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Designing a Single Slope Solar Water Still and Testing it in Omani Climate

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Abstract. Oman has a limited resources of fresh water mainly underground water. To preserve those resources and to meet the increase in the fresh water demand, the country turned to water desalination which is known to be very costly and harmful to the environment. Water desalination using solar energy is an attractive alternative for countries like Oman which has a sunny weather all year round and where the length of the day time ranges between 11 to 14 hours. Furthermore, solar energy is a clean source of energy. The aim of the present study is to (1) design and test the solar water still for Omani climate, and (2) to investigate the effect of different design parameters on the still thermal performance.

Key words

Solar energy, solar desalination, single slope solar water still.

1. The challenge

The only source for fresh water in Oman is the underground water which is limited and cannot meet the increasing demand. Oman population over the last four decades has almost tripled and the available freshwater can no longer be enough not to mention the water consumption due to the expansion in the industry. Water desalination represents a very attractive alternative especially when we know that Oman has a very long coast line of about 1700 km. Although Oman is an oil producing country, 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 demands as well as the unit cost of conventional energy is increasing every year, it's a time to look for alternative sources of energy. Solar energy is a renewable source of energy and it can be utilized very effectively in many applications in Oman such as: water heating, cooking and solar desalination. Solar energy is very abundant, clean and environmentally friendly. In addition, the weather in Oman is very hot in summer and the ambient temperature can reach up to a maximum of 48°C.

2. Climate and solar energy in Oman

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 square kilometers. The land area is composed of varying topographic features: valleys and desert account for 82 percent of the land mass; mountain ranges, 15 percent; and the coastal plain, 3 percent.

The climatic zone of sultanate of Oman is dry tropical characterized by extreme heat in the summer around June and coolness in the winter around January (figure 1).The sultanate receives a high degree of solar radiation thought the year. It is therefore advisable for the country to use the solar energy which is renewable and readily available. Oman has on average 9.49 hours of sunshine per day with a standard deviation of 1.78 hours. The range was 0 hours to 13.90 hours .The average number of sunshine hours ranges from 7.88 hours in Sallalah to 10.24 hours in Buraimi. The solar radiation averaged 18.71MJ/m2/day with standard deviation of 4 MJ/m2/day for Oman over the period. Marmoul has the highest average solar radiation 21.86 MJ/m2/day while Sur and Salallah have the lowest average of 15.92MJ/m2/day and 16.22MJ/m2/day respectively. The most radiation occurs in April, May and June with the highest level of radiation occurring in May (figure 2). The May average is 23.11MJ/m^2/day. The least radiation is in December and January [1].

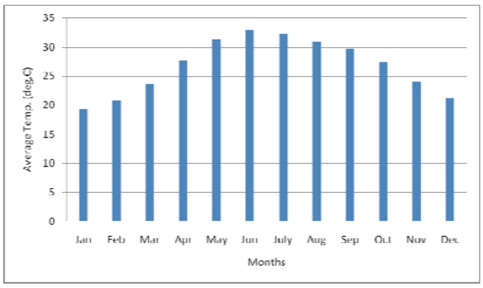

Fig. 1. Average temperature in Oman during the year 2006 [1]

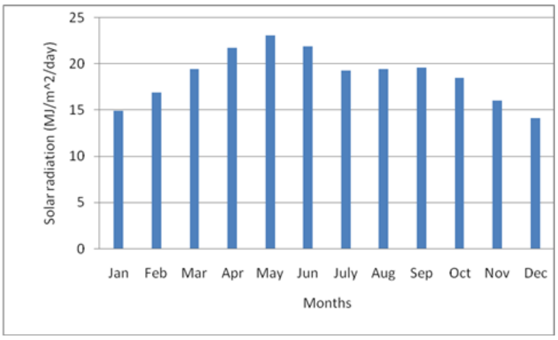

Fig. 2. Average solar radiation in Oman during the year 2006 [1]

3. Introduction

The so called single slope water still simply consists of a thermally insulated box with a glass cover. The solar energy penetrates the glass and causes a greenhouse effect inside the box. The water inside the box heats up, evaporates leaving behind any impurities such as the salt. The water vapour then condensate when it hits the underside of the cover glass. The condensate pure water can then be collected.

