PROCESS ENGINEERING

STUDY OF SOME FACTORS EFFECTING ON PRODUCTIVITY OF SOLAR DISTILLERS

Keshek, M.H. [(1)]; **Mohamed, M.A.** [(2)] **and Maha A. El-Shafey** [(3)]

ABSTRACT

The aim of this research was increasing the productivity of solar distillation. In order to reach this aim a solar distiller was created with three glass sides sloping 30° at the horizontal level, and the experiments were carried out on the solar distillation unit during the period from 24th August, 2016 till 24th May, 2017 at the Agricultural Engineering and Bio Systems Department, Faculty of Agriculture, Menoufia University. Three gap lengths were used between the water level and the inner glass cover, those were 3, 6, and 9cm. As the result of change the gap length between the water level and the inner glass cover the total volume of basins were changed from 15.5, 13, and 11L respectively. The total basin volume divided to three sections, to investigate the effect of water volume. The three water volumes were 100%, 75%, and 50%. Every section was supplied with one, two or three heaters. The one heater power was 15 W. The results showed that, by increase in distance between the basins edge and the inner edge of the glass cover an increase occurs in the percentage of temperature difference with maximum value was 52% at distance 9cm from each edge, an increase occurs in the productivity with maximum productivity was 3.3L/m^2 at distance 9cm from each edge and an increase occurs in the efficiency with maximum efficiency was 70% at distance 9cm from each edge

Keywords: *Water distillation; solar energy; the still productivity; and distillation efficiency.*

1. INTRODUCTION

Desalination is growing rapidly worldwide. However, there are still obstacles to its wider implementation and acceptance such as: (a) high costs and energy use for fresh water production; (b) environmental impacts from concentrate disposal; (c) a complex, convoluted and time-consuming project permitting process; and (d) limited public understanding of the role, importance, benefits and environmental challenges of desalination **(Zotalis et al.2014).**

(1) Associate professor, Agric. Eng. Dept., Faculty of Agric., Menoufia University.
(2) Professor, Agric. Eng. Dept., Faculty of Agric., Menoufia University.
(3) Postgraduate student, Agric. Eng. Dept., Faculty of Agric., Menoufia University.

The basic principles of solar water distillation are simple, yet effective, as distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapor rises, condensing on the glass surface for collection. This process removes impurities, such as salt, sand and heavy metals, and eliminates microbiological organisms.

The end result is water cleaner than the purest rainwater **(Bhupendra et al.2013).** Improving solar still productivity has been the subject of intensive research efforts and remains a challenge to the scientists. This improvement can be achieved through a proper modification in the still design and its operation mode by adopting different techniques **(Kabeel et al. 2014).** Solar desalination is one of the most appropriate solutions to overcome the water shortage problem which threatens the human life in many regions around the world **(Abdelouahab and Rahmani 2017).** There is a relation between the cover tilt angle and productivity of simple solar still in various seasons is established together with a relation between the optimum tilt angle and the latitude angle by an extensive review of the literature. He found that increasing the tilt angle increase the productivity in winter while, in summer the trend is the opposite. He added that increasing the tilt angle would increase the productivity throughout the year and optimum cover tilt angle that is close to the latitude angle of the site **(Khalifa 2011).** The efficiency of the single-basin solar still is in the range of 30-50%. The major problem behind this is the loss of latent heat from condensation through the glass cover of the stills. The used of a plate solar collector to supply the heat to the still was slightly improved the desalination efficiency, but the increase in the cost of the unit was significant. They added that some investigators was make the water flow over the glass cover to Preheating of the feed water by passing it over the glass cover allowed only partial utilization of the latent heat with only a limited increase in the production. However, the flow of water over the glass cover reduced the amount of solar radiation received by the water in the still and the accumulation of salt was also some of the defects of these units **(Yahya 2011).** The saline water temperature controls the evaporation rate as the latter increases with the increase of the temperature of the unpurified water. Parabolic concentrators, plate collector, mini solar pond are combined with the solar still to increase its temperature. Large amounts of energy may be

