Chapter 3
Single Slope Solar Water Still with Enhanced Solar Heating System

Abdullah M. Al-Shabibi and M. Tahat

Abstract This paper experimentally investigates the thermal performance of a conventional solar water still with an enhanced solar heating system in Oman. A number of variables have been considered, including the water depth inside the still and the saline water temperature inlet to the solar still from the preheater solar collector system. A single slope, single effect conventional solar still with a solar preheating unit was constructed and experimentally tested under different Omani weather conditions. The still had been modified to include a preheating solar energy system so that saline water would be preheated before entering the solar still and this preheating would enhance hourly or daily yield of pure water. Different quantities of water in the solar still basin were tested to find the effect of water quantity on the hourly yield and also to assess the thermal efficiency of the still.

It was found that 1 cm depth gives the best performance in terms of fresh water yield and thermal efficiency. The addition of the solar water preheater to the system significantly increases the inlet basin saline water temperature to almost saturated temperature. The saline water in the basin needed only a small amount of heat to be vaporized, hence increasing the production of fresh water and enhancing the solar still's thermal efficiency.

Keywords Single slope solar water still • Solar collector • Solar desalination • Solar energy • Thermal performance

3.1 Introduction

The main source of fresh water in Oman is the underground water supply which is limited and cannot meet the increasing demands on fresh water. Oman's population over the last four decades has almost trebled and the availability of freshwater is

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becoming critical. Furthermore, there is increased demand for water from the expansion of the industrial sector in Oman. Water desalination represents a very attractive alternative to produce enough fresh water to maintain sufficient supply and Oman has a very long coast line of about 1700 km.

Oman is an oil-producing country but the oil is expected to run out in the near future. Furthermore, water desalination using fossil fuel is known to be costly and harmful to the environment. The demand for, as well as the unit cost of, conventional energy is increasing every year, so alternative sources of energy need to be utilized. Solar energy is a renewable source of energy which can be utilized effectively in many applications in Oman such as water heating, cooking and solar desalination.

Oman is located in the southeastern quarter of the Arabian Peninsula and according to official estimates, covers a total land area of approximately 300,000 km^2. The land area is composed of varying topographic features where valleys and desert account for 82 % of the land mass, mountain ranges, 15 % and the coastal plain, 3 %.

The climate of the Sultanate of Oman is dry and tropical and is characterized by extreme heat in the summer around June and by coolness in the winter around January (Fig. 3.1a). The Sultanate receives a high degree of solar radiation thought the year. It is therefore advisable for the country to use solar energy which is renewable and readily available. Oman has on average 9.49 h of sunshine per day with a standard deviation of 1.78 h. The average number of sunshine hours ranges from 7.88 h in Salalah to 10.24 h in Buraimi. The solar radiation averaged 18.71 MJ/m^2/day with a standard deviation of 4 MJ/m^2/day for Oman over the period. Marmoul has the highest average solar radiation of 21.86 MJ/m^2/day while Sur and Salalah have the lowest average of 15.92 MJ/m^2/day and 16.22 MJ/m2/day respectively. The greatest amount of radiation occurs in April, May and June with the highest level of radiation occurring in May (Fig. 3.1b). The May average is 23.11 MJ/m^2/day. The least amount of monthly radiation is in December and January (Seeb Meteorological 2006).

A single slope water still consists of a thermally-insulated box with a glass cover. Solar energy penetrates the glass and causes a greenhouse effect inside the box. The water inside the box heats up and evaporates leaving behind any impurities such as the salt. The water vapor then condenses when it is in contact with the inside of the glass cover. The pure water condensate can then be collected. The single slope still was studied both theoretically and experimentally by a number of researchers. Nafey et al. (2000) investigated the effect of solar radiation, wind speed, brine depth and glass tilting angle on still productivity. It was found that solar radiation is the greatest affecting parameter on condensate productivity. Productivity decreases with the increase of the wind speed due to the decrease in the fractional energy of evaporation. Furthermore, when the brine depth was increased, the productivity decreased. Moreover, it was found that in summer the tilt angle of the glass cover should be maintained at as acute an angle as possible because the horizontal plane receives more radiation than the inclined plane does, while in winter the productivity increases when the inclination is increased. The

