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Water Purification Process by Using One Side Vertical Solar Still

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Abstract. Solar desalination is a rapidly growing field of research. The coming global oil crisis implies that alternatives to the conventional desalination plants based on fossil fuels must be developed. Solar desalination can be either direct, with collectors and condensers integrated with each other, or indirect, with condensers externally connected to the condensers. Direct solar desalination requires large land areas and has a relatively low productivity compared to the indirect technologies. It is however competitive to indirect desalination plants in small-scale production due to its relatively low cost and simplicity. Indirect solar desalination usually means combining conventional desalination techniques, such as MSF, ME or RO, with solar collectors for heat generation. The main advantages of the investigation is providing for water purification process in the desert of K.A.S. The paper presents the performance evaluation of one-side vertical solar still tested under desert climatic conditions of K.A.S. Hourly and daily measurements of still productivity, temperatures of water film, glass cover, inlet of brackish water into solar still, ambient air temperature and solar radiation were recorded. The highest value of hourly still efficiency is 59 % recorded at 15:30.

Keyword: Solar energy – Desalination – Solar collector - Productivity

1. Introduction

Water is available in abundance on the earth; however, there is a shortage of potable water in many countries in the world. In the MSF and RO countries and elsewhere, non-renewable energy from oil and natural gas is used to desalinate water from sea water in multi-effect evaporators. Water shortages occurs most at places of high solar radiation, which usually peaks during the hot summer months of maximum solar radiation. Hence, solar desalination could be one of the most successful applications of solar energy in most of the hot climate countries having limited resources of fresh water.

Solar energy is the most appropriate energy source for desalting water. It is sufficient to remember that it is simply due to solar radiation that the renewal of water on earth is made possible, by the cycle of evaporation and successive water condensation in the form of rain. Solar stills could, however, be considered attractive for domestic purposes, especially in areas having no access to the electric grid and low labor cost.

The coupling of solar energy and desalination systems holds great promise for increasing water supplies in water scarce regions. An effective integration of these technologies will allow countries to address water shortage problems with a domestic energy source that does not produce air pollution or contribute to the global problem of climate change. Meanwhile the costs of desalination and renewable energy systems are steadily decreasing, while fuel prices are rising and fuel supplies are decreasing.

2. Literature Review

Solar stills Interest in seawater desalination goes back to the fourth century BC, when Greek sailors used to obtain drinking water from seawater. However, the first solar still was designed and constructed in Chile by the Swedish engineer, Carlos Wilson, in 1872, as described by Malik et al. [1]. Following that, no work was conducted on solar desalination till the end of the First World War. During World War II, Telkes [2] developed a plastic still inflated with air, which was used by the US Navy and Air Force in emergency life rafts.

The single insulated basin still was found to distill water with low efficiency (usually below 45%), depending on the operating conditions, as reported by Malik et al. [1], Cooper [3], Kudish et al. [4] and Farid and Hamad [5]. The low efficiency of the still is mainly due to the high heat loss from its glass cover. They found that a double glass cover reduces heat losses, but it also reduces the transmitted portion of the radiation. The productivity increases when the solar still is operated under reduced pressure Yeh et al. [6]. However, this was found impractical because of the difficulties associated with the reduced pressure operation. Solar radiation received by a horizontal surface is not at its maximum except near the equator. Many investigators have modified the horizontal single-basin still, usually fixed on a horizontal surface, to an inclined type to receive maximum solar radiation. Later, the tilted tray and the wick-type solar still were developed.