needed for increasing the temperature of the entire solar still water. The evaporation rate is directly proportional with the temperature of the water free surface area. Therefore, we can use baffle suspended absorber plates to increase the water free surface area **(Velmurugan and Srithar 2011).** The main factors affecting the productivity of a solar still as mentioned before are solar intensity, wind velocity, environmental temperature, water–glass temperature difference, depth of water, temperature of inlet water, absorber plate area and glass cover angle. Metrological parameters such as solar intensity, wind velocity and environmental temperature cannot be controlled **(Sharshir et al. 2015).** Solar still is suited to villages and to mass production water purification. Around the world, concerns over water quality are increasing, and in special situations a solar still can provide a water supply more economically than any other method. The two big advantages of a solar still are that it uses low grade solar energy which is available forever and there is no greenhouse pollutant evolution as is the case with other desalination techniques using fossil fuels. Further it can be utilized in remote places where there is no electricity and fuels **(Bhupendra et al, 2013).** So that the objective of this study was studying some factors effect on solar desalination such as distance between the basins edge and the inner edge of the glass cover, water basin volume, and number of addition heaters on productivity and efficiency of solar distillers.

2. MATERIALS AND METHODS
2.1. Equipment and materials
2.1.1. Solar distillers.
The solar distillers were created in the form of pyramid, as shown in figure (1). The three sides of the still were sloping 30° to its horizontal base, and the fourth side of the still was vertical on the still's base. Solar distiller base area was 0.82 m^2.

2.1.1. Solar distiller's basins
Basins were isosceles trapezium. Their thicknesses were 3 cm. Three gaps between the basins edge and the inner edge of the glass cover, those gaps were 3, 6, and 9cm. According to the length of the gap the total volume of the basins were 15.5, 13, and 11L (liter) for gap length 3, 6, and 9cm respectively. Each basin its total volume divided to three parts,

to investigate the effect of water volume on the productivity. The three parts were 100%, 75%, and 50% from the total basins volumes.
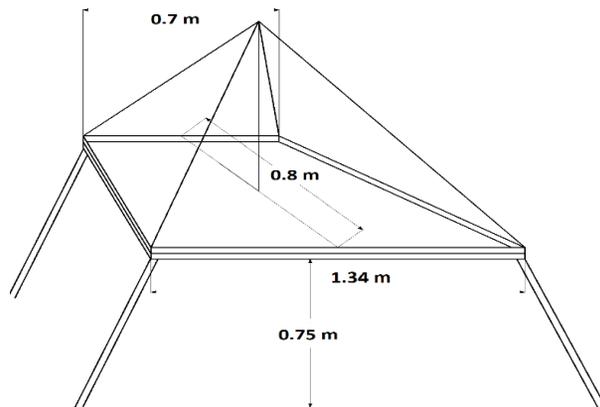
Figure (1) Schematic diagram of the solar still.

2.1.2. Water specifications

Due to seawater wasn't available in experiment's place, brackish water was used. Salinity was 170 ppm. Salt was added to simulate the salinity of seawater (35000 ppm), in the rate of 35 gram salt per liter of water. The following table (3.2) showed the quantity of water in liter which was used in each basin.

	Section 1	Sec. 2	Sec. 3	Total
First basin	7.5	4.25	3.75	15.5
Second basin	6.5	3.2	3.3	13
Third basin	5.5	2.5	3	11

2.1.3. Heaters

Handmade heaters were used in these experiments. Its length was 15 cm. Each one of them was consists of glass tube included welding heater, to isolate it from water. Sand was put between them, to let air out. The power of this heater was 15-Watt, figure (2).

Figure (2) Heaters

Measurements

Temperatures measurements

LabJackU3 HV (High-Voltage) was used to record the air and inner water temperatures, which were measured during the experiments. Out

temperatures of the pyramid still and air temperature were measured by four thermometers. Temperature range of the thermometer reached to 110º Celsius, figure (3).

