# USING OF SINGLE SLOPE SOLAR STILL FOR SALINE WATER DESALINATION

**Nagwa[1], M. Taha.; M. N. El Awady[2] and M. F. Abdel-Salam[3]**


## ABSTRACT

*In this study، solar energy was utilized to distillate and purify saline water throw a single slope solar still. The used solar still is from the conventional type which is one of the best solutions to overcome the lack of drinking water in remote arid areas. It consists of square basin of area 1 m2, black box fitted with saline water, and transparent glass cover with 4 mm thick. The experiment was conducted at four saline water depths (1, 2, 3 and 4 cm from the still bottom) and at two levels of water salinty (15000 ppm and 35000 ppm). Several experiments carried out (January, February, March and April 2018). Experiment was carried out on single slope solar still designed and installed at Solar Energy Laboratory, Department of Agricultural Engineering, Faculty of Agriculture, Ain Shams University, Cairo (φ=30°N) from 8:00 am to 6:00 pm. Results proved that the maximum quantity of distillate water rate was 2372 mL at water depth of 1cm and water salinity of 15000 ppm. While, the minimum value of distillate water rate was 1002 mL/h at water depth of 4 cm with salinity 35000 ppm. The average of distillate water in April was 2322 mL. while, the average of distillate water in January was 1095.5 mL.* It is recommended to use a single slope solar still because it is cheap, easy to maintain and gives better efficiency.


**Keywords:** *Solar desalination; Solar still; Passive solar still، Single slope solar still.*

## 1. INTRODUCTION

The lack of fresh water is seems to be the biggest problem of the world in the next years due to higher consumption rates and population growth, as well as increased pollution of drinking water resources (lakes rivers, and underground water) via industrial wastes has raised the problem. **Kabeel (2009).**

[1] **M.Sc. student of Agric. Eng. Dept., Fac. of Agric., Ain Shams Univ.**
[2]**Prof. of Agric. Eng., Fac. of Agric., Ain Shams Univ.**
[3]**Assistant Prof. of Agric. Eng., Fac. of Agric., Ain Shams Univ.**

The productivity of fresh water through conventional type solar still depend on environmental conditions, still material, slope of transparent glass cover, orientation of solar still and water depth. The distillate water output get from the single slope is so low. Thus, **Jani and Modi (2018).**
Water is consider one of the biggest resources on earth, which covers about 75% of the surface of the earth though 97% of it is salt water in the oceans, and about 3% is drinking water. Out of the available fresh water, less than 1% is available for human and animal needs**. Kumar and Tiwari (2009).**
**Eltawil et al. (2009)** said that the renewable energy sources that is used in desalination processes include wind, photovoltaic, solar thermal, and geothermal.
Desalination technique can be divided by their mechanical separation into membrane and thermal based on desalination. Thermal desalination removes salt from water through evaporation and condensation, whereas in membrane desalination water diffuses via a membrane, while salts are almost completely retained. Thermal desalination includes multi-effect distillation, multi-stage flash, thermal vapor compression and mechanical vapor compression, while membrane desalination include reverse osmosis, ion exchange, and electro-dialysis processes. Multi-stage flash and reverse osmosis are the techniques that are most extensively used all over the world. **Sharaf Eldean (2011).**
**Muftah et al., (2014)** said that solar stills are classified into two distinct types; active and passive. In case of passive stills, the still water in the base undergoes direct heating, which basically did not need any external heating sources and causes the distillation and heat collection to occur within one system. Active solar stills water undergoes direct heating too, although it also receives water heated earlier by an indirect channel which is being heated by an external heat resources , for example, hot water coming from solar collector, heater, and a recirculation of water outgoing from the resources mentioned above to increase temperature of water in the basin, that will inevitably raise the evaporation rates.
**Modi et al. (2018a)** conducted the experiments to investigate the effect of the depth of water on the performance of double basin single slope and

deduced that higher fresh water that was obtained for the lower depth of water in basin.

**Sahota and Tiwari (2016a)** They have concluded that the passive type solar stills are more cost effective to deliver the potable water for the domestic applications compared to the active solar stills. Among the various solar desalination methods, the cheapest and simplest desalination systems are conventional type and double slope single sloped systems. Solar still can clean the saline water composed of salt to the limit of 10,000 ppm.

**Jamal and Siddiqui (2012)** stated that the maximum distillate collected were 1030 ml, 785 ml, 655 ml and 305 ml for the water depths of 0.02 m, 0.03 m, 0.04 m and 0.05 m, respectively at the East-West orientation of the still. However, they were 1160 ml, 890 ml, 715 ml and 395 ml for the water depths of 0.02 m, 0.03 m, 0.04 m and 0.05 m, respectively at the North-South orientation of the still.

**Abd-El-Salam (1998)** design a solar still with three different levels of brine depth of 2, 3,4 and 5 cm. The results explained that the distilled water quantity was 2.89 Liter /$m^2$.day and the overall daily efficiency was 38% at sea water depth of 3 cm into the solar still basin.

**Kabeel and El-Agouz (2011)** Today's state-of-the-art single-effect solar stills have an efficiency of about 30–40%. The amount of daily drinking water humans needed varies between 2 L and 8 L per capita and the ideal requirement for distilled water is 5 L per capita per day, hence approximately 2 $m^2$ of still are needed for each person served.

The objectives of this research are:

1. Improving the efficiency of a solar still by studying some effective parameters on the still.
2. Investigating the effect of some factors on the solar desalination processes which include solar intensity, water depth and salinity.
3. Low operation and maintenance cost.

