L, 20 g/L, 25 g/L and tap water. The experiments were performed under the prevailing weather conditions which allow testing the unit under various ambient temperatures and solar irradiation. It should be mentioned that the effect of cooling the outer glass cover on the unit productivity was also tested by performing experiments where cold water from the tap was poured on the outer glass surface.

3. Results and Discussion

A typical solar irradiation in Irbid-Jordan is depicted in Fig. 2 where it can be seen that the solar intensity rises and reaches its maximum at noon time then drops. The amount of desalinated water collected at various weather conditions using water as a thermal fluid is shown in Fig. 3. The data in the figure shows that about 0.15 L/hr-m^2 is collected. As can be also seen there is a variation in the amount of water collected which can be attributed to the difference in the average solar irradiation and weather conditions (ambient temperature, wind speed and presence or absence of clouds in the sky).

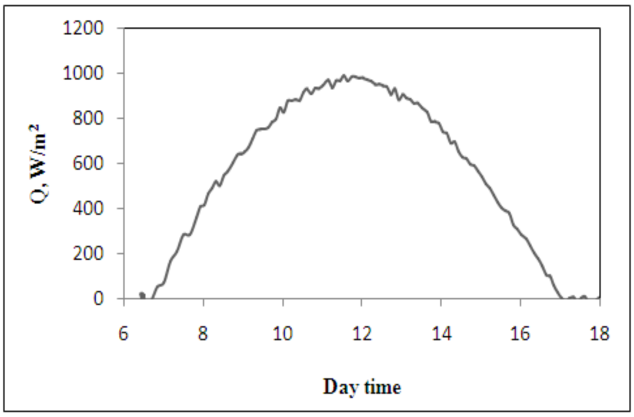

Fig. 2: Typical solar irradiation intensity versus day time in Irbid-Jordan.

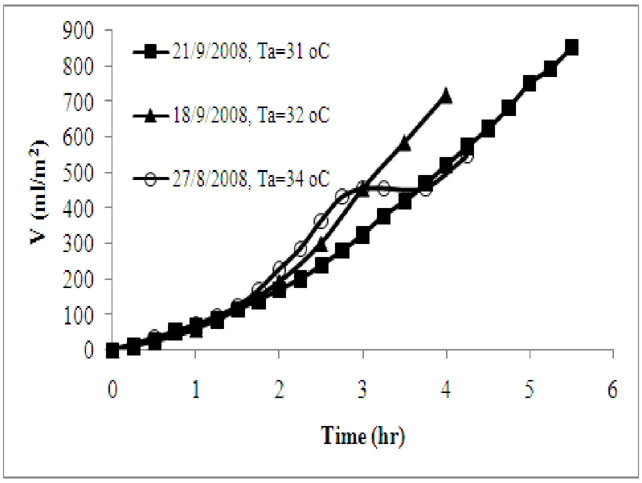

Fig. 3: Cumulative volume of desalinated water at different time of the year using water as a thermal fluid.

The amount of water collected using jojoba oil as a thermal fluid is depicted in Fig.4. It can be seen that as the ambient temperature increases the unit productivity increases. A comparison between the two thermal fluids is portrayed in Fig. 5. It can be seen that using water as a thermal fluid gave higher productivity compared to jojoba oil. This is due to lower heat transfer coefficient associated with the oil flowing in the tubes compared to the case where water is used as the thermal fluid [15].

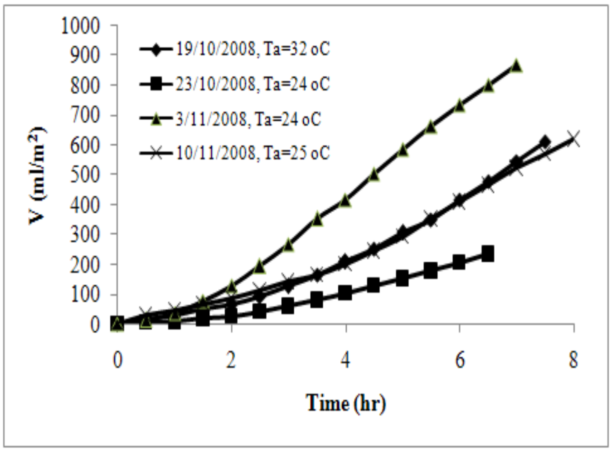

Fig. 4: Cumulative volume of desalinated water at different time of the year using jojoba oil as a thermal fluid.

The effect of cooling the glass cover was investigated by sliding water on the outer surface of the glass cover. The amount of water collected was compared to the case where no cooling was employed. The results are shown in Fig. 6 where it can be seen that the unit productivity was improved by 26%. The reason for this is that cooling the glass cover increases the driving force for condensation. A similar result was obtained by Abu Arabi et al [1] who found about 29% improvement in productivity upon cooling the outer glass cover.