Figure (3) LabJackU3 HV (High-Voltage)

Quantity of water

Measuring cylinder was used to measure the quantity of water entering still and distilled water.

TDS meter

A TDS meter indicates the total dissolved solids (TDS) of a solution, i.e. the concentration of dissolved solid particles.

Daily efficiency of solar (passive and active) distillers.

The overall thermal efficiency ($\eta_{p\text{-}ss}$) for S-SSU is represented as the ratio between net energy output from solar distiller to net available solar radiation intensity which is given by **Tiwari et al. (2007)** as follows:

$$\eta_{p\text{-}ss1} = (\text{daily yield} \times L)/(A_s \times \Sigma\ I_s \times 3600) \times 100\%$$

Where daily yield L/hr, L was the water vaporization latent heat kJ/kg, A_s was area of the basin still m^2, and $\Sigma\ I_s$ total solar irradiance on solar distiller kW/m^2.

The overall thermal efficiency of the proposed still ($\eta_{A\text{-}ss\text{-}HPVT}$) was calculated by summing the thermal efficiency of the active still and the electrical efficiency of the solar PV. With the reference of **Tiwari et al. (2007),** the overall efficiency was calculated by the following equations:

$$\eta_{p\text{-}ss2} = (\text{daily yield} \times L)/[(A_s \times \Sigma\ I_s) + (\ n \times \Sigma\ I_p) \times 3600] \times 100\%$$

Where n was number of using heaters, and $\Sigma\ I_p$ the heater power, which was 15 W.

The percentage of temperature difference between inside and outside was calculated by the following equations:

$$(T_{in} - T_{out})/T_{in} \times 100$$

Then the average temperature difference is calculated during the day (av t, %).