## 2-MATERIALS AND METHODS

**System description:**

The experimental system consists of conventional still. The conventional still is consisted of simple basin. This basin is made up of 3 mm thick galvanized iron (GI) steel with a square aperture of $1m^2$ (1m length ,1m width,) the still in front is 0.003 m and 0.877 m back high. The saline water depth for the sill is 1, 2, 3 and 4 cm with salinity (15000 ppm and 35000 ppm). The bottom and sides of the basin are insulated by wood of 8 mm thick and glass wool of 25 mm to minimize the heat losses to the ambient. The top glass cover is used as a condensing surface with 4 mm thick and tilted at an angle of 30 degree to the horizontal Tiwari et al., (2005). The size of the glass is 1.154 m length and 1m width. The collection channel is used to collect the dstillate water which evaporated from the still and condensate on the inner of the glass cover. The channel made of P.V.C with diameter 25.4 mm . In order to stop reduce energy leakage to the surrounding , a rubber seal is located between the cover of the glass and the still. The still is placed on an galvanized iron with 1000 mm lenght ,1000 mm width as explaine in Fig. (1) and Fig. (2) photography and elevation and side view for conventional solar still respectivly.

Fig. (1): photography of conventional solar still.

**Instrumentation and measurements:**

**Temperature data logger:**

A data logger has 8 ports used to measure the temperature using a thermocouple (type K) sensor. It measures the temperature every 15 minutes (basin liner temperature, water temperature, wick temperature, the temperature of the gap between the cover of the glass and the base of the still, internal glass temperature, and external glass temperature).

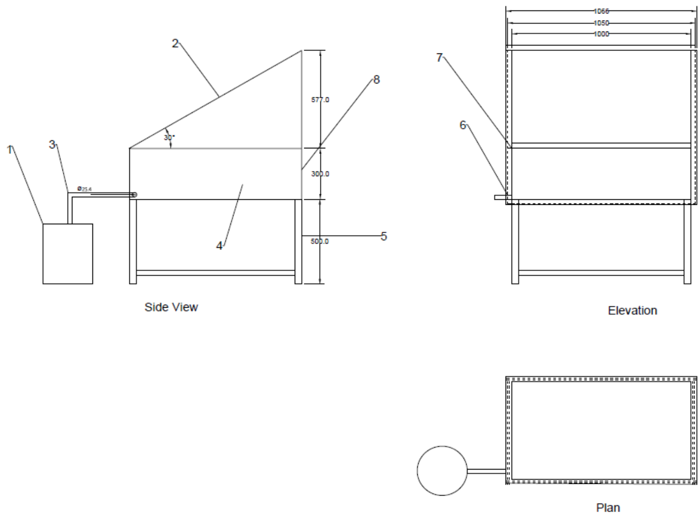
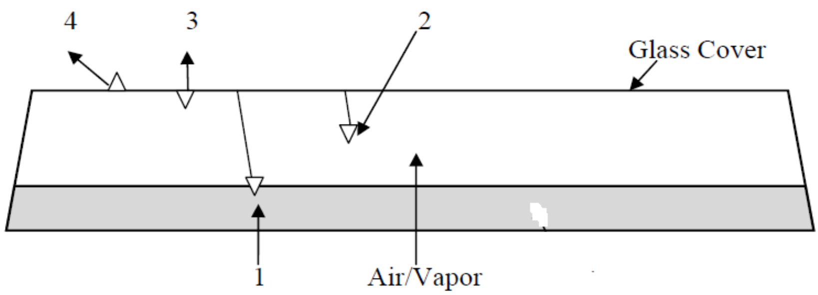



Fig. (2): An elevation ,side view and plan for conventional solar still.

| **Part name** | **No. off** |
|---|---|
| **Tank distillate water** | **1** |
| **Glass cover** | **2** |
| **Outlet pipe** | **3** |
| **Water in basin** | **4** |
| **Iron stand** | **5** |
| **Glass wool** | **6** |
| **Galvanized iron** | **7** |
| **Wood** | **8** |

All dimention . mm scale 1:1




| Part name | No. off |
|---|---|
| Thermocouple measuring saline water temperature | 1 |
| Thermocouple measuring vapor temperature | 2 |
| Thermocouple measuring glass in temperature | 3 |
| Thermocouple measuring glass out temperature | 4 |

**Thermometer type -k:**

The ambient temperature was measured by thermocouples (type k) which were connected to digital thermometer ($DM6801A^+$).

The temperature was read every 15 minutes.

Temperature Range: -50 ºC to + 750 ºC.

Accuracy: -50 ºC to 199.9 ºC (± 2 ºC) with 0.1 Resolution.

**Solar power meter:**

The solar power meter is used to measure solar radiation

Every 15 minutes. Accuracy: ± 10 $W/m^2$. Range: 1999 $W/m^2$.

Resolution: 1 $W/m^2$

**Methods:**

Experiments were conducted at Ain Shams University, Egypt. (Latitude 30° 06′ N, Longitude 31° 14′ E). Experiments started at 8:00 a.m. to 6.00 p.m. The experimental work was performed on the solar still during four months of the year (January, February, March and April 2018) on different day and all reading of temperatures, solar intensity were measured every 15 minute and water productivity was measured every 60 minutes with graduated cylinder at 1,2,3,4 cm level water depth from the base with 15000 and 35000 ppm salinity water. and water productivity were measured for the conventional solar still.

The daily thermal efficiency of the still $(\eta)$ can be measured using the equation given by (Tiwari 2002) as follows:

$$\eta = \frac{Daily\ yield * L}{A_S * \mathcal{E}\mathrm{Is(t)} * 3600} \mathrm{X}100$$

$$\eta = \frac{2372 * 10^{-3} * 2.35 * 10^{6}}{1 * 6856.375 * 3600} X100 = 22.6\%$$

Where:

$\eta =$ The thermal efficiency of the still.