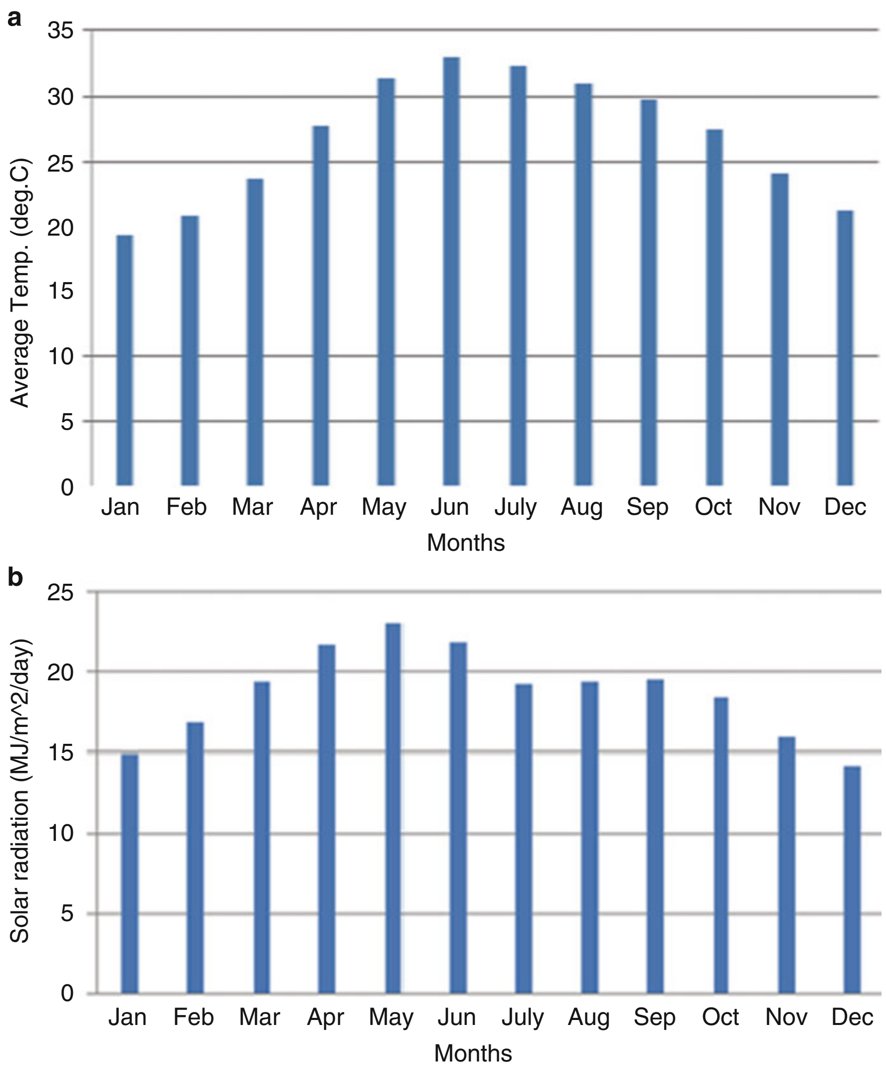

Fig. 3.1 (**a**) Average temperature in Oman during 2006 (Seeb Meteorological Center). (**b**) Average solar radiation in Oman during 2006 (Seeb Meteorological Center)

solar still was tested in different climatic conditions in many places around the world. Singh and Tiwari (2004) studied the monthly performance of passive and active solar stills for different Indian climatic conditions. Medugu and Ndatuwong (2009) designed and tested a solar still under the actual environmental condition of Mubi, Nigeria. They developed a theoretical analysis of heat and mass transfer mechanisms inside the still. They did experimental and theoretical investigations on the distillation performance of the solar still and found that the instantaneous efficiency increases with the increase of solar radiation and the feed water temperature.

Radwan et al. (2009) conducted a study on the single slope solar still for sea water distillation. The investigation was carried out under the open environmental conditions of Egypt on a single slope still inclined at 20 %. The investigation addressed the following parameters: still productivity, distilled water salinity and still performance in term of the still efficiency and the coefficient of performance. They found that still productivity and efficiency increases when solar radiation increases. The highest productivity was 0.226 L/m^2 obtained during the month of July. Also, they found that still performance increases gradually from sunrise until it reaches the maximum value at noon and an hour later and then decreases until it reaches the minimum value at the time of sunrise.

Arjunan et al. (2009) conducted an experimental study on a solar still which had a sponge liner. Two types of measurements were performed for the same climatic conditions: one with the sponge sheet placed on the inner wall surfaces (the back and the side wall) and one without the sponge sheet. It was found that the productivity of the solar still was 15 % higher than the conventional still. They also found that decreasing the water depth increases the productivity of the still.

