Experimental Study on Enhancement of Single-Basin Solar Still Using Dye Solutions

Kadhim H. S. AL-Zaedy
Engineering College, University of Al Nahrain /Baghdad
Email:Kadhim_Askar@yahoo.com

Received on: 1/2/2012 & Accepted on: 4/10/2012

ABSTRACT

An enhancement of single slope solar still using different dye solutions was studied experimentally. Single-basin solar still can be used for water desalination. Probably, they are considered the best solution for water production in remote, arid to semi-arid, small communities, where fresh water is unavailable. However, the amount of distilled water produced per unit area is somewhat low which makes the single-basin solar still unacceptable in some instances. The purpose of this work is to study the effect of using different dye solutions in a solar still, and thus enhance the productivity of water. Experimental results show that the productivity of distilled water was enhanced for some materials. Using Methyline Blue solution increased the daily water productivity by 18%. While using Methyle Orange solution increased by 28 %. Also the better efficiency of 74.3 % has taken when using Methyle Orange solution compared with efficiency of 62.53 % when Methylene Blue solution was used while the better efficiency is 58.89 % when only water used in still. Therefore it is concluded the productivity of water still per unit area is increased when using dye solutions as Methylene Blue solution and Methyle Orange solution.

Keywords: Single basin type, Solar still, Desalination, Enhancers, Absorbing materials.

دراسة تطبيقية لتحسين أداء مقطر شمسي أحادي ألميل باستخدام محاليل صبغية

الخلاصة

تم دراسة تحسين أداء مقطر شمسي أحادي ألميل باستخدام محاليل صبغية عمليا. أن المقطر الشمسي يستخدم عادة لتقطير المياه غير نقية التي تحتوي على الاملاح والشوائب الاخرى. وفي الاماكن النائية التي لايوجد فيها الماء النقي بالكمية المطلوبة يكون المقطر الشمسي الحل ألامثل لتوفير الماء النقي. لكن الكمية التي ينتجها المقطر الشمسي لوحدة المساحة تكون قليلة. لذلك يلجأ الى البحث على زيادة ألانتاجية للمقطر وهذا هو الغرض من هذه الدراسة، والفكرة هي زيادة انتاجية مقطر شمسي احادي الميل باستخدام محاليل صبغية مثل (ألمحلول ألأزرق ألمثيليني وألمحلول ألبرتقالي ألمثيلي) في داخل أنابيب زجاجية محكمة الغلق تغمر داخل الماء الموجود في المقطر الشمسي. النتائج التطبيقية بينت ان أستخدام ألمحلول ألأزرق ألمثيليني يعطي زيادة بانتاجية المقطر

https://doi.org/10.30684/etj.30.18.1
2412-0758/University of Technology-Iraq, Baghdad, Iraq

بمقدار 18% وبكفاءة 62.53% بينما استخدام ألمحلول ألبرتقالي ألمثيلي يعطي زيادة بانتاجية المقطر بمقدار 28% وبكفاءة 74.3% مقارنتا مع انتاجية المقطر عندما تكون كفاءته 58.89 % في حالة استخام الماء فقط في المقطر الشمسي. لذلك نستنتج ان استخدام المحاليل الصبغية اعلاه تعطي زيادة في انتاجية المقطر لنفس وحدة المساحة.

Nomenclature

B	Methyline Blue solution.
I (t)	Solar radiation intensity (W/m^2).
O	Methyle Orange solution.
T	Temperature (°C)
η	Efficiency (%)

Subscript

g	glass.
w	water.
wBs	water with Methyline Blue solution.
wOs	water with Methyle Orange solution.

INTRODUCTION

Solar energy is an important alternative energy source that likely will be more utilized in the future. One main factor which limits the application of solar energy is that it is a cyclic time-dependent energy resource. Therefore, solar systems require energy storage to provide energy during the night and overcast periods [1]. Distillation is one of many processes that can be used for water purification. The energy required to evaporate water is the latent heat of vaporization of water. This has a value of 2260 kJ/kg. This means that to produce 1 liter (i.e. 1kg since the density of water is 1kg/litre) of pure water by distilling brackish water requires a heat input of 2260 kJ.