However the construction cost of these complicated stills added significant cost penalties, while the increase in the productivity of the stills was very limited. The loss of energy in the form of latent heat of condensation of water at the glass cover is the major problem of the single-basin still. Tiwari et al. [7] arranged the still in such a way as to have the water flow over the glass cover. Preheating of the feed water by passing it over the glass cover allowed only partial recovery of the latent heat, with an increase in the still production. The flow of water over the glass cover reduced the amount of solar radiation received by the water in the still. Accumulation of salts and vapor leaks also frequently caused defects in these units. Further work in improving the efficiency of solar stills was carried out by El-Bahi and Inan [8]. The effect of adding an outside passive condenser to a single-basin-type solar still with minimum inclination (4º) was investigated experimentally. This solar still yielded a daily output of up to 7 L/m^2. They have reported still efficiency of 75% during the summer months. They also found that when the solar still was operated without a condenser, the yield decreased to 70% of that with a condenser. Solar stills were presented by Fath [9], who highlighted the impact of utilizing latent heat of condensation via multi-effect solar stills. Mink et al. [10] conducted an in-depth study on heat recycling using a laboratory-scale solar still of 1 m^2 area, designed to recycle the condensation heat of the distillate. The exposed wick surface area was 1 m^2, with thermal incident energy of 650 W/m^2 being supplied by a solar simulator at a tilt angle of 20º. The forced circulation of ambient air was achieved using a low-pressure variable speed ventilator. Preliminary results showed an increase in productivity per unit area by a factor of two to three compared with tilted wick or basin-type solar stills, respectively.

One of the most recent designs of such a still is that described by Grater et al. [11] and Rheinlander and Grater [12] of a four-effect still. The evaporation process in a four-effect still for the desalination of sea and brackish water was experimentally investigated in a test facility under different modes and configurations of heat recovery. The experimental unit consisted of a base module of the four-effect distillation unit. Multi-effect still: technology for the desalination of 10 ml/d of water Rheinlander and Grater [12].

The gain output rate (GOR) increases by up to 80% due to heat recovery from the distillate latent heat. The model predicted a distillate output in the first effect that was 50% higher than the measured values when the feed temperature was raised to 90°C. It is to be noted that the unit of Grater et al. [11] and Rheinlander and Grater [12] was operated with hot water at a constant temperature of 90°C. Under such high operating conditions, the evaporation and condensation will be very efficient, but long-term operation is not practical due to scale formation. Furthermore, if a solar collector is used to drive the desalination unit, then its collection efficiency will drop to a very low value at such a high temperature. Thus, multi-effect solar stills may carry out more efficient desalination of seawater compared to a single-basin still, but for only small capacities since the condenser and the evaporator are integral parts of the still. The low heat and mass transfer coefficients in this type of still require operation at a relatively high temperature and the use of large and expensive metallic surfaces for the evaporation and condensation. In the following sections, a new class of solar desalinations system is discussed, whose design is based on a more efficient utilization of the latent heat of condensation. Using solar energy source for water desalination, power generation and many other thermal applications has a great deal to save the total national income, Hammons [13] and Ozgener and Kocer [14].

Many studies have been compared between the different renewable energy as desalination driven power for each of brackish and seawater Tzen et al. [15] and Rodrhguez [16]. They found that solar energy is suitable for different desalination process at reasonable cost wherever a proper source is available. One of the main disadvantages is that energy storage is required.

3. Experimental Set Up and Procedures

For the purpose of this study a One Side Vertical Solar Still was constructed and erected in the College of Engineering, Qassim University. A photo of the test rig is shown in Fig. (1). It consisted essentially of three main parts:

(a) Flat plat collector
(b) Evaporation chamber
(c) Condensation chamber.

Fig. (1). Photo of the test rig.