Afrand et al. (2010) carried out a theoretical study of solar distillation in a single basin under the open environmental condition of Chabahar, Iran. In this research, they investigated still productivity, distilled water salinity and still performance in terms of still efficiency. They found that the maximum efficiency of the solar still was at noon due to the high radiation at that time.

Another study about a single solar still was conducted in India by Prasad et al. (2011). The still was modified with graphite powder to maximize absorptivity. In this study, the effects of four parameters were investigated; the amounts of silicate, acid and graphite powder as well as water depth. The maximum productivity of the still was 1.6 L/m^2. It was found that the productivity of the solar still decreases as the amount of water is increased. When the amount of sodium silicate is increased, the productivity increases, but when more than 150 g was added, the productivity decreased. The same result was obtained when increasing the amount of acid and graphite. Peak performance was obtained with 150 g of sodium silicate, 100 ml of 2NHCl, and 50 g of graphite.

The main aim of the present work is to design and test a single slope water still with a presolar water heating system. The effect of the amount of water in the basin, and of the inlet water temperature to the basin from the presolar water heater on the amount of fresh water yield and on its thermal performance will be investigated.

3.2 Test Rig

A single slope solar water still with a solar preheater system was designed and constructed. The still consisted mainly of a base unit, made from galvanized steel, and a glass cover. The surface area of the still is 1 m^2. The bottom inner surface of the base unit is painted black and the inner side walls are painted white. The side walls of the base unit are insulated from outside with Styrofoam. At the bottom end of the

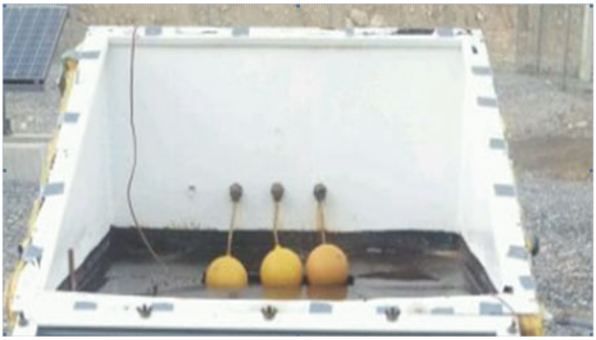

Fig. 3.2 Float valves attached to the still

Fig. 3.3 Experimental set up of single slope solar water still with solar energy heating system

inclined surface of the base unit, a passage is made to collect the fresh water coming down from the cover glass. Three floating valves are attached to the back of the still to allow the adjustment of the water depth inside the basin of the still (see Fig. 3.2). A simple solar collector was constructed and made of a single glass cover with a water loop to preheat the saline water before it entered the still. The whole system, the still, the collector and the supply tank, was assembled as shown in Fig. 3.3.

3.3 Experimental Procedure

The experiments were conducted to study the effect of water level in the basin and the effect of using a solar preheater on the yielded fresh water and on the solar still thermal performance. Thermocouples were positioned at different locations in the still to measure the temperatures throughout the day and were connected to a data logger to record and save the temperature readings every 15 minutes.

First, the solar collector was connected to the inlet of the solar still basin and the correct amount of saline water was introduced into the basin. The basin inlet and the solar collector outlet temperatures were measured by the thermocouples and recorded every 15 minutes in order to find the mean average hourly temperatures. The same procedure was followed for measuring the still water, the cover glass, the vapor and the ambient temperatures. The fresh water yield was collected and recorded using sealed graduated glass containers on an hourly basis.

3.4 Thermal Efficiency of the Water Still

To assess the performance of the still, it is important to identify its thermal efficiency. The still efficiency can be calculated using the following formula

$$\eta = \frac{evaporation\ heat}{total\ input\ solar\ energy} = \frac{\dot{Q}_{ev\,p}}{\dot{Q}_{in}}$$

The heat of vaporization can be calculated using the following formula

$$\dot{Q}_{ev\,p} = \dot{m}h_{fg}$$

Where $\dot{m}$ is the mass flow rate and h_{fg} is the latent heat of vaporization. The energy input due to solar radiation can be calculated as

$$\dot{Q}_{in} = \alpha\tau A_p I$$

Where α, τ, A_p, and I are the absorptivity coefficient, the transmission coefficient of the glass cover, the area of the absorbing plate and the solar intensity on the horizontal surface respectively.