Many others work to development and enhancement water still as, Khalifa A. N. and Ibrahim H. A. [2] Presents an experimental investigation on the productivity of a basin type solar still with internal and external reflector tilted at angles of 0° (vertical), 10°, 20° and 30° for still cover angles of 20°, 30° and 40°. It was found that the daily productivity is greater for a still with a larger cover angle at any reflector angle. Foster R. E. et al. [3] discussed solar still performance and acceptance along the U.S. Mexico border. Three organizations have been active in promoting the use and development of solar distillation on the Border, namely the El Paso Solar Energy Association, New Mexico State University and SolAqua. Khalifa A. N. [4] studied literature on relation between cover tilt angle and productivity of simple solar stills in various seasons for relation between optimum tilt angle and latitude angle and concluded that, cover tilt angle should be larger in winter and smaller in summer, increasing tilt angle would increase productivity and maximum productivity achieved by using cover tilt angle close to the latitude of place. Akash B. A. et al. [5] studied the effect of using different absorbing materials in a single-basin solar still, and thus enhancement the productivity of water. Experimental result shows that the productivity of distilled water was enhanced for some materials. Black dye was the best absorbing material used in terms of water productivity. It resulted in an effective. Abdallah S. and Badran O.O. [6], deployed for enhancing the solar still productivity by using a sun tracking system. A comparison between fixed and sun tracked solar stills showed that the use of sun tracking increased the productivity for around 22% and increase of overall efficiency by 2%. El-Sebaii A. A., et al. [7] studied the transient mathematical models for a single slope-single basin solar still with and without phase change material (PCM) under the basin liner of the still. Numerical calculations have been carried out, using stearic acid as a PCM, when the still is used without the PCM. The PCM is more effective for lower masses of basin water on winter season. Naim M. M. et al. [8]. Constructed a novel continuous single-stage solar still that makes use of a phase change energy storage mixture (PCESM) for Promoting energy usage has been devised and constructed. Results indicated that the use of an energy storage material led to a larger productivity of distilled water and that the larger the concentration of the saline water the lower the productivity of the still. Ighodalo O. A., Ebhodaghe F. A [9] studied the performance evaluation of a solar still for salty water desalination. The still was tested using two different materials, aluminum painted black and black leather as the absorber. They are concluded the daily temperature and type of absorber materials are factors that can influence the distillate yield. The low cost of production is as a result of the materials employed in the fabrication Gowtham M. et al. [10] work to improve the productivity of solar still by concentrating solar thermal energy through a parabolic trough concentrator. These studies were made improving the evaporation rate of the system. This is done through increasing the energy storage capacity through paraffin wax as latent heat storage material. Productivity improved by 54%. On the performing all modifications in the solar still is verified by Khalifa A. N. and Hamood A. M. [11]. The parabolic concentrator solar distiller with latent heat storage material and energy storing materials are studied. Badran O.O. [12]. Performance of a single slope solar still using different operational parameters was studied experimentally. For this study the still productivity increased up to 51% when combined enhancers such as asphalt basin liner and sprinkler have been applied to the still. The study also showed that the daily production of still can be increased by reducing the depth of the water in the basin. Medugu D. W. and Ndatuwong L. G. [13] developed theoretical analysis of the heat and mass transfer mechanisms inside this solar still. The measured performance was then compared with results obtained by theoretical analysis. The results clearly show that the instantaneous efficiency increases with the increase of solar radiation and with the increase of feed water temperature. The distillation efficiency of the still is 99.64% as compared to the theoretical analysis. Afrand M. et al. [14] presented a theoretical study of solar distillation in a single basin under the open environmental conditions of Chabahar-Iran. By using a numerical method the investigation addressed the following: The still productivity, distilled water salinity and still performance in terms of the still efficiency. They show that still productivity is directly functioning of solar radiation. Murugave K. K. et al. [15] Modeling and Verification of Double Slope Single Basin Solar Still Using Laboratory and Actual Solar Conditions. It is found that the production rate increases with the increases of water and glass temperature. But at higher operation temperature, the production rate increases with the decrease in temperature difference between water and glass.

