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EXPERIMENTAL INVETIGATION AND DESIGN OF A SOLAR DESALINATION UNIT WHICH WORK WITH HUMIDIFICATION-DEHUMIDIFICATION PROCESS

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ABSTRACT

Solar desalination is an appropriate method for providing fresh water by using renewable solar energy. Solar desalination with humidification and dehumidification process is one of the most effective methods among solar desalination units. This technique presents several advantages such as flexibility in capacity, moderate installation and operating costs, simplicity, possibility of using low temperature energy (geothermal, solar, recovered energy or cogeneration), etc. Processes that are used in this method are the open water cycle- open air cycle, open water cycle- closed air cycle and closed water cycle- closed air cycle. Process used in this work is a open water-closed air cycle type, in which air is circulated in the unit by forced or natural draft between the humidifier and condenser. In this paper, the different effective parameters such as rate of water flow entering condenser, internal temperature to the humidifier, natural and forced air flow, etc were examined. With the temperature increase of water entering humidifier, the amount of produced steam and, as a result, fresh water was increased. However, for temperature increase of water which exits from collector the mass of salty water inflow should be decreased. This decrease of water flow causes reduction of desalinated water in the condenser section of the unit. Results show that there is an optimum rate of salty water flow entering to the unit. Besides, a considerable difference in production of present work with almost others were observed for natural and forced air flow.

Key words: Solar Desalination, humidification and dehumidification, Multi Effect Humidification.

INTRODUCTION

Water is available in plentiful quantities in nature, however there is a shortage of drinkable water in many countries in the word. Expensive non-renewable energy, such as petroleum fuel and natural gas, has been used for water desalination either directly or through its conversion to electricity, which may be used to run reverse osmosis units. Shortage of water consequence occurs at places that have hot climate with high solar radiation that may make the application of solar energy for water desalination practical. This has been the attempts of many investigators since years, using single or multiple-basin stills. The efficiency of these stills is of the order of 30-50% only, which is due to the large heat losses through the glass cover of the still, where the condensation occurs[1].

If a flat plate solar collector is used to provide the heat, where the maximum water temperature should not exceed 70° to 80° C, otherwise the collector efficiency will drop significantly. Water at such temperatures requires an efficient method of evaporation, such as spraying over some packing against countercurrent air flow. This led to the development of a desalination process known as the multi-effect humidification-dehumidification process (MEH)[2]. In this method the water heated with solar energy through the solar collector and then with heat and mass transfer between air and water, air heated and it's humidity increases. Then humidity of air decreases through the condenser and fresh water obtained. The solar desalination units which work according to humidification and dehumidification have been fabricated in different regions. From 1990 to 1996, M.Farid and his colleagues [3,4,5]made three 'MEH' units in Iraq, Malaysia and Jordan (For some of these units, simulation program and distributed temperature figures have been prepared and manufacturing of machines via existing software has been done [3]). N.K. Nawayseh et al' [6,7] had many study about this unit. 'Muller-Holst et al' and his colleagues [8,9] have applied a simulation program, TRANSY, to consider the effect of internal water temperature and amount of transferred heat to the open circulated natural air flow system. The system used in this consideration is open water-close air circle whose schematic diagram has been shown in figure 1. In this consideration after manufacturing of the solar desalination -figure 2-, the optimum amount of salty water for forced air draft flow was gained and the performance of unite in two positions- forced and natural air draft flow- was compared.

EXPERIMENTAL SETUP AND PROCEDURE

According to the Fig 1, salty water enters into unit with the temperature T_1. Then it interchanges heat with heated air in a condenser, and its temperature increases to T_2. After that, the salty water enters a solar collector and its temperature increases to T_3. Then this water enters 'Humidifier'. In this part, the heated water is sprayed downward on a 'Packing' which causes water exchange mass and heat with the air passing upward through these packings. Air is heated in this process and its temperature grows from T_5 to T_6 - notice on psychometric diagram which the warm air could absorb humidity more than cool air accordingly. The salty water, whose salt density has been increased, leaves the system with temperature T_4. The heated air which increases its humidity enters into the condenser part and after a decrease in its temperature, reaches to T_5 again. This causes desalination of existent water. The desalinated water in condenser is fresh water.