3.5 Results

The results of the experimental tests show that the production rate of fresh water is directly related to the water level height in the basin and to the solar radiation. As the water level in the basin decreases and solar radiation increases, the production rate increases. For a flat bottom surface, the hourly rate yielded and the hourly-daily accumulated fresh water for three different water depths are shown in Figs. 3.4 and 3.5. It was observed that a depth of 1 cm outperforms 2 cm and 3 cm of water depth in the solar still basin. This is due to the small heat capacitance of water at 1 cm

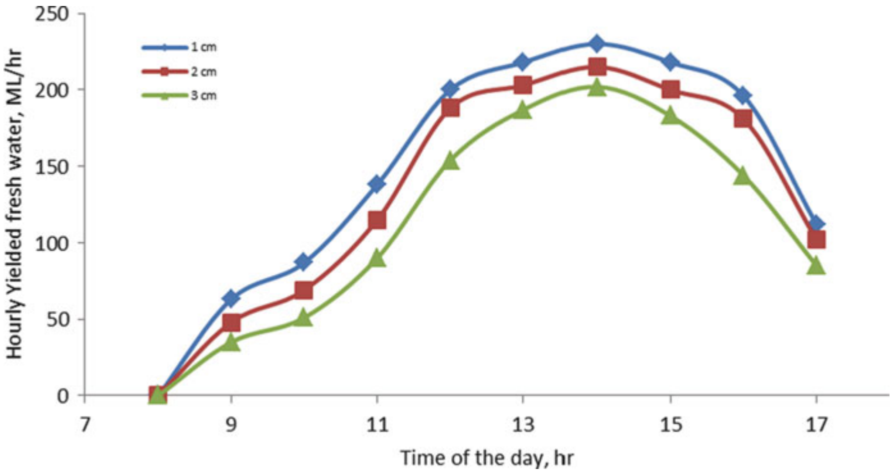

Fig. 3.4 Hourly yielded fresh water for flat surface

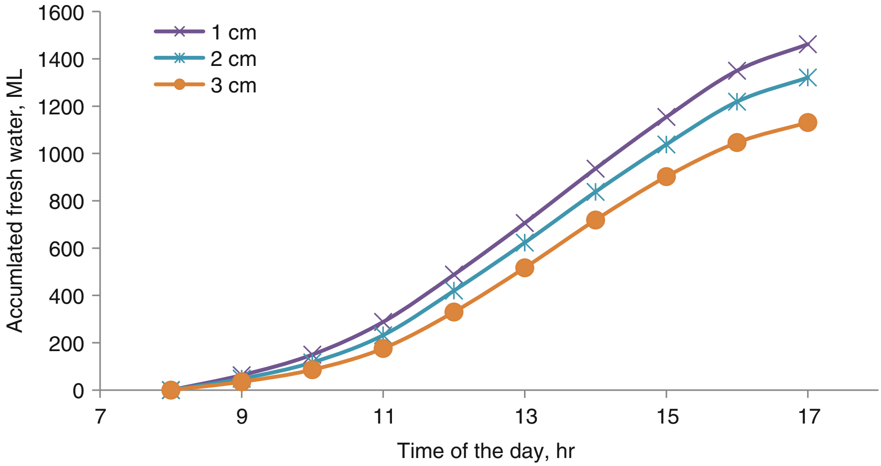

Fig. 3.5 Fresh water cumulative yield

depth compared to the other two depths and alos because it needs less energy to be vaporized. The maximum hourly amount of fresh water yield is at noon and the total hourly accumulation is 1500 ml per meter squared for a water depth of 1 cm, where the solar radiation is at a maximum (See Figs. 3.4 and 3.5).

The average efficiency is calculated over the testing time which lasted between 7 am and 5 pm and was found to be 40.8 % for a flat basin surface. The addition of the solar of water preheater to the system significantly increases the inlet basin saline water temperature to almost saturated temperature and the saline water in the basin needed only a small amount of heat to be vaporized as shown in Figs. 3.6, 3.7 and 3.8 (Table 3.1).