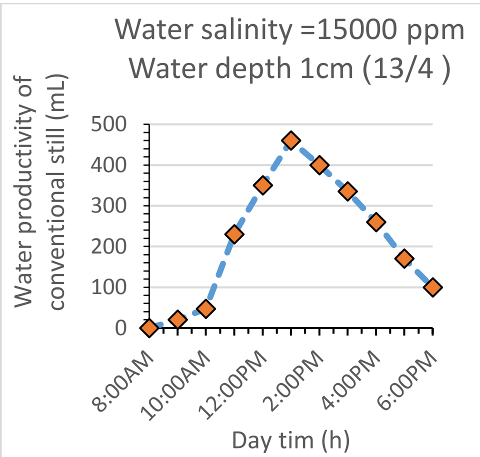
L: the latent heat of vaporization at the saturation temperature $T_w$ , (equal $2.35*10^6$J/kg).

As: area of solar still ($m^2$).

Is (t): total solar intensity on the covers of glass of solar still ($W/m^2$).

## 3-RESULTS & DISSCUSION:

Fig. (6) shows that the effect of the depth of water at 1cm , water salinity (15000 ppm and 35000 ppm)on the hourly distillate water the results explained that the distillate water attained its maximum value (460,410 mL/h) at 1:00 pm at salinity 15000, 35000 ppm respectively at the same depth water due to the maximum value of solar radiation was (1055, 1034 W/m$^2$ ) at salinity 15000, 35000 ppm respectively and the maximum value of ambient temperature was (38.58, 37.87 c°) at salinity 15000, 35000 ppm respectively .The distillate water remained its high at the afternoon hours this may be owing to the accumulative and stored energy at this period compared to the rates before noon period.



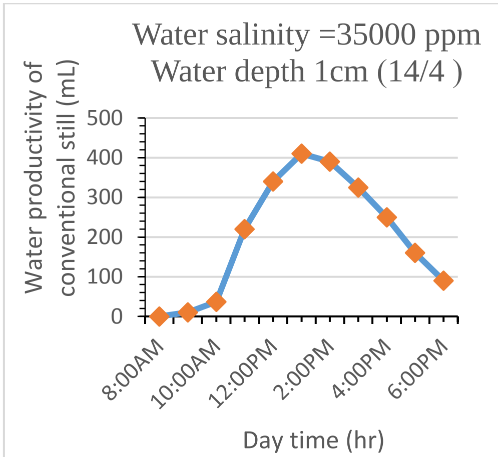




Fig. (6): Effect of the depth of water, water salinity on the hourly distillate water.

Fig.(7) shows that the effect of the depth of water at 2 cm , water salinity (15000 ppm and 35000 ppm) on the hourly distillate water the results explained that the maximum amount distillate water was (410, 400 mL/h) at 3:00 pm and 1:00 pm at salinity 15000, 35000 ppm respectively at 2 cm water depth due to the maximum value of solar radiation(970, 888 W/m$^2$) at salinity 15000, 35000 ppm was respectively and the maximum value of ambient temperature was (29.13, 29.58 c°) at salinity 15000, 35000 ppm respectively.

.

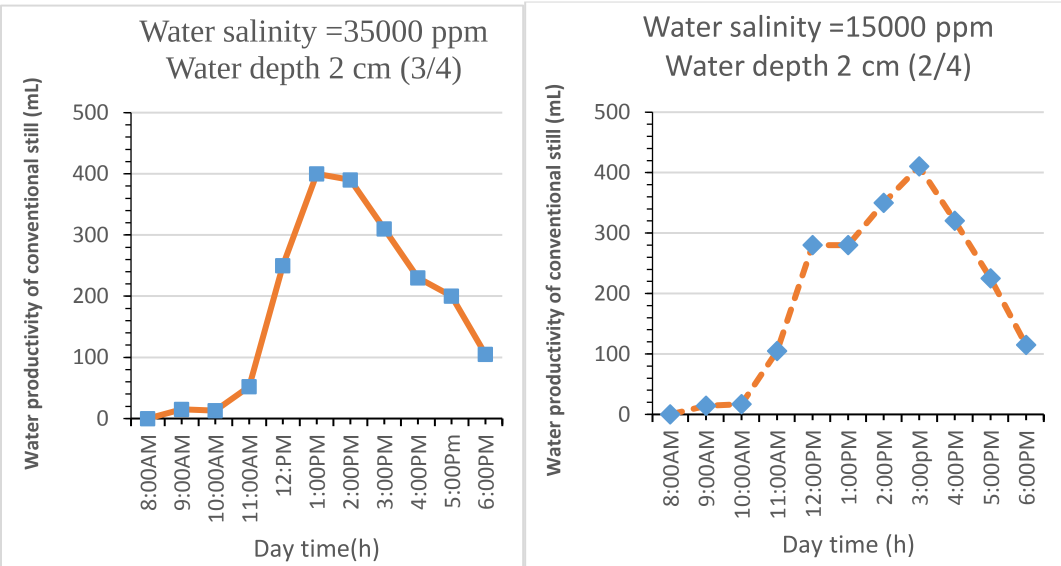



Fig. (7): Effect of depth of water, water salinity on the hourly distillate water.

Fig. (8) shows that effect of the depth of water at 3 cm water salinity (15000 ppm and 35000 ppm) on the hourly distillate water the results showed that the distillate water attained its maximum amount at salinity 15000 ppm at the same water depth .The maximum value was (395 ,330 mL/h) at 3:00 pm and 1:00 pm at salinity 15000, 35000 ppm at 3 cm water depth due to the maximum value of solar radiation was(970, 888 W/m$^2$) with salinity 15000, 35000 ppm respectively and the maximum value of ambient temperature was (35.7, 33.83 c°) at salinity 15000, 35000 ppm respectively.

Fig. (9) shows that effect of depth of water at 4cm , water salinity (15000 ppm and 35000 ppm) on the hourly distillate water the results e that explained distillate water attained its maximum amount at salinity 15000 ppm at the water depth .The maximum value 380 mL/h at 2:00 pm with salinity 15000 ppm at 4 cm water depth . It is obvious that the highest value of distillate water rate is 460 mL/h at water depth of 1cm and water salinity of 15000 ppm. On the other side the increase of water salinity from 15000 ppm to 35000 ppm at water depth of 4 cm was followed with a decrease in distillate water rate to 370 mL/h at 3:00 pm. the increase in water mass by increasing water salinity resulting in high thermal heat capacity then a reduction in evaporating rate may occur. The maximum value of solar radiation was (878.5, 845 W/m$^{2}$) and the maximum value of ambient temperature was (32.95, 31.95 c°) at salinity 15000, 35000 ppm respectively.