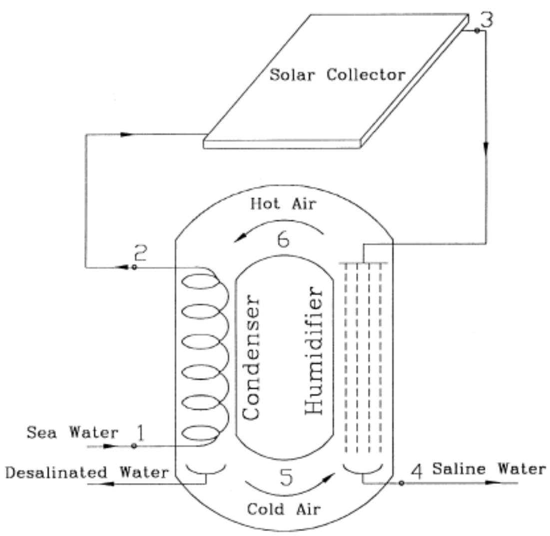

Fig 1. Schematic diagram of solar desalination unit

The setup of experimentation has been shown in figure 2. A water meter and a counter have been used for measuring the flux of salty water, and the temperature of water and air have been measured by a mercury thermometer.

Fig 2. Setup for experimentation[1]

The transmitting air has been fabricated by plexy glass with thickness of 10 mm and the height of 1800 mm. condenser and humidifier are connected by two 1200 mm widthwise channels. The condenser is a conical shape copper coil and has 800 mm long. The coil diameter is 12 mm (figure 3). There are two kinds of packings: the first one is the usual cooler straw, and the other is a reticular wooden plate whose area is $5.4m^2$. The area of utilized solar collector is $3m^2$. A kind of straw has been shown in the right side of the figure 2, and a kind of packing with well arranged shape has been indicated in Fig 4.

Fig 3. Condenser of setup (conical coil)[1]

Fig 4. The packing which has been utilized in setup[1]

For operation of unit in the forced air draft circulation, an axial fan has been placed on the bottom of the unit. The pump which has been used for pumping of salty water into the unit is a centrifuge kind with the mass flow between 5 and 40 L/min and with the produced height between 5.5 and 40m. The fan is also an axial one and the dimension of its frame is $30 \times 30 cm^2$. In addition, the diameter of its opening is 25 cm. The used solar collector is a kind of flat plate solar collector whose area is $3m^2$ and has been placed on a metallic basis with the slope of 30 degree (Fig5).

Fig 5. Flat plate solar collector which has been used in the unit[1]

Connector pipes between different sections of the unit are made from a sort of springy plastic which can tolerate the temperatures more than 100 degree centigrade. The internal diameter of these pipes is 16 mm.

THE RESULT OF EXPERIMENTS ON THE SETUP

The performed experiments consist of achieving of distributed temperature in different parts of the unit and perceiving the amount of produced fresh water. Moreover, the effect of the rate of water flow in both natural and forced air flow was examined and the results were compared.

The amount of product originates from the internal water flow that has two opposite effects. An increase in internal water flow causes a decrease in the ability of collector to increase the temperature of entrance water. On the other hand, an increase in the entrance water flow to humidifier causes increase of steam and then will result in the growth of product. These two opposite reasons cause the existence of an optimum amount for entrance water flow, which has been registered in experiments.

Air flux is also effective on the amount of the product. This has been proved by different examinations in both natural and forced air circulation and comparing them for an identical water flow.