A complete layout of the test rig and details of the test section are shown in Figs. (2-3). It consists of a solar collector which is made of a 1.2 mm thick black steel enclosure (1), covered by a 4 mm thick ordinary glazing (2), supported by a wooden frame (3) and sealed by mastic silicone (4) and an aluminum frame (5) which is support also the glazing. In the evaporation chamber (b), a copper tube distributor (7) of brackish water is provided by holes of circle cross section. The distributor is equal to width of the sponged cloth (8), and the holes are made along the copper tube distributor. Brackish water flows down through the sponged cloth. It is collected in a bottom gutter (9) and discharged from still as a waste. The wire screen (6), black steel plate (10) sponged cloth (8), and wire screen (6) form the absorber unit. In the condensation chamber (c), distilled water is collected from the lower edge (11) of the condensation surfaces in a certain time which is detected by stop watch. The vapor is transferred from the evaporation chamber to the condensation chamber through an upper vent (12) and a lower vent (13) which is made of an insulation layer (14) between the two chambers. The solar still unit is supported by an adjustable vertical stand (19) and the solar radiation intensity is measured by Pyranometer (21).

The brackish water (BW) inlet temperature T_2 , brackish water (BW) outlet temperature T_3, to the flat plate collector for and ambient temperature T_1 are measured by copper-constantan thermocouples (22) which are attached to a temperature recorder (23).

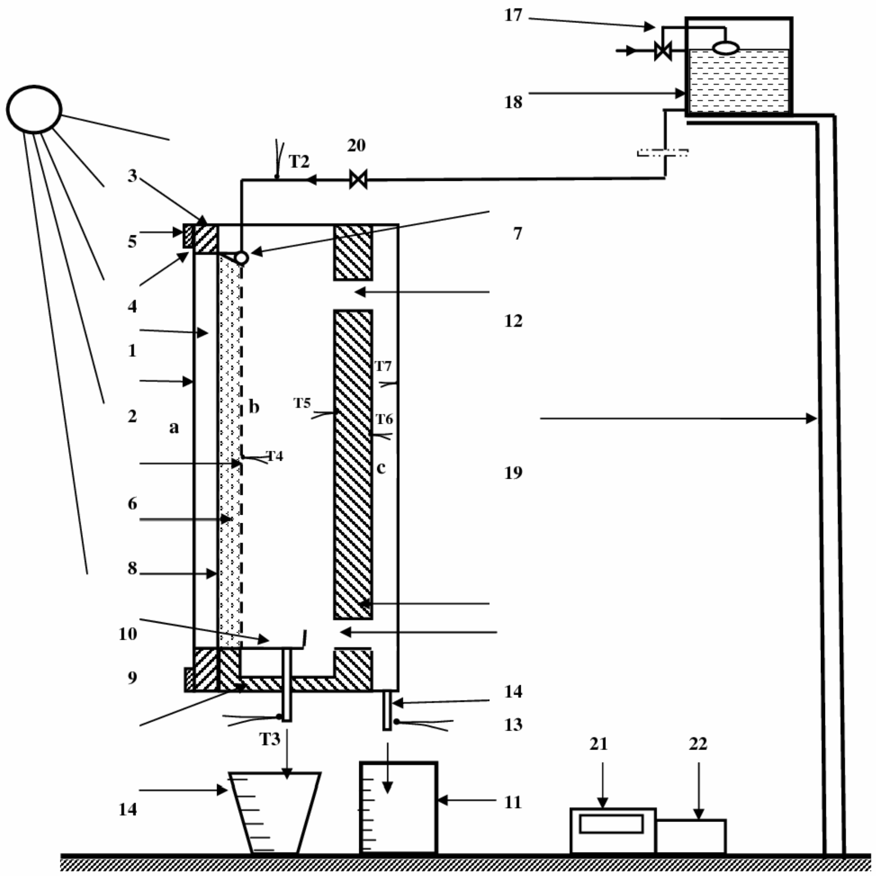

Fig. (2). Test rig of the indirect vertical solar still

1. Collector enclosure	**2. Glazing**	**3. Wooden frame**	**4. Silicon mastic**
5. Aluminum frame	**6. Wire screen**	**7. Water distributer**	**8. Sponged cloth**
9. Bottom gutter	**10. Black steel plate**	**11. Distilled water exit**	**12. Upper vent**
13. Lower vent	**14 Insulation layer**	**15. DW outlet**	**16. B W outlet**
17 Float valve	**18. Constant head tank**	**19.** Vertical stand	**20. Globe valve**
21. Pyranometer	**22. Thermocouples**	**23.** Temperature recorder	

