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The second generation of the solar desalination systems

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Abstract

In Solar Energy Laboratory, Mechanical Engineering Department, Faculty of Engineering & Technology—Sebha University, an investigation has been conducted of the productivity of solar desalination system working on the basis of evacuation. Solar energy intensity has been concentrated by means of concave mirror, which reflects the sunrays to the focus of the concave, where the still is located. The apparatus has been designed and fabricated in our laboratory, the experimental model consists of elliptical, metallic container (to resist the imposed outer pressure) located in the focus of concave reflector. The still works under vacuum of 562.5 torr (25 kPa absolute) to reduce the normal boiling point of the income water. A condenser has been used to condense the outlet vapor—and working as a water trap—before interring the vacuum pump. The experiment was carried out during the period from 15 April to 15 May 2003. The water productivity of the offered still was found about 20 l/d per unit area of the reflector. The experimental results showed a significant improvement of the productivity of desalinized water, about 303% compared with the other thermal solar stills. Moreover, the increase of the performance ratio is about 900% more than the roof-type desalination solar systems. These results encourage us to adopt the offered procedure to manufacture large-scale solar desalination plants to provide the rural regions with drinkable water.

Keywords: Desalination; Solar still; Concentrator; Vacuum

1. Introduction

Adequate quality, quantity, and reliability of drinking water supply is a fundamental need of people. Fresh water, obtained from rivers, lakes, and ponds, is becoming scarce because of industrialization and population explosion.

Geographically, the most Arabic countries locate in areas, which confined to arid or semiarid regions. For this reason, most of our countries have been adopted the seawater desalination as a strategic to overcome this problem. For example

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the water supply of AUE, Kuwait, and Arabia Saudi is almost 100% from the seawater desalination plants. Libya overcomes this problem by means of transferring the ground water from the desert to the northern coast, where there is high population intensity, by the great man-made river. Accumulation strategy was adopted by other countries whose rivers such as Egypt, Sudan, Morocco, etc., to collect rain's and river's water behind the dams to be used when it is needed [1].

Nowadays, there are no serious attempts – from the Arabic countries - to construct a large-scale solar desalination plants, except some pilot plants in some countries mainly, for research purposes. Fig. 1 illustrates the largest capacity of the conventional desalination plants for 10 countries. As illustrated, many Arabic countries have large capacity desalination plants. Unfortunately, there is not enough information about the share of solar desalination plants in these capacities!

In Libya, at 1987, the Center for solar energy studies has designed and constructed a pilot solar desalination plant in Tajiura (Eastern Tripoli—Capital of Libya) for experimental studies. The pilot plant used multistage flash evaporation technique, a solar pond of 830 m^2 surface area has been constructed behind the pilot plant to provide it with the necessary heat power for operating. The average productivity of fresh water is found to be 5 m^3/d (6.0241 l/m^{2}d) [2].

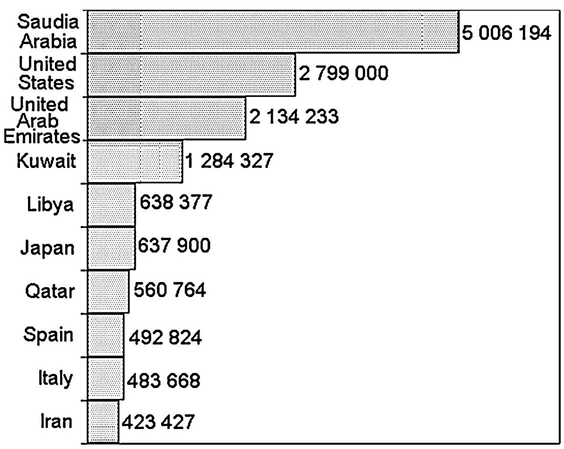

Fig. 1. Conventional desalination capacity for 10 countries with largest capacity [2].

2. Experimental approach

According to the results obtained from a previous work [3], another experiment was carried out by the Solar Energy Laboratory in Brack—Libya. Brack is a city locates at 600 km away to the south from Tripoli (Libyan capital) in the middle of the great desert, at 27.6°N latitude and 14.2°E longitude. In April and May months, the average daily temperature is around 30°C and the total solar radiation is of 4.3 kWh/m^{2}d. The solar desalination apparatus was established to study the effects of vacuum pressure on the productivity of the system.

As shown in Fig. 2, the unit consists of metallic container (1), occupied by the raw saline water to a certain level below the exit. The container was designed and fabricated in elliptical shape to increase the surface area of evaporation.

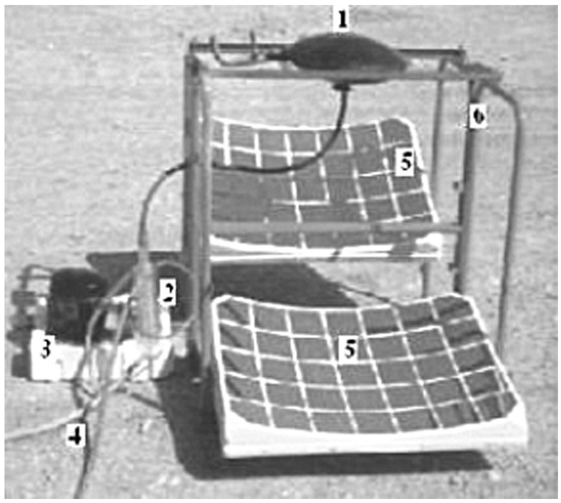

Fig. 2. Experiment apparatus.