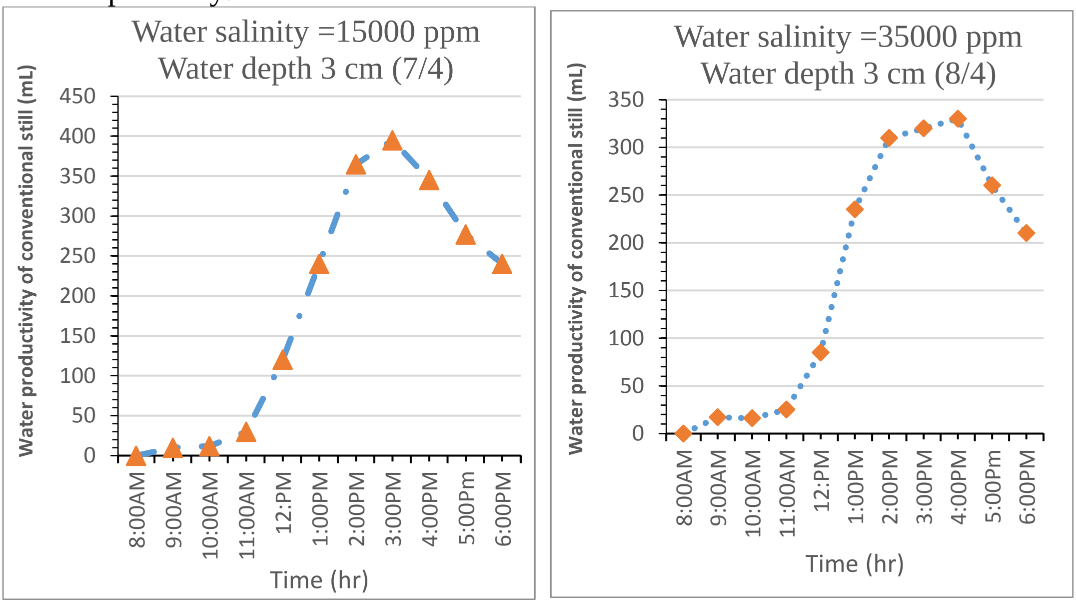



Fig. (8): Effect of the depth of water, water salinity on the hourly distillate water.

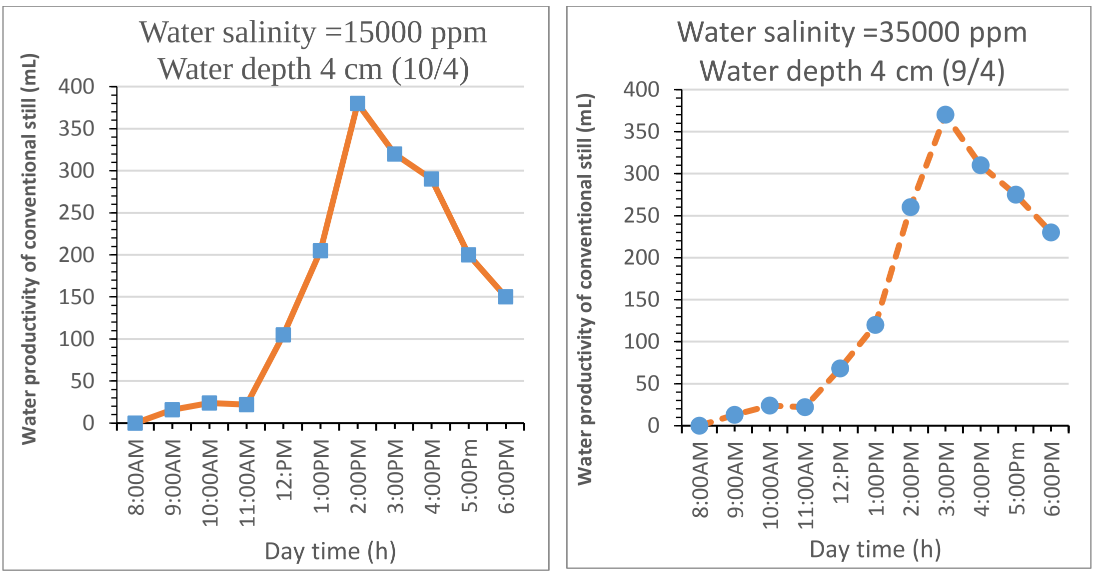



Fig. (9): Effect of the depth of water, water salinity on the hourly distillate water.

Fig. (10, 11, 12, 13) show hourly variations of average ambient temperature and average solar radiation the results explained that hourly variations of solar intensity and ambient temperature the results explained that the solar radiation value increase in the morning hours till it reaches the maximum value around noon hour , then radiation value starts to decrease rapidly in period from afternoon to the sunset hours . The ambient temperature increased with increase of the solar radiation. The maximum amount of solar intensity and air temperature is at noon hour.