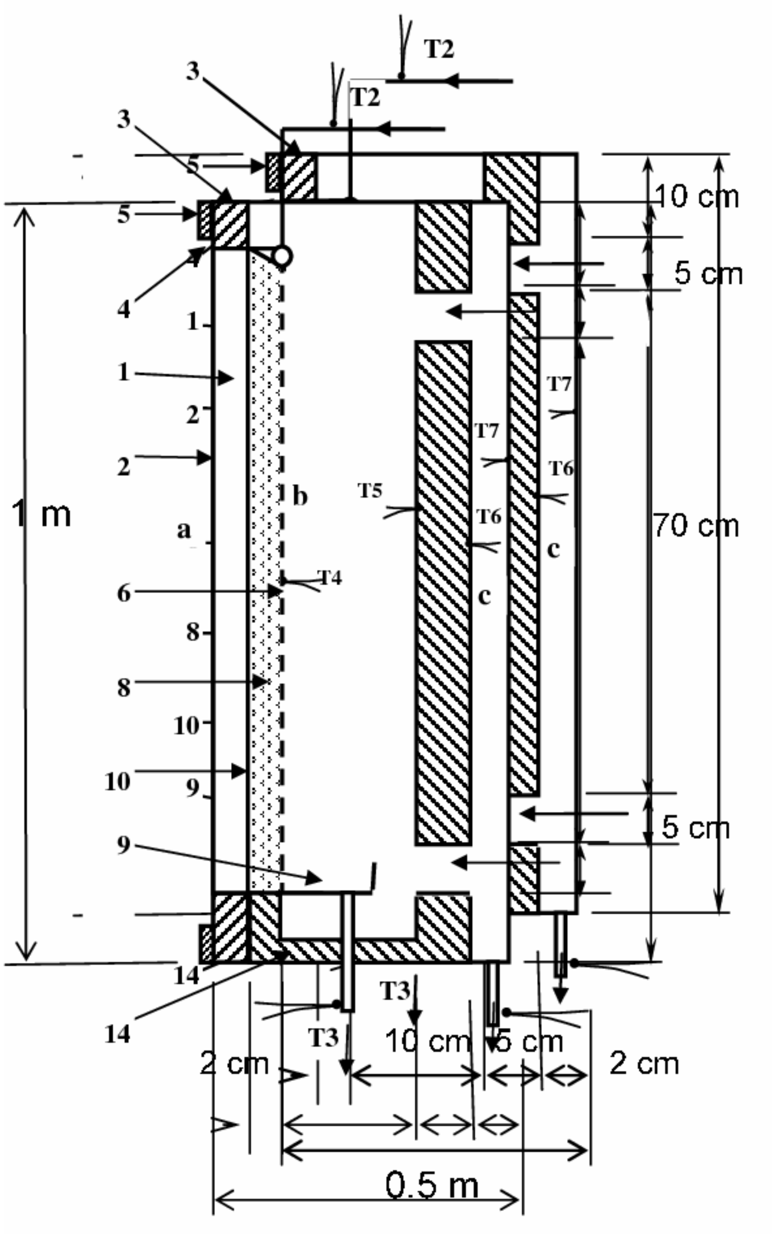

Fig. (3). Test section details.