In Fig. 6 the measured temperatures of various sections of the setup for air flow of 0.06 kg/s have been shown. In Fig.7 the results of the theory analysis have been presented. It is better to remind that although applied dimensions and sizes in the analysis of theory which Farid and his colleagues have performed are different from the fabricated unit, the procedure of diagram is the same.

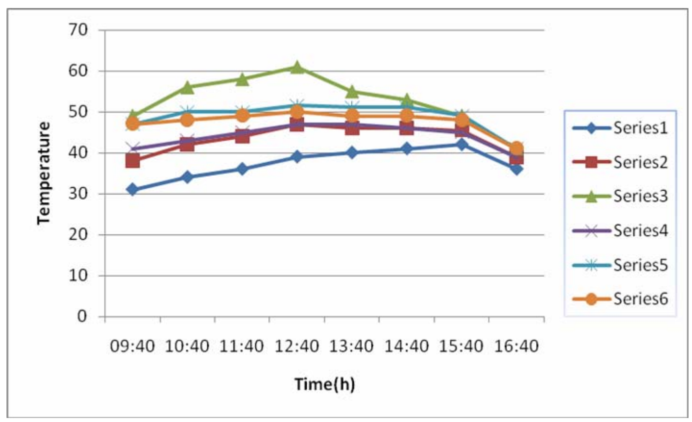

Fig 6. Tmperature distribution of unit for external water flow of 0.009 kg/s and air flow of 0.06 kg/s

In Fig. 7 the results of theoretical analysis of these kinds of unit have been shown. This result is the consequence of Farid and his colleagues' studies [3,6,7,10].

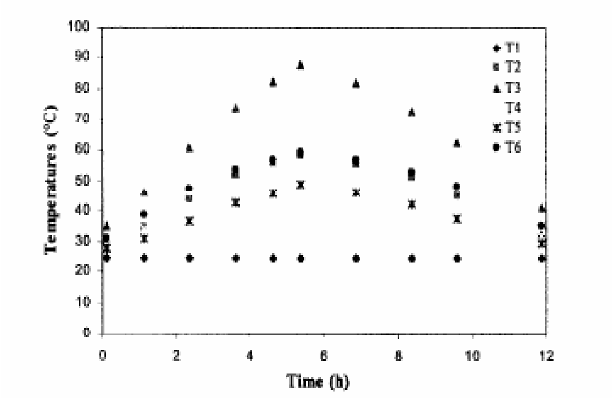

Fig7. Theoretical thermal distribution of Ferid [3]

It is better to mention that in experimental diagrams, the entrance temperature was not constant. The cause of this task is the usage of existed water -in the feeding container- which has been exposed to sun emission during the experiment. So, its temperature changes along the day time with the intensity variations of sun emission.

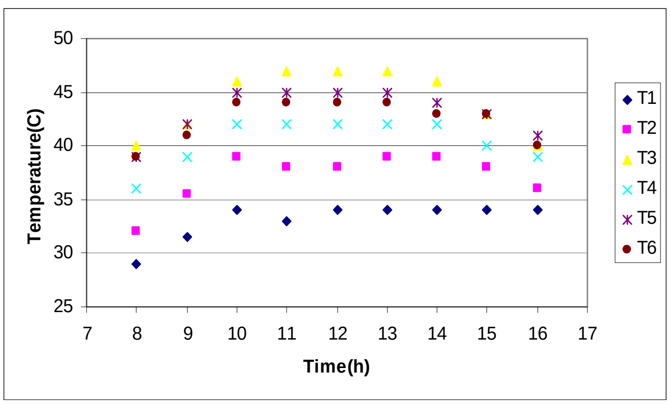

Fig 8. Distributed temperature of unit for optimum mass flow of salty water (0.017 kg/s)

As it is seen, the production of unit is less than theoretical amount of production. This is because of small area of condenser and humidifier of fabricated unit in comparison with theoretical area which has been used in simulation software. In addition, the production rate has a parabolic configuration (Fig 9), which is justifiable with changes of emission intense. Hence, with the passage of time and being close to the noon time the amount of production approaches to its maximum amount, and decreases by arriving of the evening and night.