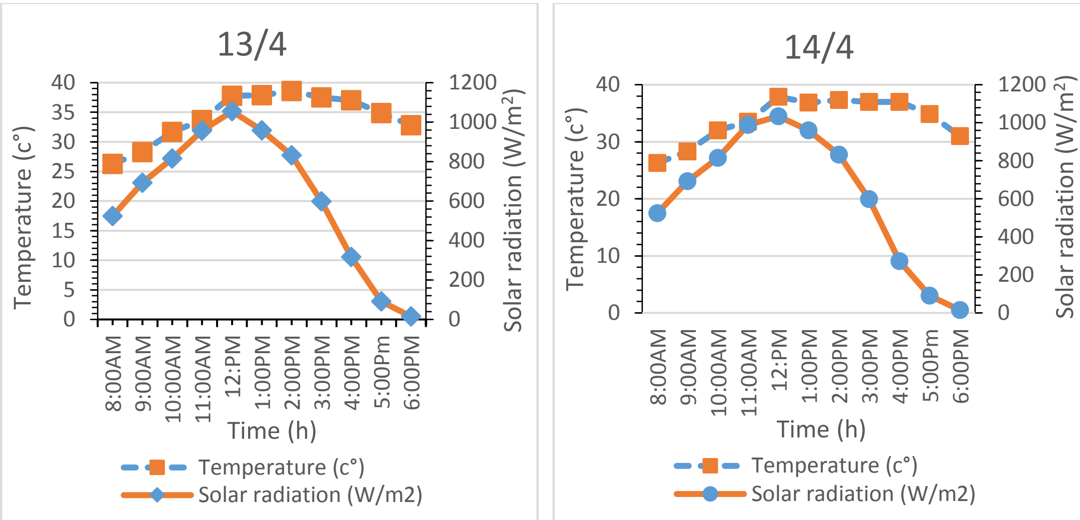



Fig. (10): Hourly variations of air temperature and solar intensity.

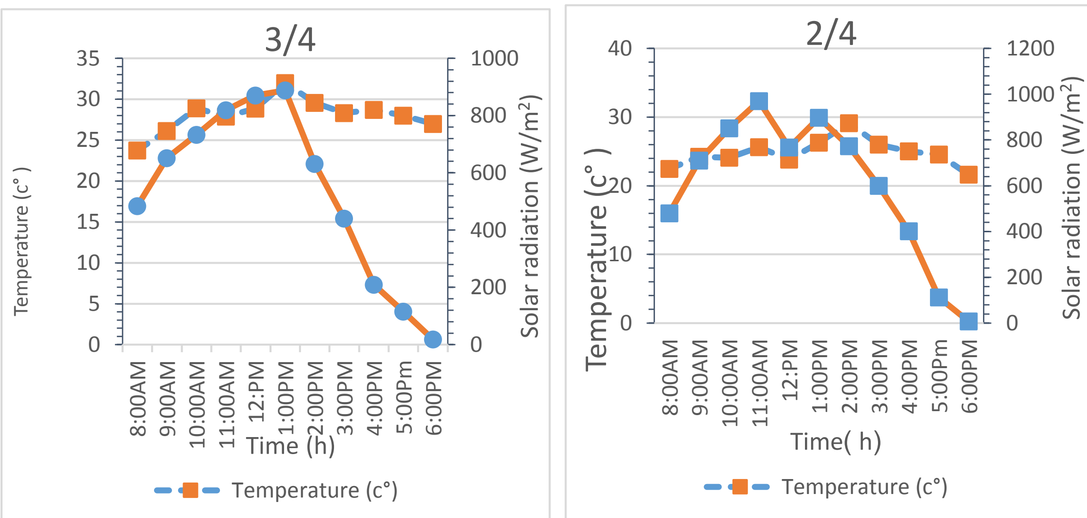



Fig. (11): Hourly variations of air temperature and solar intensity.

