

SOLAR DISTILLATION OF WATER USING INCLINED TUBES AS RECEIVER AND CONDENSER

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Abstract

Recently, the consumption of fresh water has been rising in the world. Although approximately 71% the Earth's surface is covered by water, only a very limited amount is drinkable. Solar water distillation can be used to purify water by using solar energy. In this study, a solar still was designed whereby black metal tubes, much like those used in a solar water heater, are employed in place of transparent glass in traditional distillation devices. Three models and a conventional solar still were fabricated and have been studied experimentally. The temperatures of the water inlet (T_{wi}) and water outlet of the collector (T_{wo}), the water in the basin (T_{ws}), the condenser tubes (T_{cd}), collector tubes (T_{col1} and T_{col2}), and basin (T_b) were measured. It was found that the highest water production is 2.3 L/m² day. The water outlet temperature from the tube system is very high. However, there are heat losses from the system and this leads to a lower water temperature in the basin.

Keywords: Solar still, solar collector, distillation, water production

Introduction

Solar stills are considered as one of the oldest desalination technologies and the earliest study was conducted by Arab alchemists in the 16th century (Tiwari *et al.*, 2003). They are a good solution for the recent problem of scarcity of water without the population utilizing renewable energy resources. However, solar stills have the disadvantages of a high initial cost, low production capacity, and dependence

on available solar radiation. The operation of a solar still is based on the principle of the hydrologic cycle which refers to 2 processes, namely evaporation and condensation. Distillation is always taking place in a closed system. The sun's energy goes through glass to evaporate water in the still and water vapor condenses on the inner surface of the glass.

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In recent years, a lot of passive and active solar stills have been investigated by many researchers. Different designs of passive solar water distillation were reviewed by Durkaieswaran and Murugavel (2015) while active solar stills were summarized by Kumar *et al.* (2015). The production rate of solar stills can be improved by raising the temperature difference between the glass cover (which acts as the condenser) and the water in the basin, which is considered as the driving force of the evaporation/condensation process. This temperature difference could be raised by reducing the condenser temperature and/or increasing the water temperature. In order to increase the water temperature, preheating the feed water by circulating it through the solar collector has been widely adopted. As a result, the integration between a solar still and a performance enhancement of different types of solar collectors, e.g. flat plate collectors (Rai and Tiwari, 1983), a parabolic trough collector (Singh *et al.*, 1996), evacuated tube collector (Singh *et al.*, 2013), and evacuated tube heat pipe collectors (Tanaka and Nakatake, 2004), have been investigated. Additionally, the temperature of the condenser surface can be reduced by using air or water. Tiwari and Bapeshwara Rao (1984) used water cooling of the glass cover of a conventional solar still and the daily yield of the still almost doubled. However, the increase of water flow reduced the distillate output. Arunkumar *et al.* (2013) studied a tubular solar still with flowing water and air over the cover. Its productivity was 2.05 L/m² day without the cooling flow and it increased to 3.05 L/m² day and to 5 L/m² day with the flow of cooling air and water, respectively.

Moreover, reuse of the latent heat of condensation is a solution to enhance the output of solar water distillation; however, few experiments have been conducted to utilize it. In a solar still, most of the heat energy is lost to the ambient air through the top cover. Some research was performed to reuse this heat loss to heat up the water in additional distillate, which is known as multi-stage, multi-basin, or multi-effect distillation. Sodha *et al.* (1980) carried out both an experimental and theoretical

study of a double basin solar still. The result showed that the daily distillate production of such a still is 36% higher than that of a single basin still.

The objective of the present work is to create a new technique for solar water distillation. A system of tubes which are used as the collector and condenser replaces the glass cover in a conventional still. The water vapor is condensed on the surface of the tubes and transfers its latent heat to heat up the water in the tubes in the process. In this way, it is hoped that an energy saving will be achieved resulting in efficient solar distillation.

Materials and Methods

The present experimental work of this study was carried out in the School of Mechanical Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand (latitude 14.9738°N and longitude 102.0837°E).

A cross-sectional view of the schematic diagram of the solar still is shown in Figure 1. The number of condenser tubes is equal to that of the collector tubes. The tubes are made of copper with an 8.5 mm inner diameter. The collector tubes are coated with black paint to increase the solar radiation absorption. The

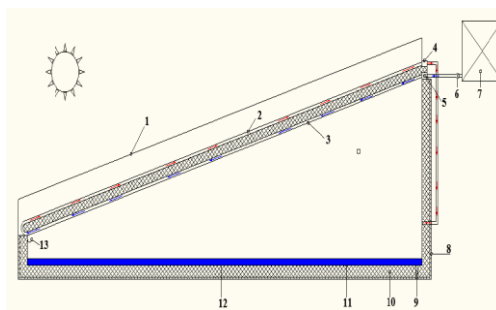


Figure 1. A cross-sectional view of the schematic diagram of solar still Model 1. 1) Glass cover; 2) upper tubes; 3) lower tubes; 4) upper trough; 5) lower trough; 6) valve; 7) water tank; 8) wood cover; 9) drainage hold; 10) insulation; 11) basin liner; 12) brackish water, and 13) water collector

