Solar Seawater Desalination Still with Seawater Preheater Using Efficient Heat Transfer Oil: Numerical Investigation and Data Verification

Ahmed N. Shmroukh, Gamal Tag Abdel-Jaber, Rashed D. Aldughpassi

Abstract**—**The feasibility of improving the performance of the proposed solar still unit which operated in very hot climate is investigated numerically and verified with experimental data. This solar desalination unit with proposed auxiliary device as seawater preheating system using petrol based textherm oil was used to produce pure fresh water from seawater. The effective evaporation area of basin is about 1 m^2. The unit was tested in two main operation modes which are normal and with seawater preheating system. The results showed that, there is good agreement between the theoretical data and the experimental data; this means that the numerical model can be accurately dependable for predicting the proposed solar still performance and design parameters. The results also showed that the fresh water productivity of the solar still in the modified preheating case which is higher than normal case, leads to an increase in productivity of 42%.

Keywords**—**Improving productivity, seawater desalination, solar stills, theoretical model.

I. Introduction

NUMEROUS methods exist for water purification, to obtain potable water which is safe for human to drink, some of the most common water purification methods are chlorination, iodination, reverse osmosis, boiling and filtration [1]. While, brackish and salty water can be obtained by solar distillation process [2]. The basic principle of solar desalination is using the sun light producing an effect as water-rain cycle. The sun's energy evaporates water by its heat, as the rises vapor condenses on the glass cover to be collected. This process removes microbiological organisms, heavy and salts metals. The main components of the solar desalination still are basin, stand, glass cover, absorber and a source for feeding brine [3] as shown in Fig. 1.

A comparison of double and single slope solar stills showed that due to the sun movement, a double-sided slope solar still can absorb more solar radiation than a single-sided slope basin solar still. On the other hand, the single-sided slope has less radiation and convection losses. Tiwari et al. [4], [5] performed a study of the two configurations and concluded that in cold climate only, the single slope basin solar still performed better than the double slope. While in hot climate, the evaporation rate increased with increasing temperature difference between the glass cover and the water surface. Another solar still design with cooling system was presented by Fath et al. [6], where an external storage tank of packed bed type condenser was constructed and integrated with the still. On the other hand, multi-effect solar desalination stills are designed to recycle a considerable amount of heat from the condensation process and using it for preheating either the seawater or the feed water. The later may be accomplished by preheating the feed water by the heat released from the condensing vapour, while, the condensation surface is kept continuously cool. This system can produce fresh water up to 20 l/day/m^2 [7].

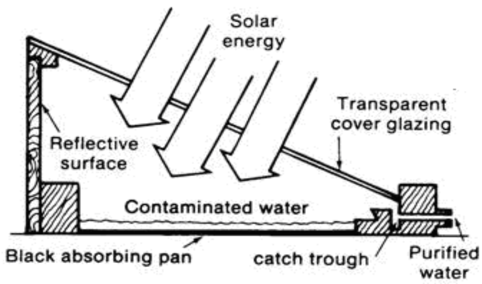

Fig. 1 Solar still components [3]

II. Solar Still Performance Analysis

To measure the performance of solar stills, the thermal circuit can be validated by building and testing two small-scale prototypes and recording nodal temperature values. It can use different thermocouples to measure the different temperature inside and outside the solar still. The thermocouples can be to the sections of the solar still prototype that represent nodes in the thermal circuit, and temperature values will be recorded for T_∞, T_{glass}, T_{air}, and T_{water} with using a data logger [8], [9]. Also, the volume of input water, the area of the basin, the area of the glass, the insulation thermal resistance, the thermal radiation value, and the wind speed were also known. When these variables, along with the final water output volume, were inserted in the thermal circuit spreadsheet, the temperature outputs for the nodes approximately matched the recorded temperature values, thus validating the thermal circuit.

III. Proposed Solar Still Used

In the investigation, a solar distillation unit with different devices for increasing productivity such as indirect water pre-

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heater, solar cooling fan, reflector was designed and manufactured. The overall components of proposed system are shown in Fig. 2.