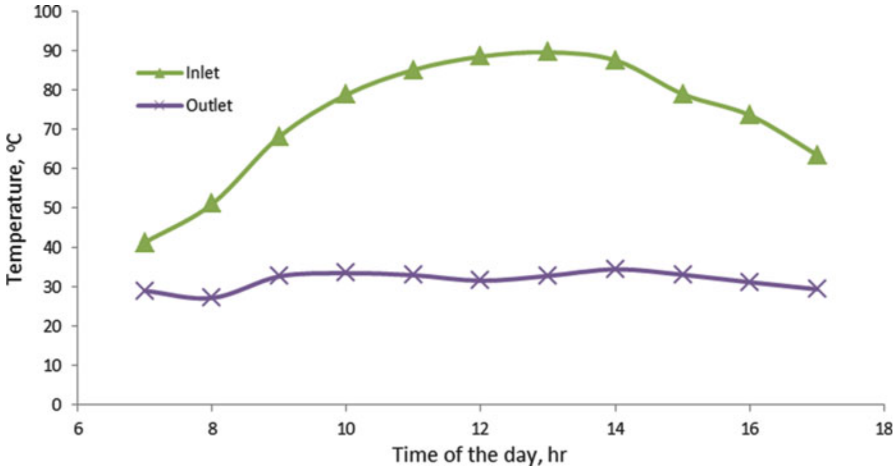

Fig. 3.6 Temperature readings at the solar preheater's inlet and outlet

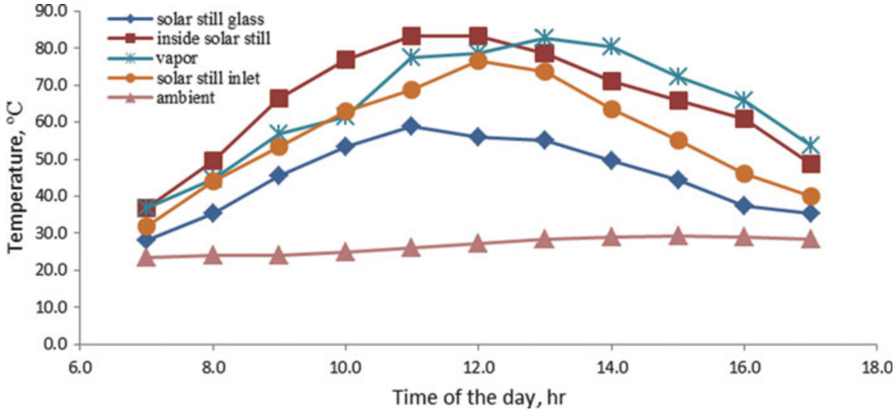

Fig. 3.7 Temperature readings at different locations in the still

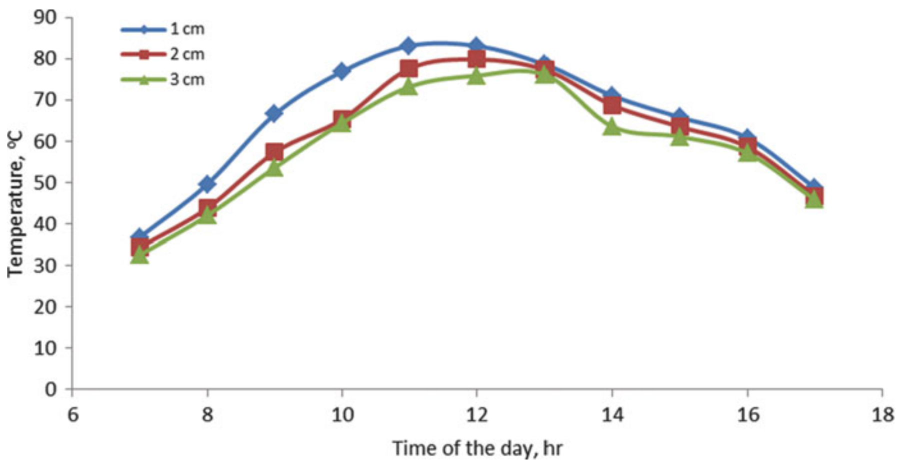

Fig. 3.8 Temperature readings inside the still for three different water depths

Table 3.1 Still thermal efficiency for different tested cases

Tested case	Average thermal efficiency (%)
1 cm depth	40.8
2 cm depth	35.1
3 cm depth	27.9

3.6 Conclusion

This paper has investigates the thermal performance of a solar water still with an enhanced solar heating system. A number of variables have been considered, including the water depth inside the still and the inlet saline water temperature to the solar still from the preheater solar collector system. It was found that a depth of 1 cm gives the best performance in terms of fresh water yield and thermal efficiency. The addition of the solar water preheater to the system significantly increased the inlet basin saline water temperature to almost saturated temperature and the saline water in the basin needed only a small amount of heat to be vaporized, thus increasing the production of fresh water and enhancing the thermal efficiency of the solar still.

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