3-RESULTS AND DISCUSSION

3.1. Productivity of solar distillers

### 3.1.1. Productivity with different sizes of basins

The productivity for the tested period of the day for the first, second, and third basin when using none, 1, 2 and 3 heaters in each section, and when the basin was filled with water volume 100%, 75%, and 50%, those volumes located when the distance between basin and glass was 3, 6, and 9cm (15.5, 13, 11L respectively). The highest productivity were 1.4, 1.8, 3.3 L/m^2 respectively.
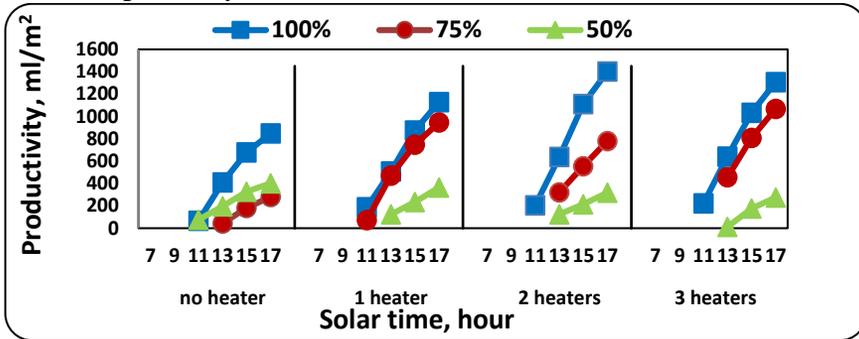
(a) for basin volume 15.5 (liter).
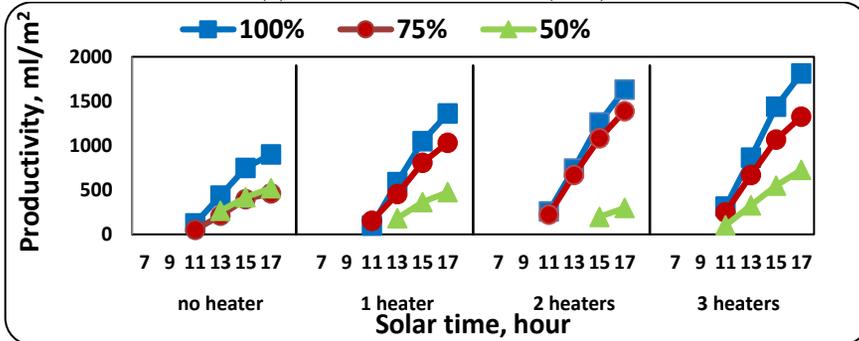
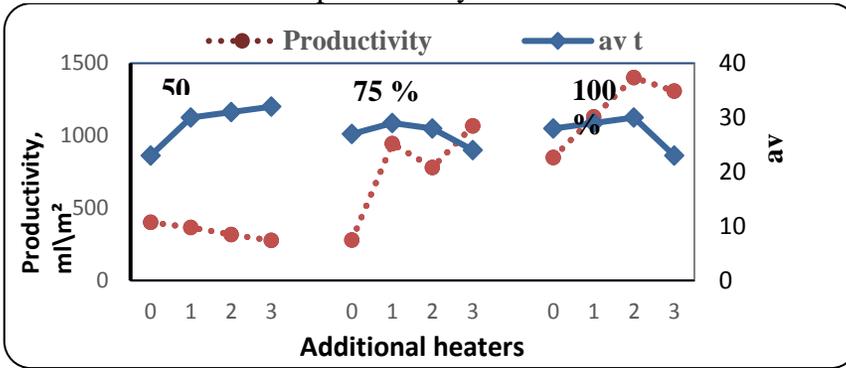**(b) for basin volume 13 (liter).**
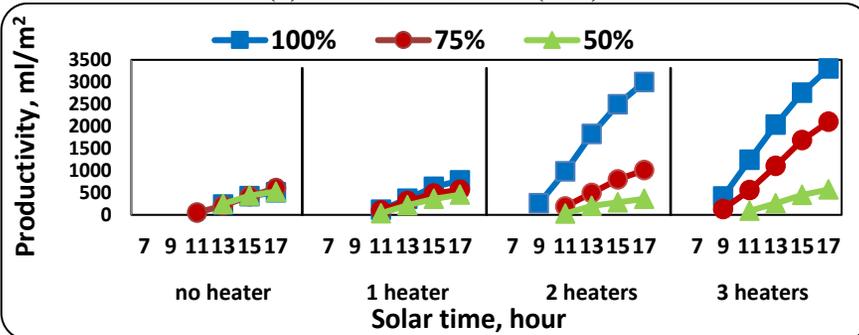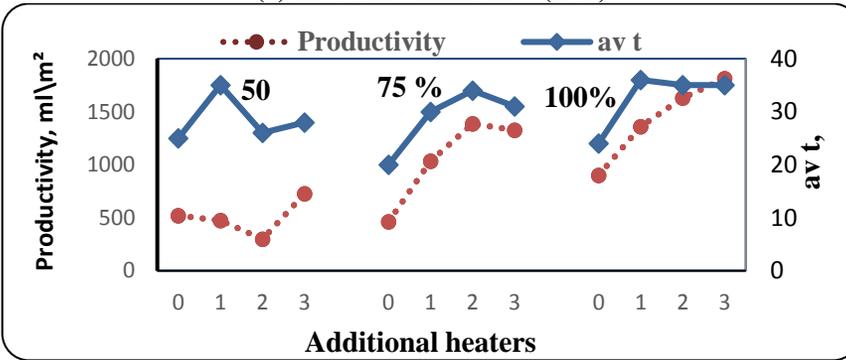

(c) for basin volume 11 (liter).
Fig.4. Productivity for basins.