Fig. 2 Proposed solar desalination unit with preheater [9]

The main components of system are one side solar still unit, pre-heating oil system, and accessories. Cover angle 40 deg (solar rays incidence angle in Kuwait = 39.9° (KISR)). The angle should be taken the same azimuth angle of place which will be put solar still. The effective evaporation area = basin area = 1 m^2. Selecting the basin boiling effective area depends on the distillated fresh water needed (needed productivity liter/hr).

Material used: sheet metal with thickness of 1mm. the pal size is same basin 1x1m approx. The glass cover was taken with 4 mm thickness and clear. The insulation was taken as fiber glass with thickness of 5 cm. the insulation was covered with sheet metals from one side. A black thermal coaling with thickness of 0.1 mm was performed for absorber surface with outer casing of 120 cm in length and 100 cm in width. The size is 80 x 80 cm with total effective area 0.7m^2. It was used special petrol product oil such as texatherm oil as a working heat transfer substance in pre-heating solar heating system. This oil is used on the heat transfer devices which is the heat exchanger shown in Fig. 3, this oil can be worked on high temperature reached 350 °C. This oil is proper in most low or medium operating temperature (lower than 300 °C).

Another heat exchanger was used during the condensation of water vapor in the storage tank and for evaporation in the feed water tank. The heat exchanger was design as multi-tube from copper tube of 1/2 inch outside diameter as shown in Fig. 3.

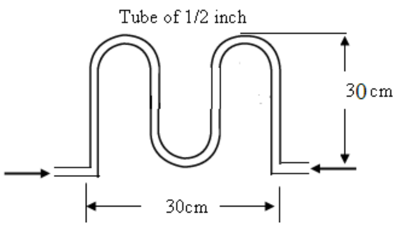

Fig. 3 U-tube HE used [9]

IV. Modes of Heat Transfer through Solar Stills

The thermal heat transfer through stills is occurred by following modes: convection, conduction, and radiation. The heat transfer rate is responsible from the evaporation and condensation processes through solar stills. So, the thermal circuit analysis is very important through the still. From this thermal circuit, an energy balance at three nodes and a spreadsheet program was developed. The energy balance is shown below along with pertinent definitions. The overall average heat transfer inside the distiller is a combination of the free convective heat transfer and the heat transferred by evaporation, therefore,

$$Q_{conv} = h*(T_s - T_\infty) \quad (1)$$

$$Q_{evap} = m*h_{fg} \quad (2)$$

where m is the mass per unit area leaving the surface, h_{fg} is the heat of vaporization of water in j/kg, T_s is the temperature of the fluid inside the distiller, and T_∞ is the temperature of the top surface and is initially unknown, h is heat transfer coefficient W/m^2 K, Q_{conv} is convection heat transfer W/m^2, Q_{evap} is evaporation heat transfer. However, the top surface temperature needs to be maintained at a low temperature as possible that will maximize condensation and yet maximize heat transferred to the fluid. The average heat transferred to the top surface is then,

$$Q_{ave} = Q_{conv} - Q_{evap} \quad (3)$$

The radiation heat transfer from water surface to the glass cover is,

$$Q_r = \varepsilon\sigma(T^4_w - T^4_g) \quad (4)$$

where: ε is emissivity of water surface which is 0.9, and σ is Stefan Boltzmann constant [10]. The glass cover and the basin can be assumed to be as two parallel infinite plates [11], [12]. The area of solar still can be calculated as,

$$A=(Q/I* \eta_s) \quad (5)$$

where: η_s is the conversion efficiency, Q is the total heat transfer rate to basin, and I is the available solar intensity W/m^2 [13], [14].

$$Q = m\, C_p\, \Delta T \quad (6)$$

where: m is the still productivity, C_p is the specific heat for water which is 4.2 kJ/kg K, and ΔT is the temperature difference in °C [15], [16].

The total solar heat to still is given by conduction and by balancing convection rate through water in basin and ambient air then,

$$h_w A(T_w - T_{air}) = h_g A(T_{air} - T_g) \quad (7)$$

Heat transfer coefficients for natural and forced convection were determined using necessary correlations. From these energy balances, a MATLAB program was developed that allows for an iterative process to determine required area for a specified water output.