4. Operating Principle of the Still

Also, figure 2 shows a schematic diagram of the working principle of the solar still. The raw brackish water from constant heat tank (18) enters the still via a copper tube with the help of float valve (17). The flow rate of brackish water is adjusted by means of globe valve (20), and then the brackish water is distributed by a copper tube (7) and water trickle on the back of the absorber plate on the sponged cloth and the wire screen (6). The brackish water exists from the still unit through a bottom gutter (15). Solar radiation, after passing the glazing (2) is absorbed by the absorber unit. The evaporation chamber is connected to the condensation chamber through 5 cm x 10 cm bottom vent (13). The transfer of water vapor from the evaporation chamber could be done through natural circulation. Saturated hot air inside the evaporation chamber tends to move upward, while saturated air inside the condensation chamber tends to move downward. Then, low humidity concentrated condenser on sides of the condensation chamber; distilled water is then collected at the bottom gutter (16).

5. Design Parameters

The design of the prototype is influenced by the desire for flexibility. The intention is to be able to evaluate different design approaches and so the initial apparatus is very easy to dismantle and modifying. During operation, water vapor will diffuse from the highly concentrated evaporator to the low condenser. The collection part of the solar still is made from black steel with the front area 1m x 0.5m. The front area of this enclosure is the absorber plate. The condensation and the evaporation chamber length and width are respectively 1 m, 0.5m, 1m and 0.5m. The air gap depth of the solar collector, evaporation chamber, and isolation layer and condensation chamber are 0.03, 0.02, 0.05 and 0.03 m, respectively. During the experiment, the brackish water flow rate varied from $1x10^{-5}$ to $1.15x10^{-5}$ $kg/s.m^2$, at an ambient temperature ranging from 22ºC to 46ºC and the average solar radiation intensity along a vertical surface of 640 W/m^2. Also, the distilled water flow rate varied from $0.9x10^{-5}$ to $3x10^{-5}$ $kg/s.m^2$. Both the mass flux of brackish water and distilled water is calculated based on the surface area of solar still.

The temperatures of brackish water at inlet T_2 and outlet T_3 of solar collector, temperature T_4 of absorber unit (evaporator), T_5, temperature of galvanized sheet forward the absorber unit, T_6, temperature of the galvanized sheet forward the condensing plate, T_6, temperature of the condensing plate, T_7 and ambient temperature T1 are recorded continuously for 12 hours. The distilled water produced by the solar still and the outlet brackish water flow through the vertical still are measured each hour by graduated test tube. The test is performed on several clear summer days.

6. Data Reduction

At any time, the still produces an amount of distillate water equal to the daily yield is the summation of the productivities over period of 24 hrs and it is expressed as the following:

$$M_d = \sum_{j=1}^{24} m\ dj$$

Where:

M_d is the daily yield in kg/m^2

The hourly efficiency η is the energy used for evaporation to that received by the vertical solar still, it is expressed as follows:

$$\eta = \frac{M_h\ H_{fg}}{I_h\ A}$$

Where:

M_h is the hourly yield in kg/h.m^2

H_{fg} is the latent heat of evaporation in kJ/kg

I_n is the solar radiation intensity received on the vertical surface of the solar collector, W/m^2

A is the surface area of the collector, m2

According to **Holman [17],** H_{fg} can be expressed in term of condensation temperature T_4 as:

$$H_{fg} = 2501 - 2.16\ (T_4 - 273.15)$$

So, the collector efficiency is calculated from:

$$\eta = \frac{M_h\ (2501 - 2.16\ (T4 - 273.15))}{I_h\ A}$$

Where:

Mb is measured each hour by a graduated test tube.

T4 is the temperature of the evaporator; is recorded continuously for 24 hrs.

I_h is the solar radiation intensity on the vertical still.

7. Results and Discussion

Typical days are presented in this paper 4, 5 and 6 July, the solar still was oriented to south and it was oriented continuously toward the sun.

Figure (4) illustrates the variation of brackish water (BW) inlet temperature T_2, brackish water (BW) outlet temperature T_3, to the flat plate collector for and ambient temperature T_1, for the summer days, 5 July and 6 July, respectively. It is clear that high values of the temperatures of T_1, T_2 and T_3 products correspond to a certain value of local time during the day.