3.1.2. <u>Productivity and average ratio of temperature difference.</u>
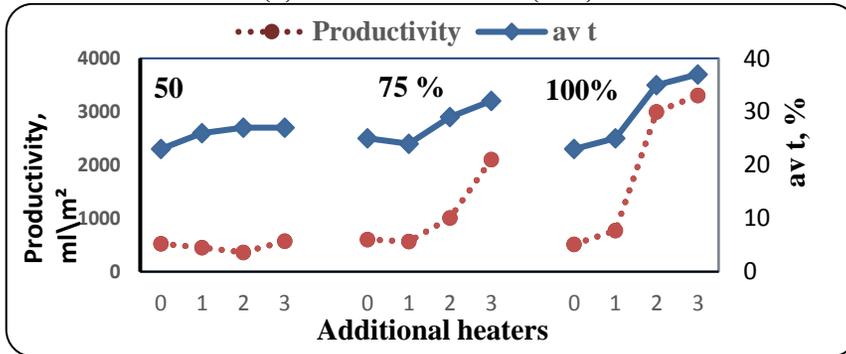
Figures (5) a, b, and c present the relation between productivity and average percentages of temperature difference (av t) with the different treatments, and from figures it can conclude that, maximum productivity was 3.3L/m^2 and minimum productivity was 0.3 L/m^2.

(a) for basin volume 15.5 (liter).
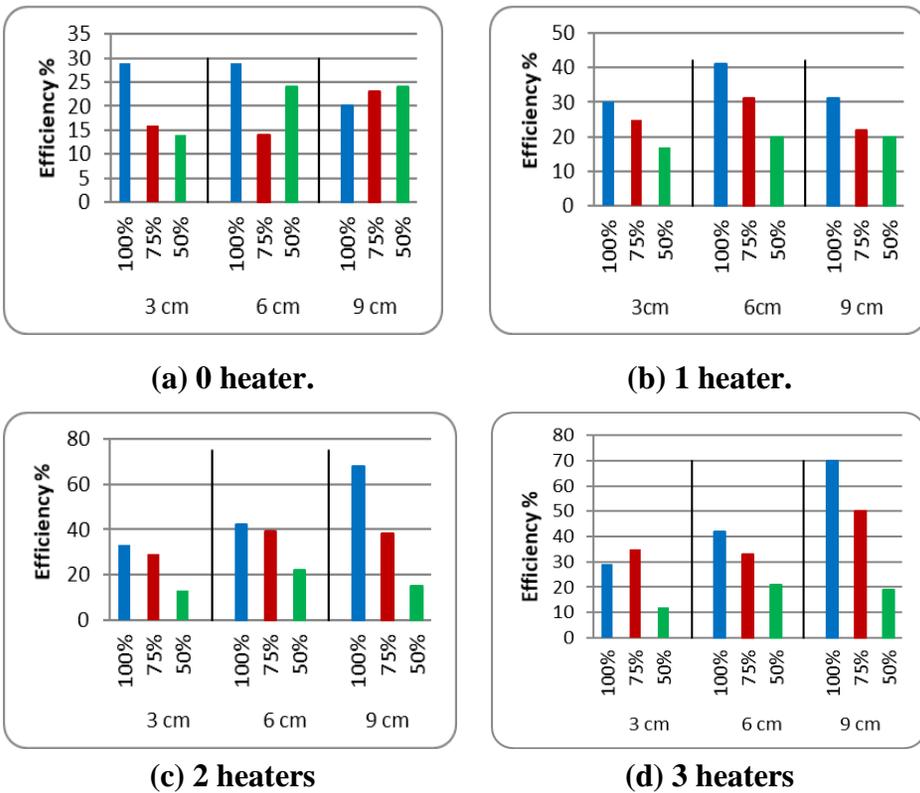

(b) for basin volume 13 (liter).

(c) for basin volume 11 (liter).

Fig.5. The productivity and average ratio of temperature difference (av t,).

3.2. Efficiency of solar distiller.
3.2.1. Thermal efficiency solar distillers.

Figures (6) a, b, c, and d show the efficiency for the distiller for all work's days. In the figures a, and b the second basin which filled with water by 13L (100%) gave the highest efficiency in two cases, without using heaters and when using one heater. In the figures c, and d the third basin which filled with water by 11L (100%) gave the highest efficiency in two cases, when using two and three heaters. The maximum efficiency was 70%, The minimum efficiency was 12%.

(a) 0 heater.

(b) 1 heater.