Single slope still was studied both theoretically and experimentally by a number of researchers. A.S. Nafey at al [2] investigated the effect of the solar radiation, wind speed, brine depth and glass tilting angle on still productivity. It was found that the solar radiation is the most affecting parameter on the productivity. The productivity decreases with the increase of the wind speed increases 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 as small as possible because the horizontal plane receive more radiation than the inclined plane does, while in winter the productivity increases when the inclination is increased. Solar still was tested in different climate conditions and in many places around the world. H.N. Singh and G.N. Tiwari [3] studied the monthly performance of passive and active solar stills for different Indian climate conditions. D.W. Medugu and L.G. Ndatuwong [4] designed and tested a solar still under actual environmental condition of Mubi, Nigeria. They developed theoretical analysis of heat and mass transfer mechanisms inside the still. They did experimental and theoretical investigation on the distillation performance of the solar still. They found that the instantaneous efficiency increases with the increase of the solar radiation and the feed water temperature. A.A. Hassanain and M.A Abu-Zied [5] conducted a study about 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 by 20%. The investigation addressed the following: The still productivity, distilled water salinity and still performance in term of the still efficiency and the coefficient of performance. They found that the still productivity and efficiency increases by increasing the solar radiation and the highest productivity was 0.226 L/m^2 which was obtained during the month of July. Also, they found that the still performance increases gradually from the sunrise time till it reaches certain maximum value at noon and afternoon by about an hour respectively and then decreases until it reaches minimum value at sunrise time. T.V. Arjunan et al. [6] conducted an experimental study on solar still with 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. Masoud Afrand et al. [7] carried out a theoretical study of solar distillation in a single basin under the open environmental condition of Chabahar – Iran. In this research, they were investigating the still productivity, distilled water salinity and still performance in term of the still efficiency. They found that the maximum efficiency of the solar still was at noon due to the high radiation. Another study about single solar still was conducted in India by P. Rajendra Prasad et al. [8]. The still was modified with graphite powder to maximize the absorptivity. In this study, the effect of four parameters was investigated; the amount of silicate, amount of acid, amount of graphite powder and 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 150g was added the productivity decreased. The same result was obtained when increasing the amount of graphite and acid. The peak performance was obtained by 150g of sodium silicate, 100ml of 2NHCl, and 50g of graphite.

The main aim of the present work is to design a more efficient single slope water still and test it in Oman climate.

4. Experimental rig

A single slope solar water still was designed and fabricated (figure 3). The still consisted mainly of a base unit, made from galvanized steel, and a glass cover. The surface area of the still is 1 square meter. The bottom inner surface of the base unit is painted black and the inner side walls are painted white (Figure 4). The side walls of the base unit are insulated from outside with Styrofoam. At the bottom end of the inclined surface of the base unit, a passage is made to collect the fresh water coming down of the glass. Thermocouples positioned at different locations in the still were used to measure the temperatures throughout the day. The thermocouples were connected to a data logger to record and save the temperatures readings.

5. Thermal efficiency of the wáter 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

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

The heat of vaporization can be calculated using the following formula

$$\dot{Q}_{evp} = \dot{m} h_{fg}$$

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 absorptivity coefficient, transmission coefficient of the glass cover, area of the absorbing plate and solar intensity on horizontal surface respectively.

6. Results

The following results reflect the average measured temperature and the fresh water yield. The experiments were conducted during the month of December where the average ambient temperature is around 23 °C. Figure 5 shows the average measured temperature readings for the water inside the still, the bottom of the base unit, the vapor, the cover glass and the ambient. A maximum temperature of about 60 °C was recorded around 2 pm. Part of the investigation was to test the effect of the water level height on the still performance. Figure 6 shows the hourly rate of the yielded fresh water for three different depths; 1,2 and 3 cm. It was found that the smaller the depth, the higher the yielding. Further investigation is needed to determine the optimum water depth. Figure 6 shows the effect of water depth on the rate of yielding. The time variation of the water temperature in the still for the three levels are shown in figure 7. Whereas the temperatures are almost the same for 2 and 3 cm of water depths, a significant improvement is seen for the 1 cm. Figure 8 shows the cumulative fresh water yield per square meter for the three water levels. The accumulation mainly happened between the hours of 12 and 17 where the radiation is the highest. Table 1 shows the hourly thermal efficiency of the still for water depth of 1 cm. The average efficiency is found to be around 37 %.