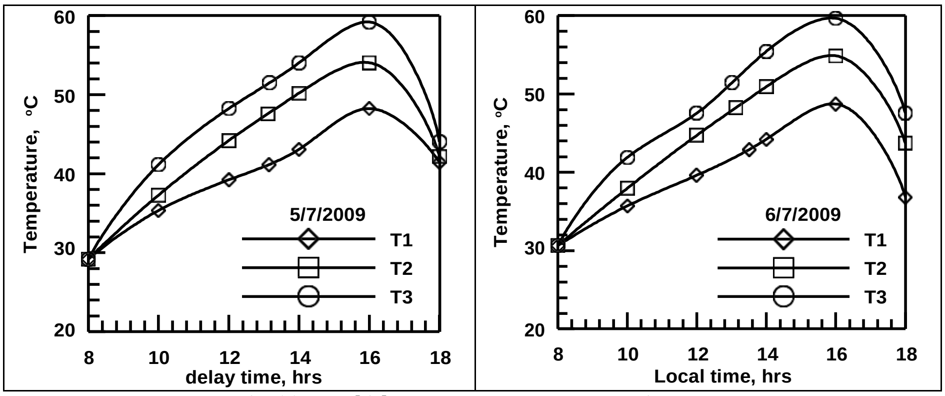

Fig. (4). Brackish water temperature versus time.

Figure (5) illustrates the variation of evaporation temperature T_4, condensation temperature T_7 and ambient temperature T1 for 5 and 6 July. It could be shown that the highest value of evaporation temperature is nearly 80°C was obtained on 5 July. The ambient temperature varied from 26°C to 44°C.

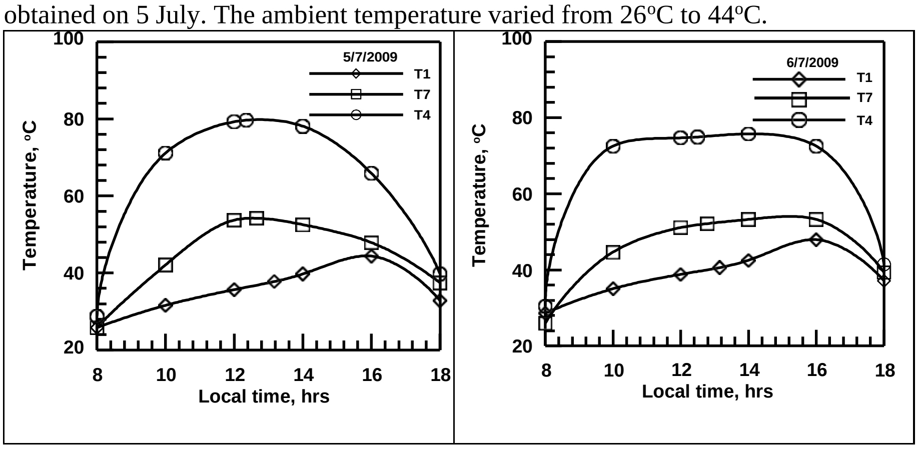

Fig. (5). Condensation and evaporation temperatures versus time.

Figure (6) illustrates the variation of temperatures respectively T1, ambient temperature, T4, evaporation temperature, T7, condensation temperature, T5, galvanized plaque in the evaporation chamber forward absorber unit, and T5, temperature of galvanized plaque in the condensation chamber forward the condensation plaque. From this figure, it is clear that the higher values of T5 were obtained on 5 July and the maximum value obtained was 58°C**.**