V. Results & Discussions

A series of experiment in different days was carried out. The following parameters were measured such as ambient temperature, basin water temperature, glass cover temperature, oil temperature at inlet and outlet, fresh water output and water vapor temperature. The data were analyzed by using MATLAB program [17]. And set in graphs with time hours and with ambient temperature. Fig. 4 shows relation between basin water temperature and ambient temperature in case of normal operation without modification. Where T_{amb} is ambient temperature in site and $T_{w\ basin}$ is temperature of saline water in basin. As shown in the figure with increase the ambient temperature, the basin water temperature also increased directly due to heat transfer through solar still unit. Increase the ambient lead to increase the rate of heat reached to basin and then the rate of water evaporation will be increased also.

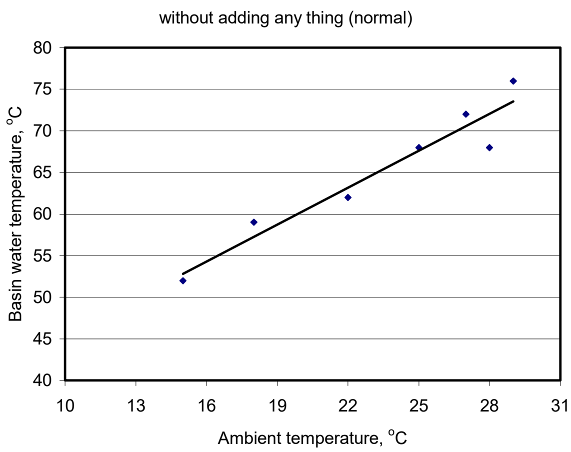

Fig. 4 Water basin temperature with ambient temperature

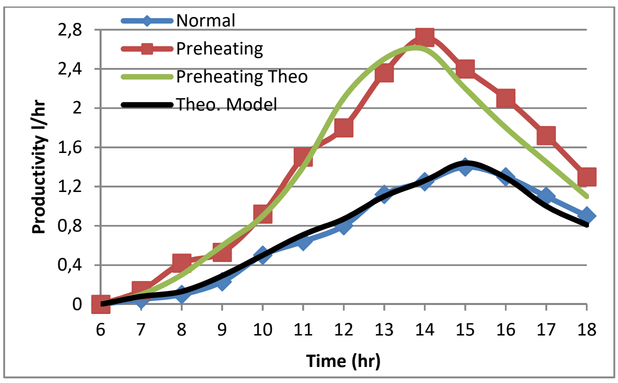

Fig. 5 Theoretical an experimental solar still productivity

Figs. 5 and 6 show the productivity and the efficiency of the still with the preheating modification device and in normal case with the theoretical data, in case of using preheated the rate of increase in the efficiency of still is reached about 42% and the productivity increased. So, using the preheating oil leads to increase the productivity of the proposed solar still. Also, there is a good agreement between the experimental results and the theoretical data in all cases and modes [18].

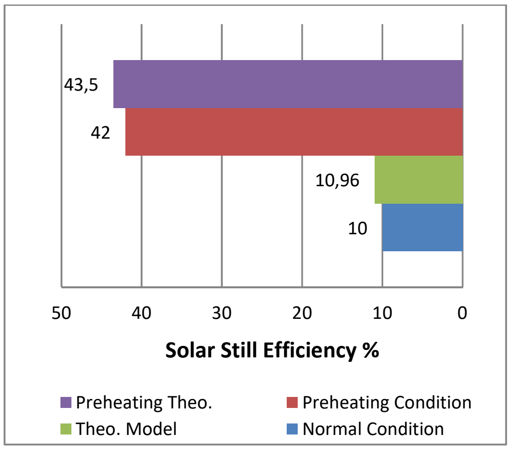

Fig. 6 Theoretical an experimental solar still efficiency

VI. Conclusions

The solar still is a promising method for providing fresh water to any region with considerable amounts of available solar energy. Using preheating oil exchanger leads to improve the productivity of the solar still. The productivity was increased over than 42% in this case with a very good agreement with the theoretical data. Also, there is a good agreement between the experimental and theoretical data. Also, the average fresh water productivity per hour in the normal case was about 0.9 liter only, otherwise in the modified case it was around 1.3 liter. On the other hand, the average efficiency of seawater solar desalination unit without and with proposed modification was reached 10% and 42% respectively.

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