Development of a Solar Water Distiller with a Receiver and Condenser

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Abstract

The solar water distillation distills brackish water, which can mitigate the demand of pure water for the human beings. This study proposes a solar water distiller with a condenser and collector made from a tube bank. The receiver and condenser are connected by the rubber tubes. The brackish water from a tank flows along with condenser. The water temperature is relatively low, so this tube bank acts as a condenser for the water vapor that evaporates from a water basin of the distiller. It is believed that this can increase the condensation rate of the system. After passing through the condenser, the brackish water flows up along the receiver and its temperature is increased. Then the water continuously flows to the basin. According to the experimental results, the water’s temperature in the proposed system is higher than that of the conventional distiller. This leads to the higher productivity of the proposed system (approximately 3.3 L/m² day). In addition, it was found that the temperature of the condenser of the proposed system was lower than that of the top cover of the conventional system.

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

1. Introduction

Water is an important substance on our planet, which is vital for a sustainable future. Although water covers approximately three-quarters of the Earth, 0.014 percentage of water is used directly for the human being and other demands [1]. Global climate change and population explosion cause the depletion and deterioration of potable water and create water-stressed areas. When water scarcity become the challenges in the worlds, seawater plays an important role as an alternative source for drinking water as well. In order to use this water, it has to be desalinated. There are various advanced techniques for seawater distillation, which among them, solar still is a promising and environmentally friendly device. The performance of a solar distillation of water based on the principle of the hydrologic cycle, which refer to two processes namely evaporation and condensation. Distillation is always taking place in a closed system. The sun’s energy goes through the glass to evaporate brackish water to vapor. Then water vapor condenses on the surface of condenser cover. Phadatare et al. [2] study the impact of water level on the performance of a single slope plastic solar still. Experimental results showed that the maximum yield is 2.1 L/m²/day at a water level of 2 cm. Meanwhile, double slope solar still was
performed by Kulandaivel and Karuppaih [3]. The experiment indicated that the average yield of the still was 2.1 L/m²/day however, Improving the productivity of solar still has remained a challenge to scientists. Vishwanath Kumar et al. [4] summarized various types of passive and active solar still.

The improvement of the temperature difference between water and the glass cover (which acts as the condenser) enhance the solar still’s productivity. This temperature difference could be raised by the increase of feed water and/or the decrease of condenser’s temperature. The former can be done by heating the feed water through the solar collector. As a result, solar still coupled with different solar receivers, e.g. evacuated tube collector, heat pipe collectors, parabolic trough collector and flat plate solar collector, have been investigated and reviewed [5-9]. The latter can be achieved by using air or water to cool condenser surface. Tiwari et al. [10] use water to reduce the condenser temperature of passive solar still and the yield of solar still is almost double. However, increasing water flow rate reduced the productivity of solar still. Arunkumar et al. [11] used water and air to improve the performance of tubular solar still. The distillate production of tubular solar still was 2.05 l/day without the cooling flow and it was improved to 3.05 l/day and to 5 l/day with the flow of cooling air and water respectively.

Furthermore, reuse of latent heat of vaporization is one of the interesting methods to enhance the efficiency of solar water distillation, however, few experiments have conducted to utilize it. In the solar still, most of the heat energy is lost to ambient through the top cover. Some authors were performed to reuse this heat loss to heat the water in the additional distillate, which known as a multi-stage or multi-basin or multi-effect distillation. Both experiment and theoretical study of a double basin of solar still was carried out by Sodha et al. [12]. The result showed that the daily yield of a conventional solar still is 36 per cent lower than that of such a solar stiller.

The present work is to create a new technique for solar water distillation. A tubes system, which is used as collector and condenser, replace glass cover in conventional still. The water vapour is transformed into fresh water on the surface of tubes and heats up the water in the tube transfer its latent heat in the process. In this way, it is hoped that an energy-saving will be achieved resulting in an efficient solar distillation.