EXPERIMENTAL SET UP

The experimental setup shown in Figures. (1, 2 and 3) is one of the simplest types of solar stills. It has an effective area of 1 m^2. The frame is made of galvanized steel. It has a top cover of transparent glass, and the interior surface of its basin is blackened to enable absorption of solar energy. The body is made of wood, 15 mm thick; and shaped as an inclined box. While the identical fixed solar still is faced due south. The temperatures of the glass cover, the water and vapuor inside the still and bottom of still plate from the system are measured by thermocouples of the same type. Radiation shields are used with the thermocouples wherever necessary. All thermocouples are connected to a digital electronic thermometer is used. The still fuelled with water by for a constant level. A ball valve is used between the water source and the inlet to the collector to control the flow rate of water to the system. Different parts of the still will be explained in the following:

Basin liner

This is the major part of the solar still Figure (1). It absorbs the incident radiation that is transmitted through the glass cover. The basin liner should be resistant to hot saline water, have a high absorbance to solar radiation and to resistance to accidental puncturing and in the case of damage, (the shape of drawer, for maintenance and cleaning purposes); it should be easily repaired. The glass cover is tilted at an angle of 15° and the still is oriented due south. Four copper-constantan thermocouples are embedded at different points in the still to measure the temperature.

Glass Pipes

Twenty glass pipes are used in the study, ten pipes are filled with Methylene Blue solution and the other ten pipes are filled with Methyl Orange solution, figure. 3. These pipes have a dimension 3mm diameter and 90 cm long and closed from two ends by using high efficiency glue to satisfy well closed and prevent the solutions to mix with the water in the basin still.

Methylene Blue and Methyl Orange solutions

Methylene blue solution is ($C_{16}H_{18}CLN_3S$) a cationic thiazine dye with the chemical name tetramethylthionine chloride. It has a characteristic deep blue color in the oxidized state;

Properties: - Dark green crystals or powder with – bronze like luster, odorless or slight odor and stable in air, soluble in water, alcohol and chloroform. Water solution is deep blue.

Methyl Orange solution is ($C_{14}H_{14}N_3NaO_3S$) para-para-diemethylamine phenylazo-benzene sulfonate of sodium; Helianthine B: orange.

Properties: - Orane-yellow powder; soluble in water, insoluble in alchohol. C. I. 13025 toxicity unknown. PH range 3.1-4.4 [16].

Transparent cover

A single glass with 4 mm was used to cover the solar still. And acts as resistance to thermal radiation heat transfer from the basin to the atmosphere. It was fixed at 15° with the horizontal on the top of the inclined still.

Insulating material

The sides and bottom of the system are insulated with 50-mm-thick rigid Styrofoam insulation board that have a density of 40 kg/m^3 and 0.045 W/m^2 °C thermal conductivity to maximize heat retention. The insulating material is used to reduce the heat losses from the bottom and the sides of the solar still. In this work, the insulating material is (Polystyrene) 5.0 cm thickness Figure(2).

Measuring instruments

Various types of measurement were used such as:

Pyranometer (The daystar meter): To measure the total radiation in W/m^2.

Glass beaker: To collect the distillate water.

Temperature thermometer type (TM-925) to measure temperature at various points in the still by thermocouples (type-k). The accuracy of this device is in the range of 0.1°C for the temperature measurements between -50.0to 1300.0 °C ± (0.4% + 0.8°C)

Air speed meter.