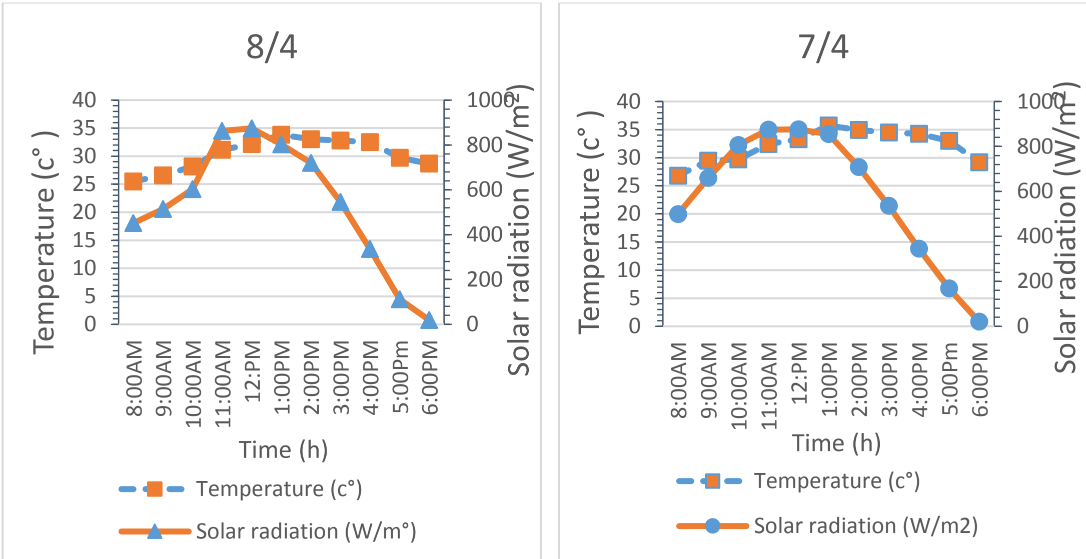



Fig. (12): Hourly variations of air temperature and solar intensity

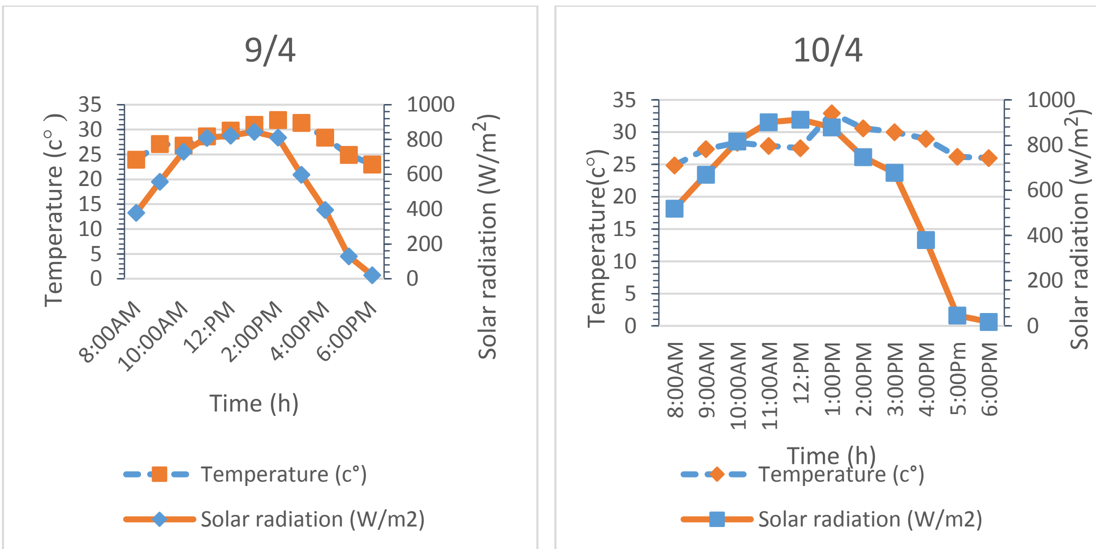



Fig. (13): Hourly variations of air temperature and solar intensity.

Hourly variations of ambient, outer glass, inner glass temperature and water temperature as explained in Fig. (14 ) .The results showed that the maximum values of $T_a$, $T_{glass\ out}$, $T_{glass\ in}$ and $T_w$ are 37.9 ,50.21 ,73.52 c° and 74.21. It is clear that the temperature of water is high due to high solar radiation, as it leads to high temperature of the base and then the temperature of water.

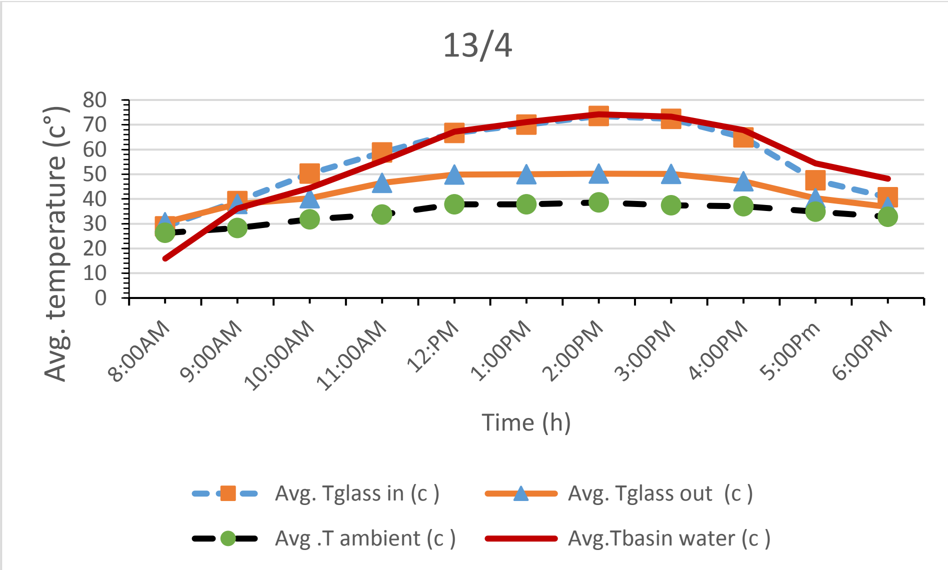



Fig. (14): Hourly variations of ambient, outer glass, basin water and inner glass temperature.

Fig. (15) shows that effect of the depth of water, water salinity on the accumulated distillate water as the results explained that the highest value of distillate water rate is 2372 mL/h at water depth of 1cm and water salinity of 15000 ppm. On the other hand, the increase of water salinity from 15000 ppm to 35000 ppm at water depth of 4 cm was followed with a decrease in distillate water rate to 1606 mL/h.

Effect of the depth of water and water salinity on the average accumulated distillated water as explained in Fig. (16) .The results explained that the highest value of distillate water rate is 2372 mL at water depth of 1cm and water salinity of 15000 ppm and the minimum value of distillate water rate to 1606 mL/h at water depth of 4 cm with salinity 35000 ppm.

The average accumulated water productivity for months with salinity 15000 ,35000 ppm on water depth 1,2,3,4 cm as shown in Fig.(17). The results explained that the maximum amount of distillate water at 1cm with salinity 15000 in April .and the minimum amount of distillate water at 4 cm with salinity 35000 ppm in Jan.