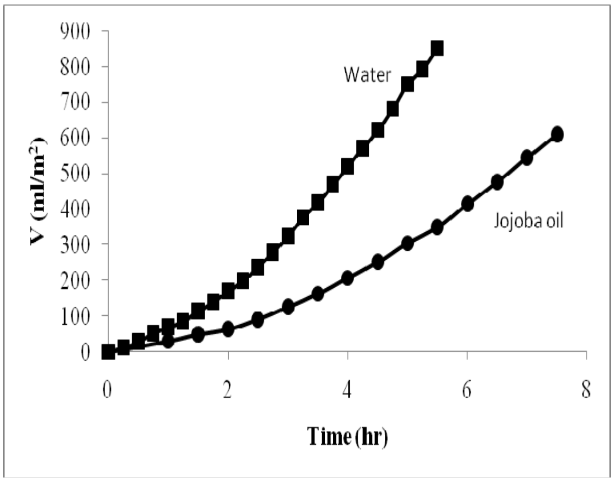

Fig. 5: Comparison between the thermal fluids used.

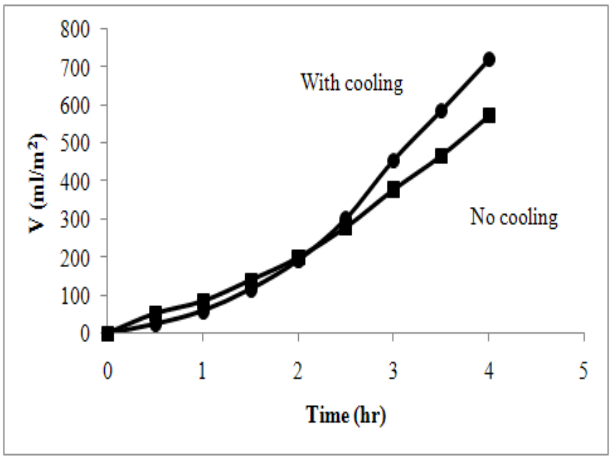

Fig. 6: Effect of cooling the glass cover on the productivity of the unit.

The effect of feed water salinity on the productivity was investigated by using feed water of salinity 5 g/L, 20 g/L and 25 g/L. The results were compared to that obtained when tap water was used as a feed to the unit. The results are portrayed in Fig. 7. It can be seen that as the feed salinity increases the productivity drops slightly. It should be mentioned that similar result was found by Abu Arabi et al [1].

As pointed out earlier such unit is capable of producing hot water as well. Figure 8 shows the temperature of the thermal fluid as it enters and leaves the evaporator (water basin). For example at 12 noon the thermal fluid (water) enters at 54 °C and leaves at 46 °C. This means that the temperature in the basin is somewhat less than 46 °C. The temperature of such water is suitable and can be withdrawn for domestic use. It should be noted that this will affect the unit productivity but this problem can be solved by using more solar collecting tubes.

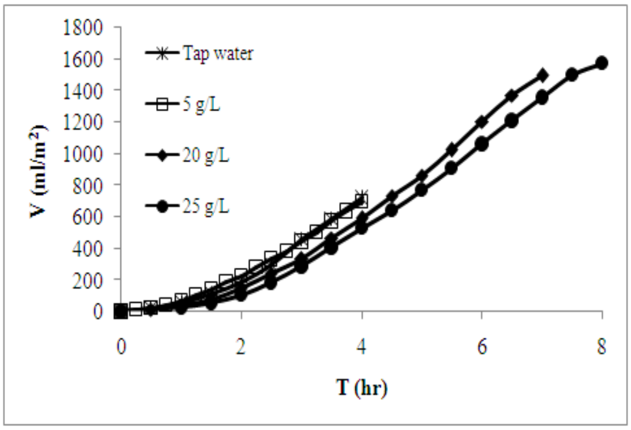

Fig. 7: The effect of feed water salinity on the productivity of the unit.

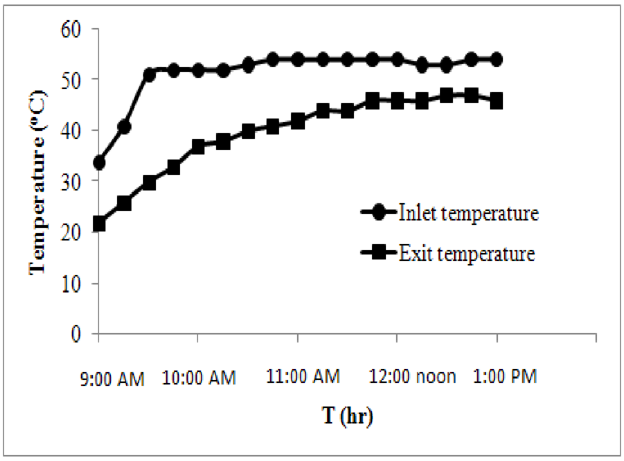

Fig. 8: The inlet and the exit thermal fluid (water) temperatures in the evaporator.

4. Conclusions

A unit to produce both hot water and desalinated water was design and tested. The main advantage of the design is that such unit can run by itself without any observation. No control is needed and hence this makes the cost of producing such unit is cheap and attainable by an average Jordanian family. Testing the unit shows that the unit productivity can be increased by about 26% upon cooling the glass cover. The unit productivity is also higher when the ambient temperature and the solar irradiation is higher. However, salinity of the feed water adversely affects the productivity of the unit.

Acknowledgments

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