RESULTS AND DISCUSSIONS

Results of the experiments are presented in the form of graphs, to show the effect of using organic solutions (Methylene Blue and Methyl Orange solutions) compared in case when using water only in the basin still. All the experiments were taken in different pair of days during the months of June and August 2011 in (30/6 and 1/7), (2/7 and 3/7), (6/7 and 7/7), (9/7 and 8/7), the fist day from any of these four pairs was to study the performance of still using water, while in the second day from these pairs was to study when using water and Methylene Blue solution at clear sky weather conditions. The speed of the air outside of the still was measured by air speed meter which is equal to 3m/s. Finally the average values of four days are taken and presented in the form of graphs. The same procedures are applied for using Methyl Orange solution for other four pair of days (15/7 and 14/7), (16/7 and 17/7), (19/7 and 18/7), (21/7 and 22/7). Figs. 4 and 5 show the solar intensity I(t) in W/m^2 versus time. The intensity of solar radiation was measured by using Pyranometer (The daystar meter) to all work hours respectively. Maximum solar radiation was about 910 W/m^2 at 12:00 hour in clear day for both cases. Hence, the radiation intensity depends on the hour of the day. It can be seen that the solar intensity in two cases has the same behavior and very close values, also when using dye Solutions the water temperature was increased because the behavior of this solutions (absorbing solar intensity and transferred as heat to the water). Figs. 6 and 8 show the average of water, glass and ambient temperatures versus time when only water in still exist for days (30/6-2, 6 and 9/7/2011) and (14, 17, 18 and 22/7/2011) respectively, from these figures it appears that when the ambient temperature increases Figure(8) causes the water and glass temperatures is increased grater than the water and glass temperature in Figure. 6 because the ambient temperature is less.

Figs. 7 and 9 show the average of water, glass and ambient temperatures versus time when using organic solutions (Methylene Blue and Methyl Orange solutions) in still for days (1, 3, 7 and 8/7/2011) and (15, 16, 19 and 21/7/2011) respectively, from these figures it appear that the water temperature is grater than the glass temperature which is grater from the ambient temperature. It can be seen that the water and glass temperatures increases as the solar intensity increases till noon, then decreases as the solar intensity decrease. Also it was found that the increases in the temperature of the glass as the solar radiation incident on glass increases. But the glass temperature is lower than the basin water temperature due to the effect of air cooling on glass. Energy is transferred from the water to the glass cover principally by the water vapor evaporating from the water surface and then condensate at inner glass surface because of effect of ambient temperature at the outer surface of glass. Figures. 10 and 11 show relationship between the volume of distilled water and the local time (6 am to 22 pm). It shows that the highest production was at 15 pm, because the heat gain to the water from the solar radiation coincident to the still with decrease in ambient temperature in this time. This indicates the heat absorbed by basin still is greater than when using water only and this effect because of the wave length for the color of the solutions so this heat is transferred to the water causing increase in the temperature of the water, therefore the quantity of vaporization is increased this is lead to the quantity of basin still productivity is increased. In Fig. 12, it can to see the better productivity was 4734.75 ml/m^2.day when Methyle Orange solution is used and 4375.5 ml/m^2/day in case Methylene Blue solution is used, while the productivity was 3706.3755 ml/m^2/day when water only is used in the still. Fig.13. Present the variation of daily still accumulative efficiency and water temperature in cases study. A better efficiency of 74.3 % has taken place at 16:00 h, in this time water temperature was (71.4 C$^\circ$) and a quantity of distillate water of about 1212.5 ml/m^{2}h when using Methyle Orange solution compared with efficiency of 62.53 % and quantity of distillate water of about 940.75 ml/m^{2}h when Methylene Blue solution was used while the better efficiency has taken 58.89 % and quantity of distillate water of about 814.0 ml/m^{2}h when only water used in still.

CONCLUSIONS

An experimental work has been conducted to predict the water productivity in a solar still can be increased with the presence of some absorbing materials such as dyes (Methyl Orange and Methylene Blue solutions). Use the combination between water and Methyl Orange or Methylene Blue solutions were more effective than when used only water in the still، the productivity of distillate water is increased such as 28 % with Methyl Orange solution, and 18% with Methylene Blue solution. Also it can be concluded that the better efficiency 74.3 % has taken when using Methyle Orange solution compared with efficiency 62.53 % when Methylene Blue solution is used while the better efficiency has taken 58.89 % when only water is used in the still.