(c) 2 heaters
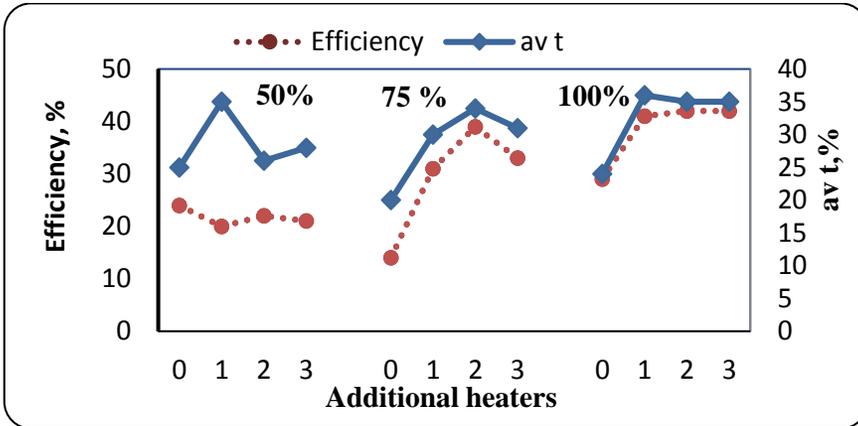

(d) 3 heaters

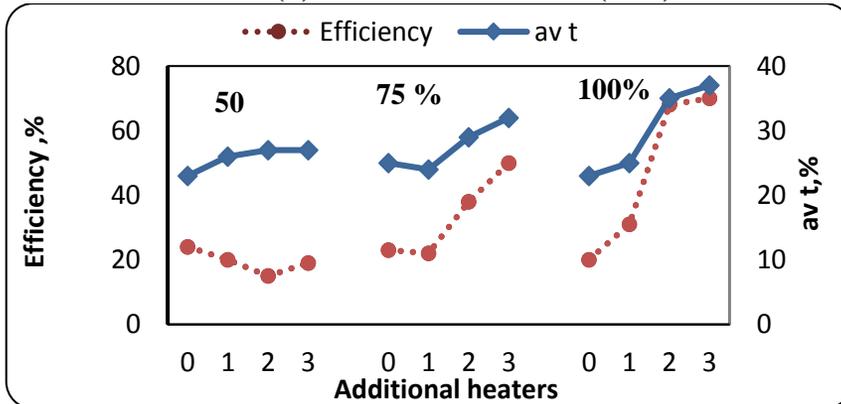**Fig.6. Thermal efficiency of solar distiller.**

Figures (7) a, b and c present the relation between efficiency and average percentage of temperature difference (av t) with different treatments. From this figures it can conclude that, by increase of basin volume, a decrease occurs in efficiency of the still.
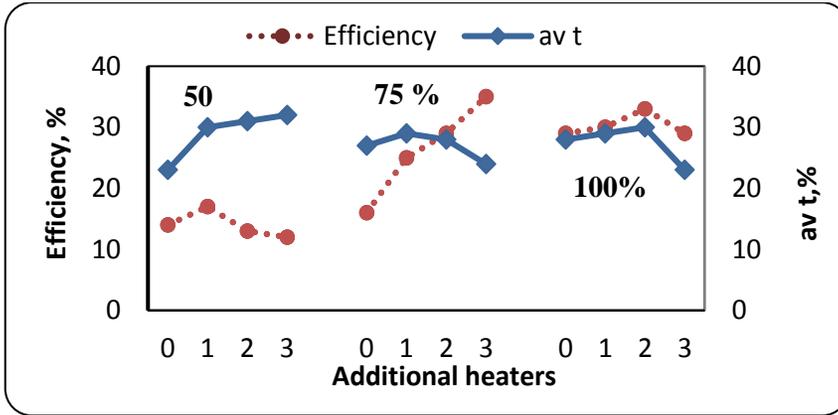
**(a) for basin volume 15.5 (liter).**

(b) for basin volume 13 (liter).

(c) for basin volume 11 (liter).