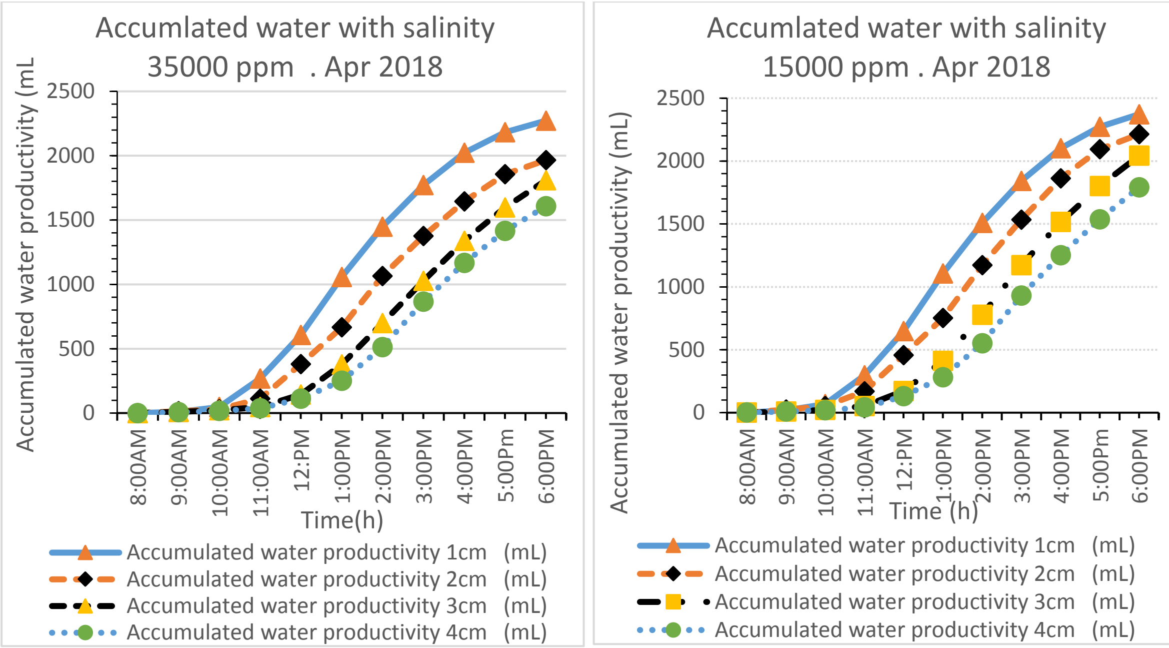



Fig. (15): Effect of the depth of water, water salinity on the accumulated distillate water.

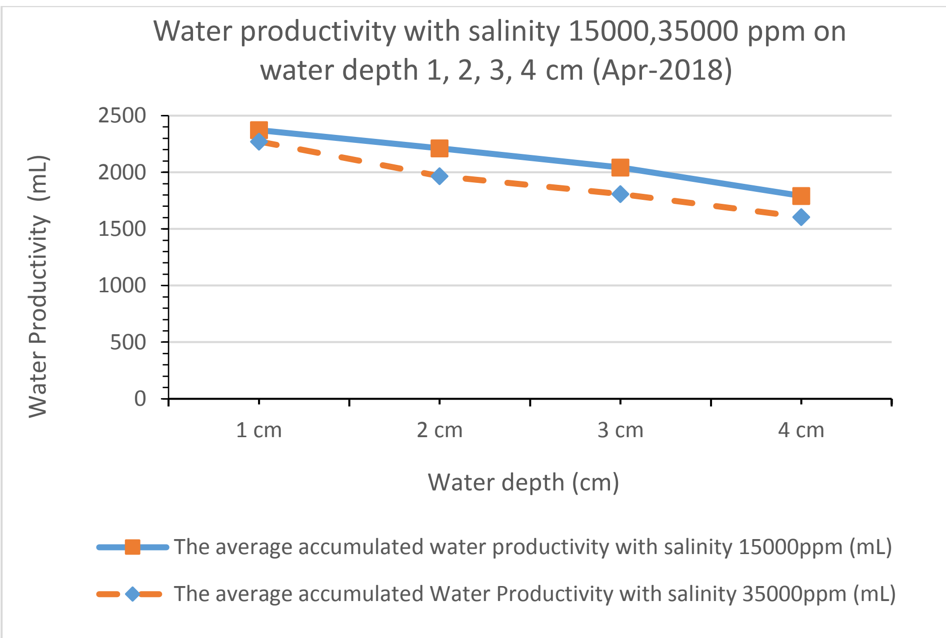



Fig. (16): Effect of the depth of water and water salinity on distillated water.

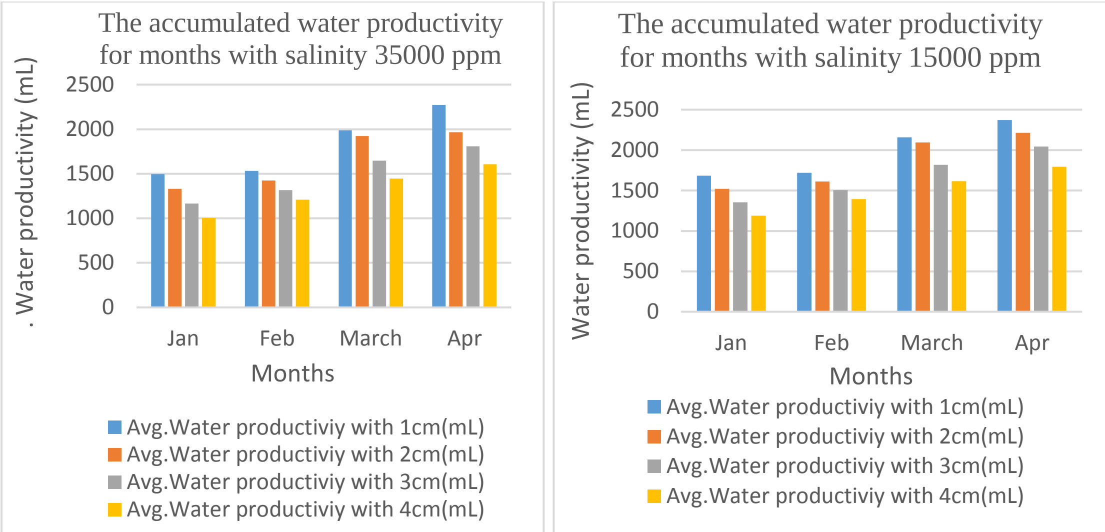



Fig. (17): The accumulated water productivity for months with salinity 15000 ,35000 ppm on water depth 1,2,3,4 cm.

## 4- CONCLUSSION

The results showed that:

1- The maximum value of distillate water at 1cm with salinity 15000 in Apr. and the minimum value of distillate water at 4 cm with salinity 35000 ppm in Jan.