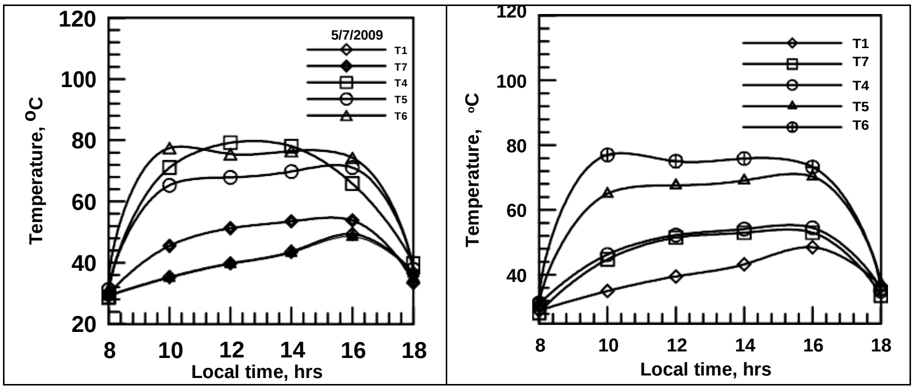

Fig. (6). Temperature variation versus time.

Figures (7 and 8) shows the variations of hourly temperature difference (T3 – T2) and brackish water yield outlet, respectively. We distinguished two intervals: before 15:00, the highest values were registered for 6 July and after 16:00 the highest values were registered for 5 July because the solar still was oriented toward sun: the solar collector was exposed to sun in the afternoon.

The highest values of brackish water was registered for 5 July, expect for the beginning, the brackish water outlet flow was equal to that 4 July and the steady values were those of 6 July, and were almost constant from 11:30 to 16:00, the lowest value of the brackish water outlet flow was on 5 July.

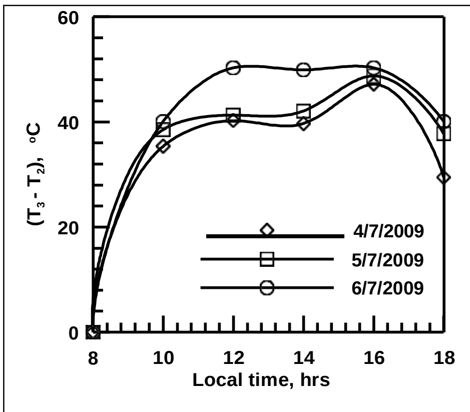

Fig. (7). Driving force temperature difference versus time.

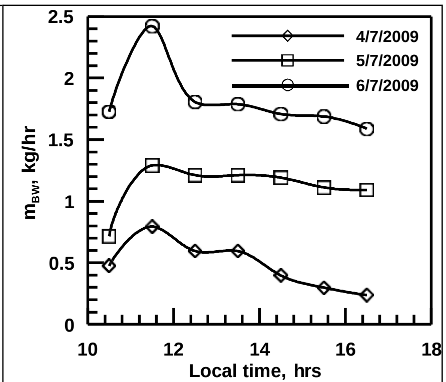

Fig. (8). Brackish water outlet flow rate versus time.

Figures (9 and 10) show the hourly efficiency and yield. The hourly efficiency of the indirect vertical solar still for this three day was almost the sun from 11:30 to 13:30. For the day of 4 July, the highest values of hourly still efficiency 59 % was registered at 15:30. For these three days the hourly efficiency varied from 19 % to 59 %. Also for these three days the hourly yield varied from 0.145 kg/h.m^2 to 0.265 kg/h.m^2

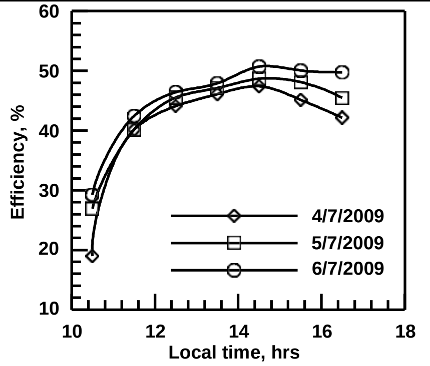

Fig. (9). Desalination efficiency versus time.