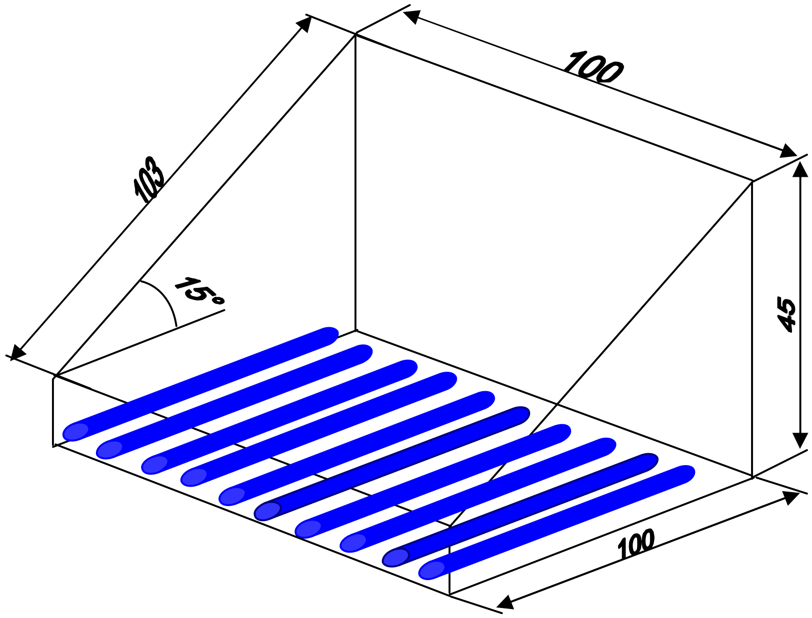
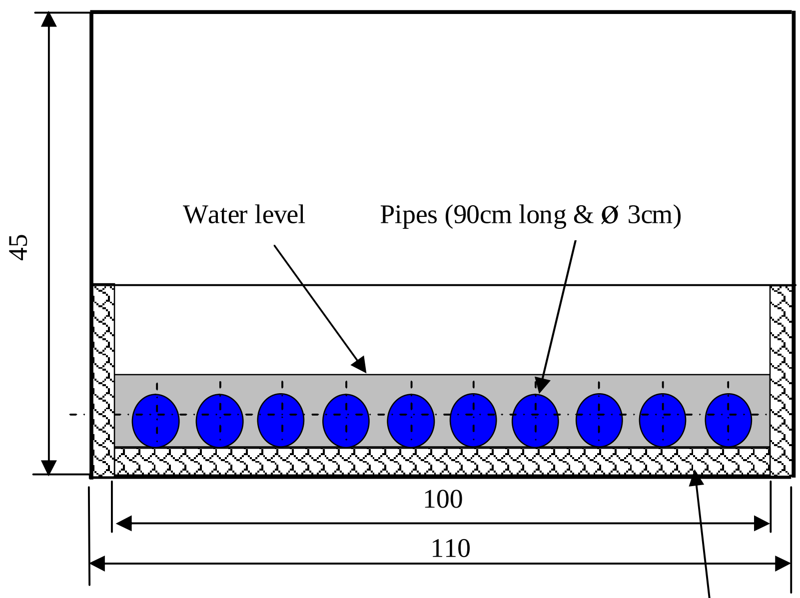


Figure (1) Schematic diagram of the single slope solar still (dimensions in cms).

(a)



(b)

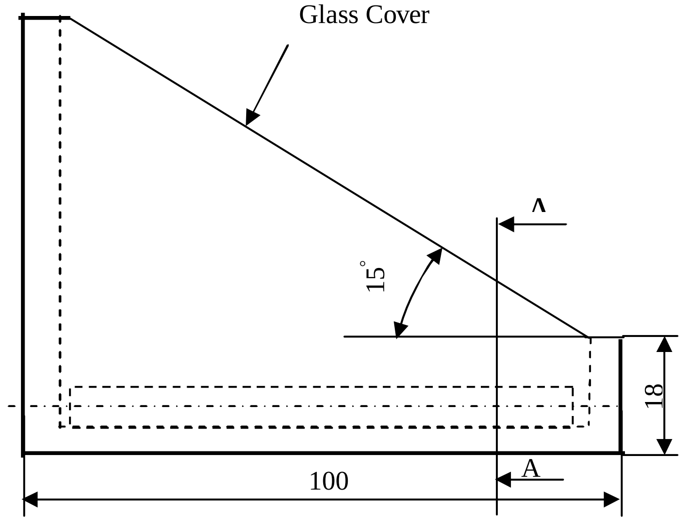


Figure (2) Water still drawing (dimensions in cm), (a) Section A-A (Front View), (b) Side View.