2. System design and experimental performance

2.1. Solar still description

![Figure 1](image)

*Figure 1*. A cross-sectional view of a schematic diagram of solar still model. 1 - Glass cover of a solar still; 2 - water tank; 3 - valve of the water tank; 4 - condenser trough; 5 - condenser tubes; 6 - receiver tubes; 7 - glass cover of receiver tubes; 8 - receiver trough; 9 - valve; 10 - connecting tube; 11 - Drainage hold; 12 -Basin liner; 13- foam insulator; 14-wood cover ; 15- freshwater collector.
The design of solar still is described in Fig. 1. The number of condenser tubes equal to that of collector tubes (40 tubes). The tubes are made of copper of 8.5 mm inner diameter. The collector tubes are painted black. The receiver and condenser tubes connect to rectangular troughs respectively. Singh and Tiwari [13] observed that in order to maximize the annual productivity of solar still, the angle of glass should be the latitude of the experimental location. Hence, the tilt angle of the collector tubes and glass cover was chosen to equals the latitude of the location (15°) while the condenser tubes incline 45°. The basin liner is made of stainless steel, 0.4 mm thickness. It was insulated through the four sides and the bottom by aero foam, 20 mm thickness. The basin liner and insulation are fabricated inside the wooden box. The silicon is used to prevent any leakage between the wooden box and top cover. The materials selection and design specification of the solar still is shown in Table 1.

| Glass cover                  | Material: glass                                      | Thickness: 5 mm |
|-----------------------------|------------------------------------------------------|-----------------|
| Condenser and receiver tubes| Material: Copper                                      | Inner diameter: 8.5 mm |
|                             |                                                      | Length of receiver tubes: 1000 mm |
|                             |                                                      | Length of condenser tubes: 450 mm |
| Rectangular trough of receiver tubes | Material: Copper                                      | Size: 400x30x30 mm |
| Rectangular trough of condenser tubes | Material: acrylic                                     | Size: 400x30x30 mm |
| Basin liner                 | Material: stainless steel                            | Size: 1000x200x380 mm |
|                             |                                                      | Thickness: 4 mm |
| Insulation                  | Material: Aero foam                                  | Thickness: 25 mm |
| Wood cover                  | Thickness: 10 mm                                     |                 |

**Figure 2.** Pictorial view of solar water distiller
2.2. Operation principle
The experimental work of this study was conducted on the campus of Suranaree University of Technology, Nakhon Ratchasima, Thailand (Latitude 14.9738°N and longitude 102.0837°E).

The brackish water was supplied from a water tank and flow through condenser and collector tubes respectively. After preheating in receiver tubes, feed water that is controlled the mass flow rate by a valve flow to the solar still through the connecting pipe. The mass flow rate of water flowing to solar still is 1 L/h and the water level is kept constant with 1 cm. Water continuously is heated by solar energy in solar still to evaporate and water vapour condense on the surface of glass and condenser tubes. The condensed water is collected through the distillation trough. During the experiment, the parameters were measured and recorded by data logger: ambient temperature (T_a), the collector temperature (T_{cl1} and T_{cl2}), condenser tubes temperature (T_{cd}), the temperature of inlet water (T_{wi} is measured in the water tank), the temperature of water out collector (T_{wo}), basin water temperature (T_{ws}), basin liner temperature (T_b), humid air temperature (T_{abs}) and relative humidity (RH). A K-type digital thermometer measures the glass’s temperature. The solar radiation was measured and recorded by a Kipp and Zonen pyranometer. Pictorial view of present work is illustrated in figure 2. All measurement points are illustrated in Figure 3.

![Figure 3](image-url)

**Figure 3.** Measurement points of solar still

3. Result and discussion
Figure 4 depicts the solar radiation with respect to time on an experimental day (21/06/2019). It is observed that solar irradiation increased to the highest value at 12.30 o’clock (approximately 700 W/m²) and decreased after that gradually. During the test, it was cloudy. This was the reason for the fluctuation appeared in the figure.
The temperature of ambient air, basin water, glass and condenser tubes according to time for solar still are described in figure 5. The graph presented that the temperature of basin water reaches a peak at 67°C at 13 o’clock, while the temperature of the glass cover and condenser tubes is in the range of 35–54°C and 34 – 48.1°C, respectively. Additionally, the temperature of the condenser tubes is lower than that of the glass cover. This is because of the cooling effect of the water flowing in the tubes. The different temperature between water in basin and glass cover range from 1°C to 14°C, while with condenser tubes range from 2°C to 18.9°C. The temperature of the other parts of the present model is shown in table 2. There is a significant rise in water temperature after flowing through collectors. The collector and the water out collector got the highest temperature at 13 o’clock at 78.97°C and 76.1°C. Relative humidity remarkably is very high during the experimental time (from 86.75 to 92.4%).
Table 2. The temperature variation in the different parts of solar still