upper and lower tubes connect to upper and lower troughs, respectively. The solar still is supplied with feed water from the upper trough through a connecting pipe. Singh and Tiwari (2004) observed that the optimum glass tilt angle for maximum annual output should be the latitude of the location. Hence, the tilt angle of the tubes was chosen to be equal to the latitude of the location (15°). The basin liner is made of aluminium with a 0.4 mm thickness. It is insulated on the 4 sides and the bottom with 20 mm thick aerofoam to reduce heat loss from the solar still to the atmosphere. The basin liner and insulation are placed inside a wooden box. The condensed water is collected through the distillation trough. Silicon is used to prevent any leakage between the basin box and top cover. The materials' selection and the design specifications of the solar still are shown in Table 1. The parameters measured during the experiment were: the solar radiation, ambient temperature, the lower and upper temperatures, the temperature and flow rate of the fluid working in the tubes, the basin water temperature, the basin liner temperature, and the fresh water yield. The solar radiation was measured with a pyranometer (Kipp and Zonen BV, Delft, The Netherlands).

The experiment of Model 1 was conducted with two different mass flow rate of 3 L/h and 1 L/h on two different days, and the solar radiation and the ambient temperature of these days with respect to time are described in Figure 3. The solar intensity and surrounding air temperature increased and reached a peak

at 12 o'clock, then they reduced gradually in the rest of the experiment time.

Table 1. The materials of the different parts of the solar still

Glass cover	Material: glass Thickness: 6 mm Gap between glass and collector tubes: 25 mm
Condenser and collector tubes	Material: Cooper Inner diameter: 8.5 mm Length: 1000 mm Inclined angle: 15° Gap between condenser and collector tubes: 20 mm
Rectangular trough	Material: Copper Size: 400x30x30 mm
Basin liner	Material: Aluminium Size: 930x200x380 mm Thickness: 4 mm
Insulation	Material: Aerofoam Thickness: 25 mm
Wood cover	Thickness: 10 mm

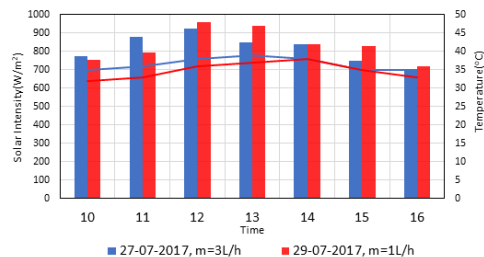


Figure 3. Solar radiation and ambient temperatures

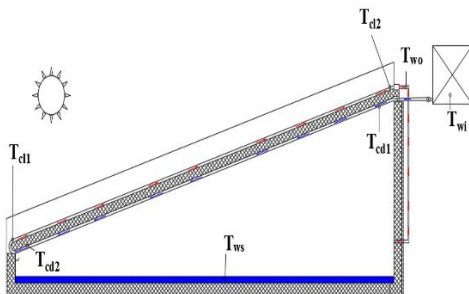


Figure 2. Measurement points in Model 1

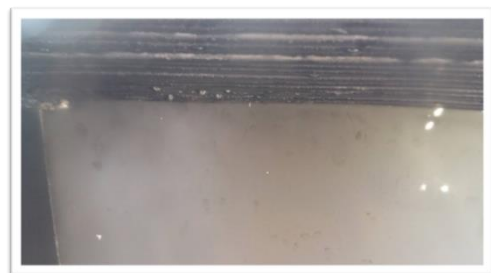


Figure 4. Condensation in solar still

[illegible]

The solar radiation is measured in the range of 630 W/m^2 to 1103 W/m^2 and the ambient temperature is in the range of 32°C to 44°C . The variation of the hourly temperatures is shown in Table 3. The highest temperatures of the water and collector are obtained at 2 pm (99°C and 97°C , respectively). Nonetheless, the temperature of the water in the basin is still low because of the low temperature of the basin. Moreover, the distribution of the water in the system is not significant due to the low

mass flow rate. The productivity of model 2 is $1.5 \text{ L/m}^2\text{day}$.

Model 3

In Model 3, 3 sides of the solar still were changed to glass to enhance the radiation absorption of the basin which is made of copper. Sketch and pictorial view of Model 3 are illustrated in Figure 7 and Figure 8, respectively. The mass flow rate of the water was controlled by a valve before flowing into the still. The air temperature and relative humidity in the solar still were measured. A conventional solar still was fabricated with the same size and materials of the basin wall in order to compare with Model 3. The climatic conditions in Model 3 are given in Table 4. The collector and the water out collector got the highest temperature at 2 pm at 88.67°C and 86.4°C respectively, as shown in Figure 9. Figure 10 shows the variation in the temperature of the water, humid air, and