Table 1
The climatic data and the productivity through the day

Productivity (ml)	Cooling water temperature (°C)	Wind speed (m/s)	Ambient temperature (°C)	Solar intensity (W/m^2)	Operation time
140	20	1	23	360	8:20–8:40
130	21	1.5	24.5	435	8:45–9:05
130	24	1.5	25.5	501	9:10–9:30
140	24	1	25.5	583	9:35–9:55
240	25	1	25.5	655	10:00–10:20
200	27	1.5	26.5	698	10:25–10:45
230	28	1.5	27.5	749	10:50–11:10
230	30	1.5	29	804	11:15–11:35
210	32	1.5	30	849	11:40–12:00
230	34	1.5	31	878	12:05–12:25
250	34	1	31.5	892	12:30–12:50
250	29.5	1	32	901	12:55–13:15
240	32	1.5	34	903	13:20–13:40
230	29	1.5	33.5	891	13:45–14:05
220	35	1.5	33	861	14:10–14:30
195	29	1.5	33	824	14:35–14:55
190	29	1	33	777	15:00–15:20
180	29	1	33.5	720	15:25–15:45
170	29	1	33	650	15:50–16:10
130	29	1	33	589	16:15–16:35
130	29	1	33	540	16:40–17:00
125	29	1	33	485	17:05–17:25

Moreover, water depth inside the container is preferable to be low to avoid of the carry-over of water droplets. Vapor is drawn from the container through flexible tube (4) of 1/4 in. diameter and condenses inside a condenser (2) which is provided with cooling water. The condenser works as a trap of desalinized water. A compressor (3) of 120 W was re-arranged to fit the experiment requirements and to work as a vacuum pump. However, the operating vacuum pressure provided was about 562.5 torr. Concave mirrors (5) were located at a distance down the container to concentrate the solar radiation in the focus, where the container was placed. The apparatus is supported by steel structure (6). Solar intensity, temperature, and wind speed measuring devices were supplied.

3. Results and discussion

The productivity of the offered solar still has been studied under the real climatic conditions of Brack city, such as, solar radiation intensity, air temperature, and wind speed and cooling water, through the period of 15 April to 8 May 2003. Table 1 represents the productivity and climatic conditions through one day testing. The productivity vis the solar radiation intensity is plotted in Fig. 3. This figure shows a linear relationship between the daily productivity of the present still and the total daily solar intensity. A comparison is carried out between the characteristics of the offered still with that of conventional effect roof-type solar still. The results are tabulated in Table 2. The parameters studied

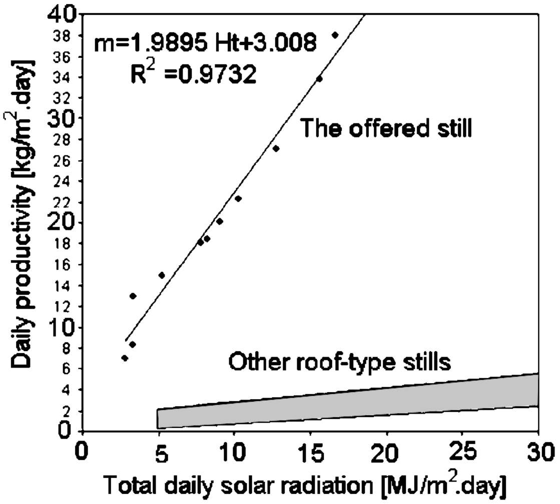

Fig. 3. The productivity of the still as a function of daily solar radiation intensity.

are: the performance ratio (PR), which defined as the ratio of the latent heat of evaporation of the product water to the energy required by the desalination system and the daily yield (P_d), which defined as the total volume of distillate, in liters, produced by the still in a day per unit heat collection area [4].

The obtained results demonstrate clearly the higher value of (PR) and (P_d) of the offered still compared with that of roof-type still. The improvement of (PR) and productivity are about 900% and 300%, respectively, which are due, mainly to the effect of vacuum applied. Accordingly, the boiling point will be reduced, e.g., the boiling point of water is 60°C at 180 torr, which is lower than the normal boiling point at atmospheric pressure. Thus, evaporation rate of the water will increase extensively at short time. Moreover, energy consumed is much lower than that of the roof-type still.

4. Conclusions

We have successfully shown the effect of the vacuum on the performance of the roof-type solar still, and the main points of our conclusions are as followed:

- The reduction in power required to product 1 kg of fresh-water will be 90.1%.
- The improvement in the performance ratio PR will be 900%.
- Under the same condition, the water production will be 20.11 kg/m^2 d, compared with the most effective existing solar still productivity of 5 kg/m^2 d.
- Economically the excess in productivity will lead to reducing the unit cost of the water.
- Furthermore, the vacuum pump in the still, may be operated by means of photovoltaic system to provide the rural villages with drinkable water.

5. Future investigations

We have to continue the development of this system by concentrating on the following aspects:

- Technical development with the aim of designing a high performance apparatus.
- Modeling of the heat and mass transfer and hydrodynamics processes in the apparatus.

Table 2
Performance ratio, energy consumption and productivity comparison between the best roof-type basin still in the world and the offered still

Improvement percent in productivity (%)	Improvement percent in PR (%)	Productivity (kg/m^2 d)	Consumed power to product 1 kg water (kJ/kg)	PR	Still type
–	–	5.00	4350.00	0.53	Roof-type still
302.7	900.00	20.133	427.55	5.30	Offered still

- Re-optimization all design parameters leading to maximum productivity.
- Determination of the operation condition limits.
- Economic analysis has to done to evaluate the cost of the unit production.

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