| Time | $T_a$ | $T_{wi}$ | $T_{cl1}$ | $T_{cl2}$ | $T_{wo}$ | $T_{abs}$ | RH    |
|------|------|--------|--------|--------|--------|--------|------|
| 9    | 32   | 28     | 51     | 55     | 38.42  | 43.2   | 86.175|
| 10   | 33.06| 28.85  | 65.67  | 62.9   | 47.39  | 47.457 | 89.92 |
| 11   | 33.02| 29.1   | 62.83  | 67.34  | 63.66  | 49.14  | 92.375|
| 12   | 35.76| 29.39  | 63.52  | 70.17  | 66.34  | 52.848 | 92.855|
| 13   | 34.88| 30.95  | 62.82  | 78.97  | 76.1   | 63.02  | 91.5  |
| 14   | 39.82| 30.36  | 60.68  | 70.84  | 68.21  | 51.57  | 91.535|
| 15   | 40.28| 31.17  | 69.16  | 74.16  | 69.05  | 51.138 | 89.535|
| 16   | 40.75| 32.35  | 67.2   | 71.37  | 66.71  | 49.536 | 86.755|
| 17   | 37.72| 33.49  | 54.5   | 63.25  | 61.17  | 44.208 | 88.595|
| 18   | 36   | 33.78  | 38.69  | 44.67  | 41.7   | 40.761 | 90.175|
| 19   | 33   | 32.01  | 33.33  | 37.39  | 37     | 37.296 | 91.5  |

Figure 6 shows the hourly freshwater productivity achieved from glass cover, condenser tubes and rectangular trough of condenser tubes. The distillate water increases to maximum values at 13 o’clock because the water evaporation rate and condensation rate are increased. The hourly accumulated yield peaked at 1 pm at 0.61 L/m² h. According to Figure 6, the freshwater gets from glass cover is higher than that of the others, because of its larger area. Figure 7 describes the accumulated productivity of solar still. The accumulated distillate freshwater is up to almost 3.3 L/m² day.

Figure 6. Variation of hourly productivity for solar still collected from glass cover, condenser tubes and rectangular trough
4. Conclusions
This paper introduces a new model of the basin type solar still and improve its yield by using condenser and receiver tubes. The experiment was conducted with a mass flow rate of water 1 liter per hour and a constant water level 1 cm. The results of the experiment have underlined the following conclusion:
- The daily yield of the proposed solar still is about 3.3 L/m² day under cloudy condition.
- The temperature difference between water in basin and glass cover, water in a basin and condenser tubes ranged from 1°C to 14°C and from 2°C to 18.9°C respectively.
- The tube system is good for preheating feed water. After flowing through collector tubes, the temperature of the water was 76.1°C at 13 o’clock
- The performance of the studied system was improved compared with conventional solar still.

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Reference
[1] Kabeel A E 2009 Energy 34 10
[2] Phadatare M K Verma S K 2007 Desalination 217 1–3
[3] Kulandaivel M K Karuppaiah S 2014 Therm. Sci. 18(Suppl. 2) S429–S438
[4] Kumar P V Kumar A Prakash O Kaviti A K 2015 Renew. Sust. Energ. Rev. 51(C) 153–181
[5] Rai S N Tiwari G N 1983 Energ. Convers. Manag. 23 3
[6] Singh S K Bhatnagar V P Tiwari G N 1996 Energ. Convers. Manag. 37 2
[7] Singh R V Kumar S Hasan M M Khan M E Tiwari G N 2013 Desalination 318 25–33
[8] Tanaka H Nakatake Y 2004 Desalination 160 2
[9] Kumar P V Kumar A Prakash O Kaviti A K 2015 Renew. Sust. Energ. Rev. 51 1038–1054
[10] Tiwari G N Bapeshwara Rao V S V 1984 Desalination 49(3) 231-241
[11] Arunkumar T Jayaprakash R Amimul A Denkenberger D Okundamiya M S 2013 Appl. Energ 103 109–115
[12] Sodha M S Nayak J K Tiwari G N Kumar A 1980 Energ. Convers. Manag. 20 1
[13] Singh H N Tiwari G N 2004 Desalination 168 145–150