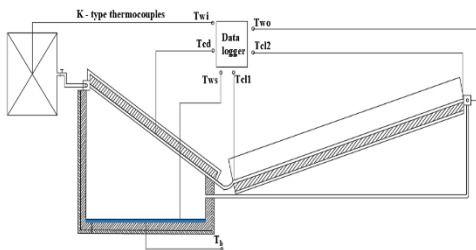


Figure 5. A cross-sectional view of the schematic diagram of Model 2

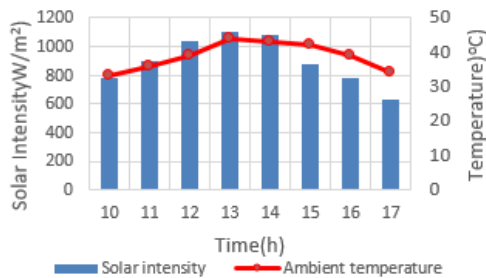


Figure 6. Solar radiation and ambient temperatures on 09/05/2018

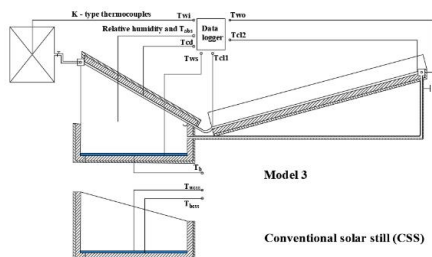


Figure 7. Sketch of Model 3 and conventional solar still



Figure 8. Photographic view of Model 3

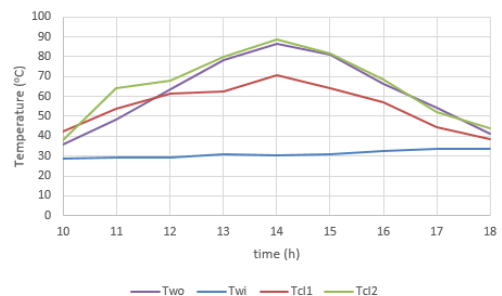


Figure 9. The temperatures of the inlet and outlet water and of the collector at 2 points of Model 3

relative humidity inside the still. The relative humidity was remarkably below 55% before 3 pm and increased significantly during the rest of the experimental time due to the temperature increase of the air and the evaporation rate decrease. It is clear that the relative humidity of the humid air is definitely not saturated in the daytime. Figure 11 gives information about the temperature variations of the water of Model 3 and the conventional solar still. The temperatures of the water and glass cover of the conventional solar still are in the range of 36.93–73.5°C and 36–51°C, respectively. Compared with the conventional solar still, the temperature of the water after flowing out of the collector tubes in Model 3 is higher but it is opposite to the water temperature in the basin walls. Moreover, from Figures 10 and 11, the temperatures of the condenser tubes (in the range of 34.2 to 43.4°C) and glass (from 36 to 45°C) in Model 3 are lower than that of the glass cover in the conventional solar still (in the range of 36 to 51°C). The yield of the conventional solar still was 2.1 L/m² day while the accumulated productivity of Model 3 was 2.3 L/m² day.

Table 4. Solar radiation and ambient temperatures in the experiment with Model 3

Time	Solar Intensity (W/m ²)	T _a (°C)
10	677	34
11	836	36
12	965	37
13	956	38
14	899	38
15	730	39
16	476	38
17	71	37
18	28	35

Conclusions

In this paper, the design, implementation, and performance evaluation of 3 models under the climatic conditions of Nakhon Ratchasima, Thailand are presented. The effect of the mass flow rate was studied in Model 1 and it was

found that the temperature of the water and the productivity were higher with the reduction of the mass flow rate. Comparing the 3 models and the conventional solar still, Model 3 has the highest yield (approximately 2.3 L/m² day). There is a significant increase in the water temperature after flowing through the system of tubes, especially in Models 2 and 3. However, the temperature of the water in the stills is not as high as expected which causes the low productivity of these stills.

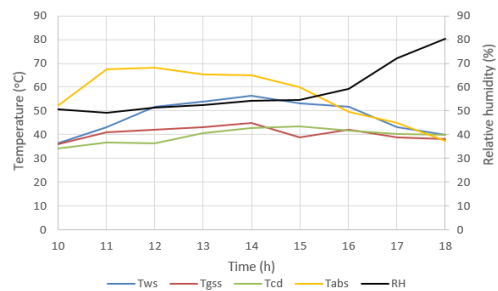


Figure 10. The temperatures of the water in the Model 3 solar still (T_{ws}), condenser tubes (T_{con}), glass (T_{gss}), humid air (T_{abs}), and relative humidity (RH)

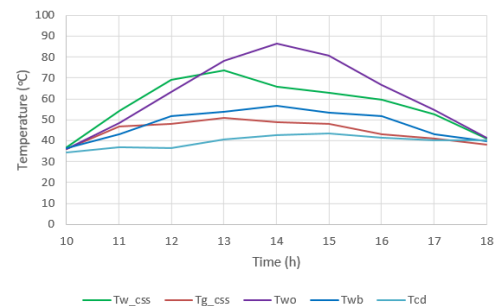


Figure 11. The hourly temperature variations of the water in Model 3 and the conventional solar still

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