Fig. 3. The base unit of the solar still

Fig. 4. Single slope solar water still

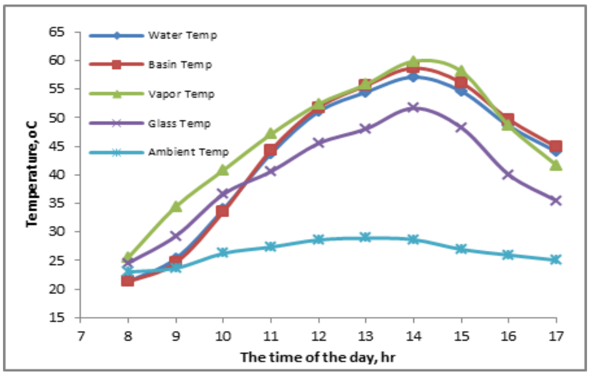

Fig. 5. Temperature readings at different locations in the still

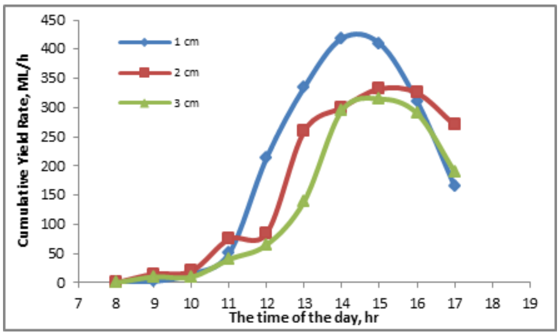

Fig. 6. Yielded rate of fresh water

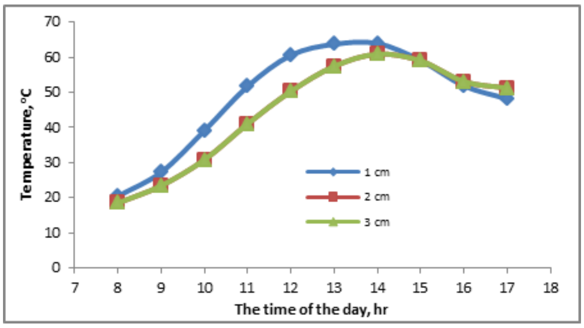

Fig. 7. Water temperatures for the three different levels of water in the still

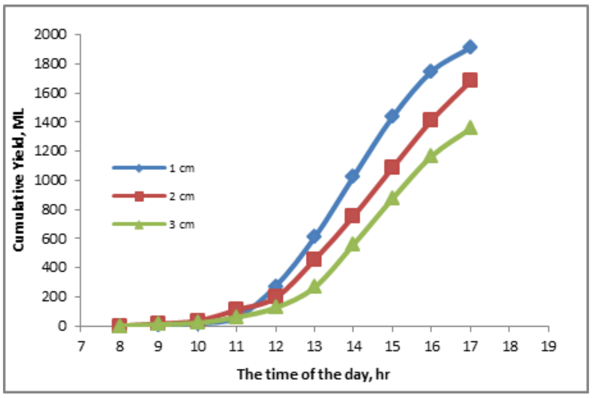

Fig. 8. Cumulative yield of fresh water

Table I. The efficiency of the still for 1 cm water depth

Time, hr	Vapor Temp, °C	Latent Heat, kJ/kg	Yielding Rate, kg/hr	$\dot{Q}_{evp}$, J/s	Efficiency η (%)
8	25.4	2436.9	0	0.0	0.0
9	36.9	2425.3	2.5	1.7	0.5
10	46.8	2389.7	15	10.0	2.9
11	57.95	2362.7	50.5	33.1	9.7
12	63.9	2348.1	214.5	139.9	40.8
13	66.25	2342.3	335	218.0	63.5
14	66.5	2341.7	418.5	272.2	79.4
15	62.3	2352	410	267.9	78.1
16	52.05	2377	311	205.3	59.9
17	46.3	2390.9	165	109.6	31.9

7. Conclusion

This paper investigates the thermal performance of a solar water still under different conditions in in Omani climate. As anticipated, decreasing the depth of the water level in the solar still improves the still's thermal performance. An amount of about 2000 ml was accumulated during the testing period which lasted from 8 am to 5 pm. The test was carried out during the month of December where the average temperature is around 20 ^{o}C. The highest thermal performance was calculated to be 37% for a water depth of 1 cm. It is expected that the thermal performance and the yielding rate will be higher during the summer time where the ambient temperature reaches 45 ^{o}C.

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