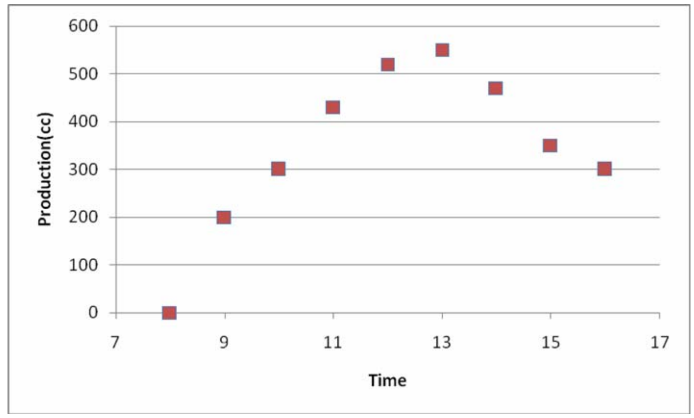

Fig 9. The production figure in different time for optimum mass flow

In Fig. 10 and 11, the production diagrams according to entrance mass flow of water to the unit have been presented both theoretically and experimentally.

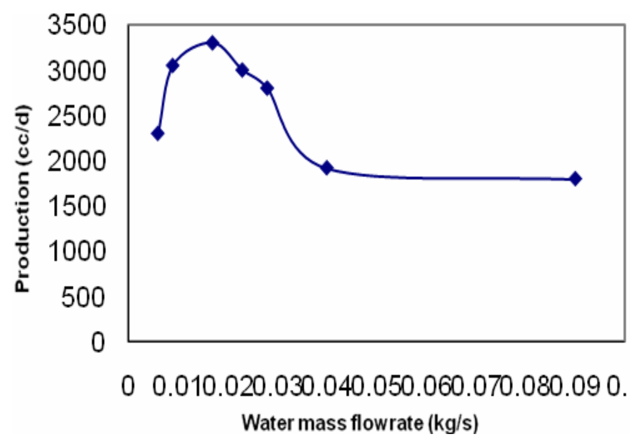

Fig 10. The experimental amount of production according to entrance mass flow of water

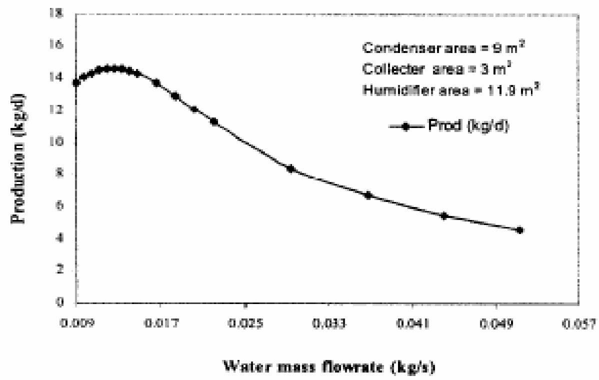

Fig 11. The Farid theoretical amount of production according to entrance mass flow of water[3]

As it is observed, the results of both theoretical and experimental analyses shows an optimum operational point of unit for the different rates of salty water.
The changing process of unit production according to mass flow of entrance water is similar to theoretical variations; although, the amount of experimental production is less than theoretical one, which is because of small area of condenser and humidifier of manufactured setup.

THE COMPARISON OF PRODUCTION OF UNIT IN BOTH NATURAL AND FORCED AIR FLOW

As it is observed in Fig. 12 and 13, the amount of unit production in the case of natural air flow has been deduced less than half, which shows the effect of air mass flow on machine operation. This is because of significant pressure drop in packings. In this status, the natural flux of flowing air doesn't have the ability to overcome this pressure drop. Thus, the produced steam can not arrive at condenser surface.