**Fig. 7. Thermal efficiency average ratio of
temperature difference (av t,).**

Effectiveness of water production

Figures (8) a, b, c, and d show the efficiency by divide output and input water for the distiller. From these figures it can conclude that, the maximum efficiency was 24.6% at distance 9cm from each edge and full 100% with water, and that when using 3 heaters in each section. The minimum efficiency was 2% at distance 3cm from each edge and full 75% with water, and that without using heaters.

(a) 0 heater.

(b) 1 heater.

(c) 2 heaters

(d) 3 heaters
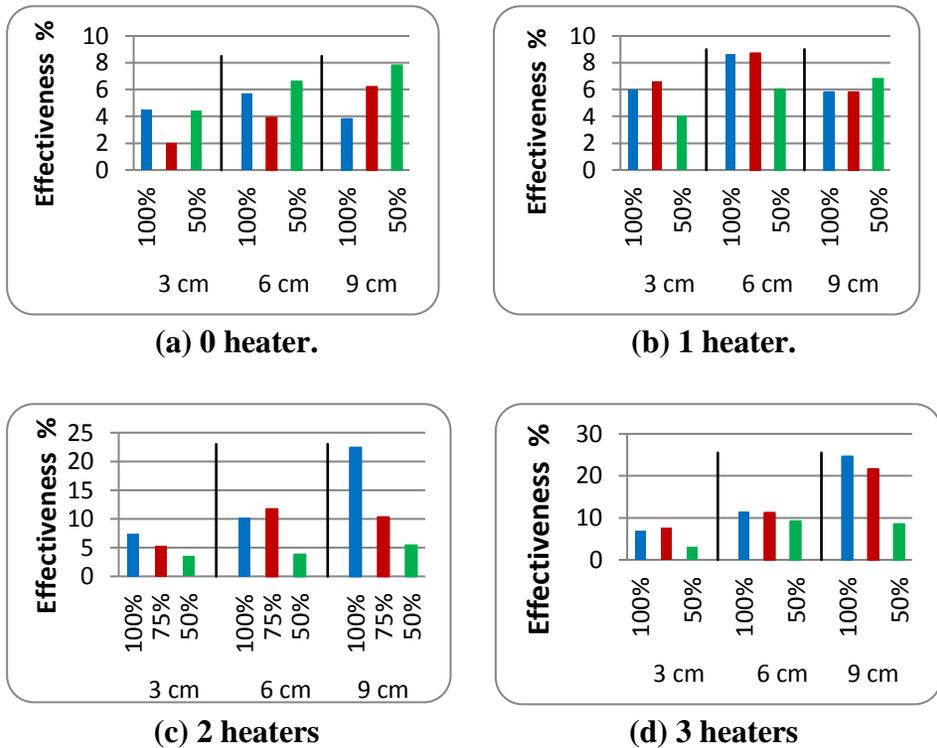
Fig.8. Effectiveness of water production.

4. CONCLUSIONS

We can concluded that by increase in distance between the basins edge and the inner edge of the glass cover an increase occurs in the percentage of temperature difference with maximum value was 52% at distance 9cm from each edge, an increase occurs in the productivity with maximum productivity was $3.3L/m^2$ at distance 9cm from each edge and an increase occurs in the efficiency with maximum efficiency was 70% at distance 9cm from each edge.

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الملخص العربى

دراسة بعض العوامل المؤثرة على انتاجية مقطرات شمسية

د/محمود حسن كشك[1]   ،   أ.د/ محمود محمد على[2]   و   م/مها أشرف الشافعى[3]