2-The maximum value of distillate water rate is 2372 mL at water depth of 1cm and water salinity of 15000 ppm and the minimum value of distillate water rate to 1002 mL/h at water depth of 4 cm with salinity 35000ppm.

3-The solar radiation value increase in the morning hours till it reaches the maximum value around noon hour, and then radiation value starts to decrease rapidly in period from afternoon to the sunset hours . The ambient temperature increased with increase solar radiation.

4- The thermal efficiency of the conventional solar still =22.6 %.

## RECOMMENDATION

**It is recommended that:**

1- Use water depth at 1 cm because it gives the highest productivity.

2- Use high thermal insulation of the sides and base of the solar still for reducing the thermal loss.

## REFERENCES

**Jamal, W., M. A. Siddiqui (2012).** Effect of water depth and still orientation on productivity for passive solar distillation, International Journal of Engineering Research and Applications, 2, 1659-166.

**Jani, H.K., K.V. Modi (2018)** A review on numerous means of enhancing heat transfer rate in solar-thermal based desalination devices Renew. Sustain, Energy Rev: 93,302–317.

**Kabeel, A. E. (2009)**. Performance of solar still with a concave wick evaporation surface. Energy, 34(10), 1504–1509.

**Kabeel , A.E., S.A. El-Agouz , (2011)** Review of researches and developments on solar stills, Desalination, 276; 1–12.

**Kumar, S., & Tiwari, G. N. (2009).** Life cycle cost analysis of single slope hybrid (PV/T) active solar still. Applied Energy, 86(10), 1995-2004.

**Modi, K.V., Ankoliya, D.B., Shukla, D.L., (2018a)**. An approach to optimization of double basin single slope solar still water depth for maximum distilled water output. J. Renew. Sustain. Energy, 10, 043708.

**Muftah, A. F., M. A. Alghoul, A. Fudholi, M. M. Abdul-Majeed, K. Sopian (2014).** Factors affecting basin type solar still productivity: A detailed review. Renewable and Sustainable Energy Reviews, 32, 430–447.

**Sahota, L., G.N. Tiwari, (2016a).** Effect of $Al_2O_3$ nanoparticles on the performance of passive double slope solar still. Sol. Energy, 130, 260–272.

**Abdel-Salam; M.F.M. (1998**) Design of solar still for sea water desalination, Annals Agric. Sci., Sp. Issue 3, 613-643.

**Sharaf Eldean, M.A. (2011).** Design and Simulation of Solar Desalination Systems Suez Canal University Egypt, Research Gate, 4.

**Eltawil, M. A., Z. Zhengming, L .Yuan, (2009).** A review of renewable energy technologies integrated with desalination systems. Renewable and Sustainable Energy Reviews, 13(9), 2245–2262.

**Tiwari G.N.( 2002**). Solar energy: fundamentals, design, modelling and applications, Alpha Science Int'l Ltd.

**Tiwari Kr, G.N. Tiwari,(2005).** Effect of the condensing cover' s slope on internal heat and mass transfer in distillation: an indoor simulation. Desalination, 180,73-88.

## الملخص العربى

# إستخدام المقطر الشمسى أحادى الميل لتحلية المياه المالحة

**[١] نجوى محمد طه ، [٢] محمد نبيل العوضى و [٣] مصطفى فهيم محمد عبد االسلام**

يعد نقص المياه الصالحة للشرب أكبر مشكلة في العالم بسبب ارتفاع معدلات الاستهلاك والنمو السكاني ايضا ، وكذلك زيادة تلوث موارد المياه العذبة (الأنهار والبحيرات والمياه الجوفية) بسبب النفايات الصناعية.لذلك تم البحث عن ستخدام موارد بديلة لانتاج المياه العذبة من البحار والمحيطات وهي استخدام المقطرات الشمسية لتحلية المياه المالحة. يتكون المقطر الشمسى التقليدى من حوض بسيط الحوض من الحديد المجلفن بسمك ٣ مم ومساحته ١ متر مربع (طول ١ متر وعرض ١ متر) ، ويبلغ ارتفاع من الامام ٠,٠٠٣ متر والارتفاع من الخلف ٠,٨٧٧ متر. عمق المياه المالحة هو ١ ، ٢ ، ٣ و ٤ سم مع ملوحة (١٥٠٠٠ جزء في المليون و ٣٥٠٠٠ جزء في المليون). تم عمل التجارب في معمل الطاقة الشمسية - قسم الهندسة الزراعية - كلية الزراعة - جامعة عين شمس - القاهرة. في الفترة من الساعة ٨ صباحا وحتى السادسة مساءاً.

وقد اظهرت النتائج التالي:

اعلى قيم تتمثل فى عمق المياه ١سم وملوحة ١٥٠٠٠جزء فى المليون للشهور الاربعة (يناير ، فبراير ، مارس و ابريل). وهى ١٦٨٤، ١٧٢٠، ٢١٥٨ و ٢٣٧٢ مللي لتر على الترتيب. واقل قيم تتمثل في عمق المياه ٤ سم وملوحة ٣٥٠٠٠جزء فى المليون للشهور الاربعة ( يناير ، فبراير ، مارس و ابريل ) وهى ١٠٠٢ ، ١٢٠٩ ، ١٤٤٤ و ١٦٠٦ ملي لتر علي الترتيب .

وتوصي الدراسة بالآتي:

١- استخدامة المقطر الشمسى ذو الميل احادى التاثير لانه يعطى يعطى كفاءة جيدة .

٢- استخدام مادة عزل للمقطر من الجوانب والقاعدة لتقليل الفقد الحرارى .

[١] طالبة ماجستير – قسم الهندسة الزراعية – كلية الزراعة – جامعة عين شمس.

[٢] أستاذ الهندسة الزراعية – قسم الهندسة الزراعية – كلية الزراعة – جامعة عين شمس.

[٣] أستاذ الهندسة الزراعية المساعد -قسم الهندسة الزراعية - كلية الزراعة – جامعة عين شمس.