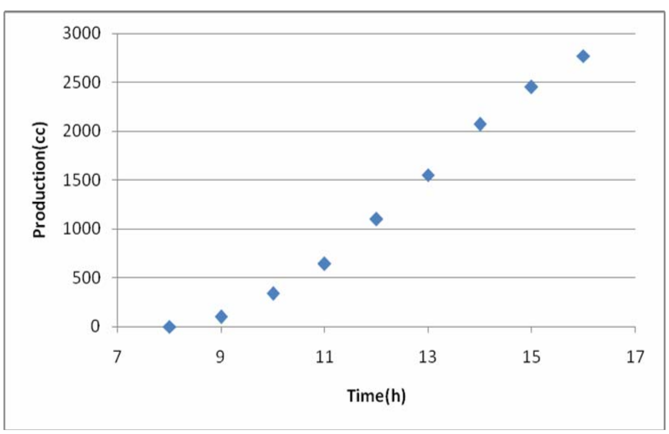

Fig 12. The product figure for mass flow of 0.019 kg/s salty water and forced air flow

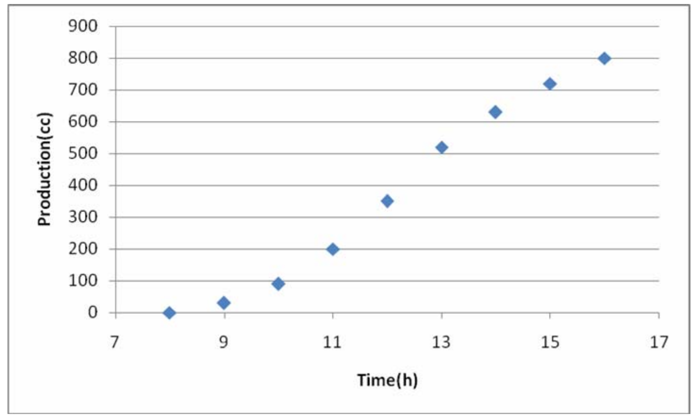

Fig13. The product figure for mass flow of 0.019 kg/s salty water and natural air flow

CONCLUSION:

The following can be expressed according to achieved results of the experiments:
The effect of mass flow of water on unit operation seems to be very significant. Increasing the mass flow of water decreases the collector's efficiency and maximum entrance temperature of humidifier. This matter causes a decrease in production amount of steam in the humidifier and in general affects the amount of production. Increasing the mass flow of water leads to an increase in the local heat transfer coefficient of water in collector and prevents from the temperature increase of water in it. The decrease of mass flow increases not only the collector efficiency but also the entrance temperature of humidifier. However, the decrease of sprayed water in humidifier reduces the amount of water condensation in condenser. According to what has been explained, there is an optimum amount of water mass flow for each mass flow of passing air in the unit 0.017 kg/s water mass flow was obtained by experiments for this purpose (Fig 10).
The effect of air mass flow on unit operation is noticeable. According to the achieved experimental results, the marked differences of production amount in two statuses demonstrate the effect of forced air flow on unit operation. During experiments, the effect of forced air flow on production amount of steam is clearly observable. This conclusion is different from any other report in this subject [11,12,13]. The reason of this, might bee due to the pressure drop of air flow in packings and straw that causes the deduction of forced air flow and produced amount of fresh water in the condenser.
The surface of the condenser plays an important role in the amount of production. The inlet water temperature to the condenser affects the performance. This inlet temperature has an optimum amount [1,2], which is not considered here; Application of condenser with more extended surface is one of the most important cases which should be noticed in the future studies. Because the increase of condenser surface raises the amount of desalinated water, in addition to the enhance of the inlet temperature of water to the collector. This matter leads to

increase of entrance maximum temperature to the humidifier, which causes the production of more steam.
Enhancing the humidifier surface and use of other materials in packing may be considered as other cases which lead to better performance of humidifier and more production of steam.

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