أجرى هذا البحث لدراسة بعض العوامل المؤثرة على رفع كفاءة المقطر الشمسى. ولتحقيق الهدف من الدراسة تم إنشاء مقطر شمسى ودراسة العوامل المؤثرة على هذا المقطر، حيث تم تصنيعه بقسم الهندسة الزراعية والنظم الحيوية – كلية الزراعة – جامعة المنوفية (خط عرض ٣٠ درجة) واجريت التجارب فى الفترة من ٢٤ اغسطس ٢٠١٦ حتى ٢٤ مايو ٢٠١٧. المقطر على شكل هرمى، جوانبه الثلاثة تميل على الافقى بزاوية ٣٠ درجة، وهى زاوية الميل المثلى طول العام لخط عرض مكان الزراعة. وهذه الجوانب مصنوعة من الزجاج بسمك ٤ مم. واطار المقطر وقاعدته مصنوعين من الالومنيوم. قاعدة الجهاز على شكل شبه منحرف متساوى الضلعين، طول الضلعين المتساويين ٠,٩ م وطول الضلعين المتوازيين ٠,٧ و ١,٣٤ م. ثلاثة احواض لوضع الماء المالح بها، مصنوعة من الصلب بسمك ٣ مم. كل حوض له مقاس مختلف، حيث تم تصميم أكبر حوض بحيث يبعد عن كل اطراف الجهاز ب ٣ سم من الاربع جوانب، وحوض متوسط يبعد ٦ سم عن الاربع جوانب، واصغر حوض يبعد ٩ سم عن الاربع جوانب. كل حوض مقسم الى ٣ أقسام لتعطى نسب احجام مختلفة من الماء. تم تجربة تحلية الماء بالمقطر بدون استخدام سخانات او باضافة سخان فى كل قطاع او اضافة سخانين فى كل قطاع او اضافة ٣ سخانات فى كل قطاع. كانت تؤخذ القراءات من الساعة ٧ صباحا كل ساعتين حتى الساعة ٥ مساءا. تم تسجيل درجات الحرارة للثلاث جوانب الهرمية للمقطر ودرجة حرارة الجو باستخدام ترمومترات حرارية مثبتة على جوانب المقطر واخر مثبت فى الهواء. تم تسجيل كمية المياه الناتجة عن كل جانب من جوانب المقطر على حدة. وكانت عوامل الدراسة هى :- استخدام ثلاث احجام من احواض الماء، وهى ١٥,٥ لتر، ١٣ لتر، و١١ لتر وبنسب ملىء مختلفة ١٠٠%، ٧٥%، و٥٠%. واستخدام ثلاث مسافات بين حوض الماء وبين حدود المقطر، وهى ٣، ٦، و٩سم. وبدون استخدام سخان و استخدام سخان و اثنين و ثلاثة فى كل قطاع بقدرة ١٥ وات لكل سخان. وأخيرا دراسة تأثير هذه العوامل على كفاءة المقطر الشمسى والانتاجية وتوزيع درجات الحرارة. وتوصلت الدراسة الى النتائج الآتية:-

عند زيادة كل من المسافة بين اطراف الأحواض وجوانب المقطر من الداخل، أحجام الماء فى الأحواض، و عدد السخانات المضافة يحدث ما يلى:

- زيادة فى نسبة فرق درجات الحرارة. اقصى قيمة كانت ٥٢%. واصغر قيمة كانت ١٥%.

- زيادة فى الانتاجية. اقصى قيمة كانت ٣,٣ لتر/م². واصغر قيمة كانت ٠,٣ لتر/م².

- زيادة فى الكفاءة. اقصى قيمة كانت ٧٠%. واصغر قيمة كانت ١٢%.

وأقصى قيم كانت تنتج من حجم الحوض الثالث الذى كان يبعد عن ٩سم عن جوانب المقطر، ومملوء ١٠٠% بالماء، ومضاف لكل قطاع ٣ سخانات. أما أصغر قيم كانت تعطى من الحوض الأول الذى يبعد ٣ سم عن جوانب المقطر، ومملوء ٥٠% بالماء، وبدون اضافة سخانات.

١) ـ أستاذ مساعد بقسم الهندسة الزراعية والنظم الحيوية ـ كلية الزراعة – جامعة المنوفية.
٢) ـ أستاذ متفرغ بقسم الهندسة الزراعية والنظم الحيوية ـ كلية الزراعة – جامعة المنوفية.
٣) ـ طالبة دراسات عليا بقسم الهندسة الزراعية والنظم الحيوية ـ كلية الزراعة – جامعة المنوفية.