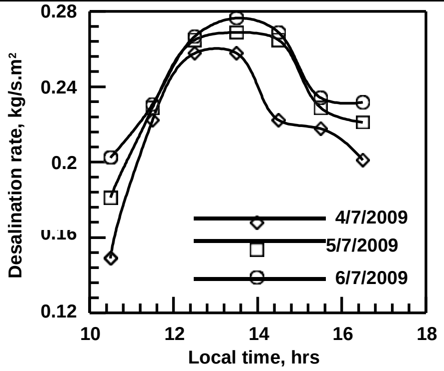

Fig. (10). Desalination rate versus time.

8. Conclusions

The preliminary performance testing of the indirect vertical solar still has been presented and the main conclusions of this research project are:

- The highest value of evaporation temperature of 80 °C was obtained on 5 July.
- The best brackish water outlet flow rate was 1kg/h.m^2.
- The maximum value of the evaporation temperature obtained is 77 °C for ambient temperature ranging from 22 °C to 46 °C.
- The highest value of hourly still efficiency is 59 % recorded at 15:30.

9. Recommendations

For future investigations more types of spongy cloth and insulation layer have to be tested to find the best one for evaporation chamber and condensation chamber. Also, a study of the effect of the multiple vertical solar still on the amount of water distillation may be performed.

10. Acknowledgement

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11. References

[1] Malik, M.A.S, Tiwari, G.N, Kumar, A. and Sodha, M.S, *"Solar Distillation*", Pergamon, (1982).

[2] Telkes, M., *"Solar distiller for life rafts", US Office of Science, R&D Report No. 5225*, (1945).
[3] Cooper, P.I, "The maximum efficiency of a single effect solar still", *Solar Energy*, (1973).
[4] Kudish, A.I, Gale, J. and Zarmi, Y, "A low cost design solar desalination unit", *Energy Conversionm*, (1982).
[5] Farid, M.M, and Hamad, F, "Performance of a single basin solar still", *Renewable Energy*, (1993).
[6] Yeh, H.M, The, L. and Chen, L.C, "Basin type solar distiller with operating pressure reduced for improved performance", *Energy*, (1985).
[7] Tiwari, G.N, Madhuri and Garg, H.P, "Effect of water flow rate over the glass cover of single basin still with an internal flow of waste hot water in the basin", *Energy Conversion Mgmt*., (1985).
[8] El-Bahi and Inan, D, "A solar still with minimum inclination, coupled to an outside condenser", *Desalination*, (1999).
[9] Fath, H.E.S, "Solar distillation: a promising alternative for water provision with free energy, simple technology and a clean environment", *Desalination,* (1998).
[10] Mink, G, Aboabbous, M.M. and Karmazsin, E, "Air blown solar still with heat recycling", *Solar Energy*, (1998).
[11] Graeter, F, Duerrbeck, M, and Rheinlaender, J, "Muhieffect still for hybrid solar/fossil desalination of sea and brackish water", *Desalination*, (2001).
[12] Ghose, M.K, "Environmentally Sustainable Supplies of Energy with specific Reference to Renewable Energy", *Energy Sources*, (2004).
[13] Hammons, T.J, "Power Generation Worldwide: Global Perspective", *Technology, Field Experience, and Research and Development*, Electric Power Components and Systems (2004).
[14] Ozgener, O, and Kocer, G,."Renwable energy Heating Applications", *Energy Sources*, (2004).
[15] Tzen, E., and Morris, R. "Renewable energy sources for desalination", *Solar Energy*, (2003).
[16] Rodriguez, L., Marrero, A., and Camacho, C., "Thermo-economic Optimization of SOL-14 Plant (Plataforma Solar de Almeria, Spain)", *Desalination*, Vol. No. 136, (2001), pp. 219-223.
[17] Holoman J. P, "*Thermodynamics*", 3 rd ed, McGraw Hill, New York, (1980), pp. 393-455.

عملية تنقية المياه باستعمال وحدة شمسية عمودية جانبية من جانب واحد

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