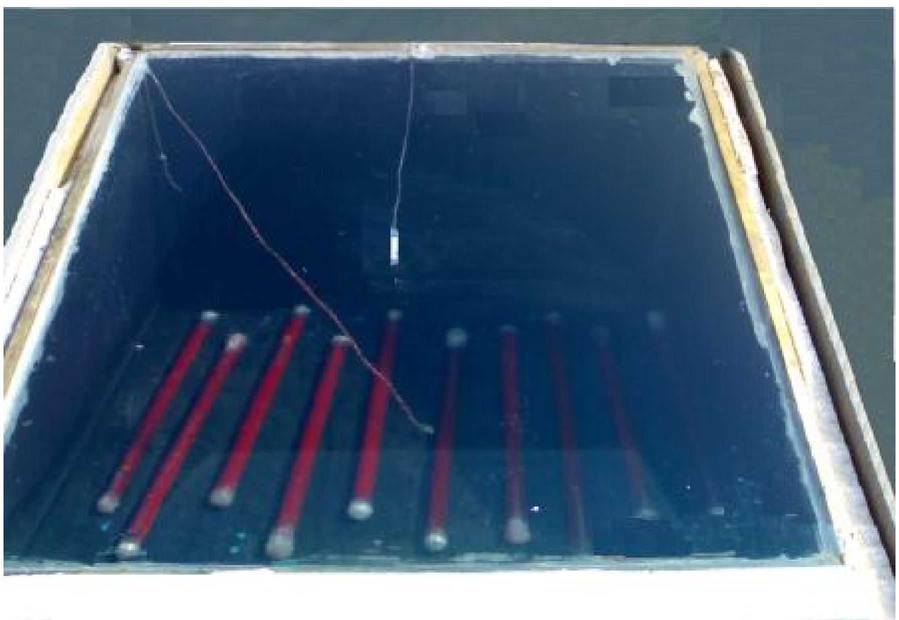


Figure (3) Front water still photo.

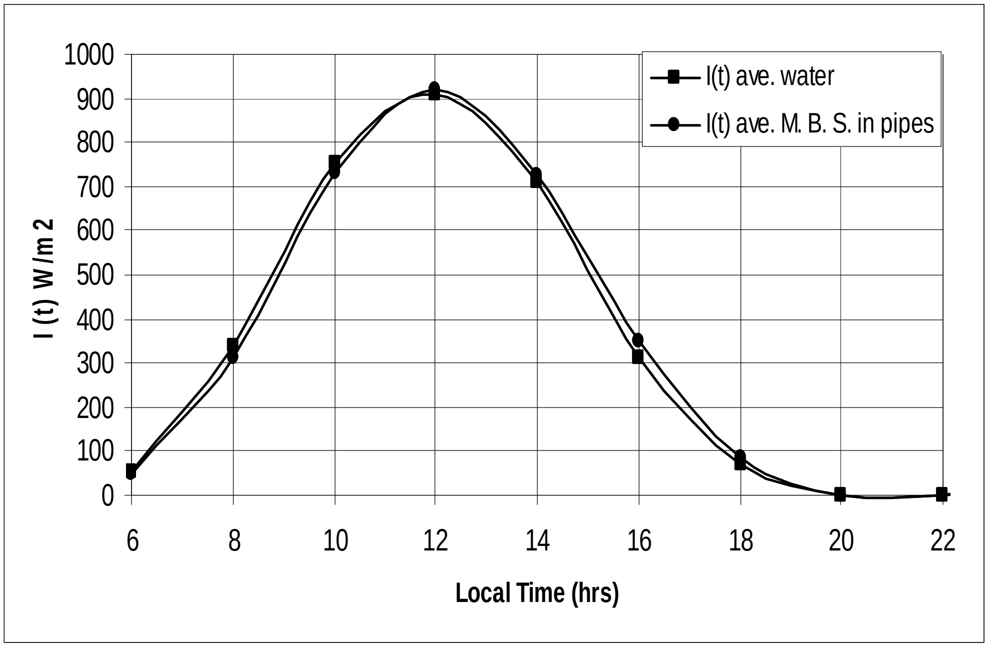


Figure (4) Shows the solar radiation intensity versus time of the day in cases with and without using Methylene Blue solution in glass pipes.

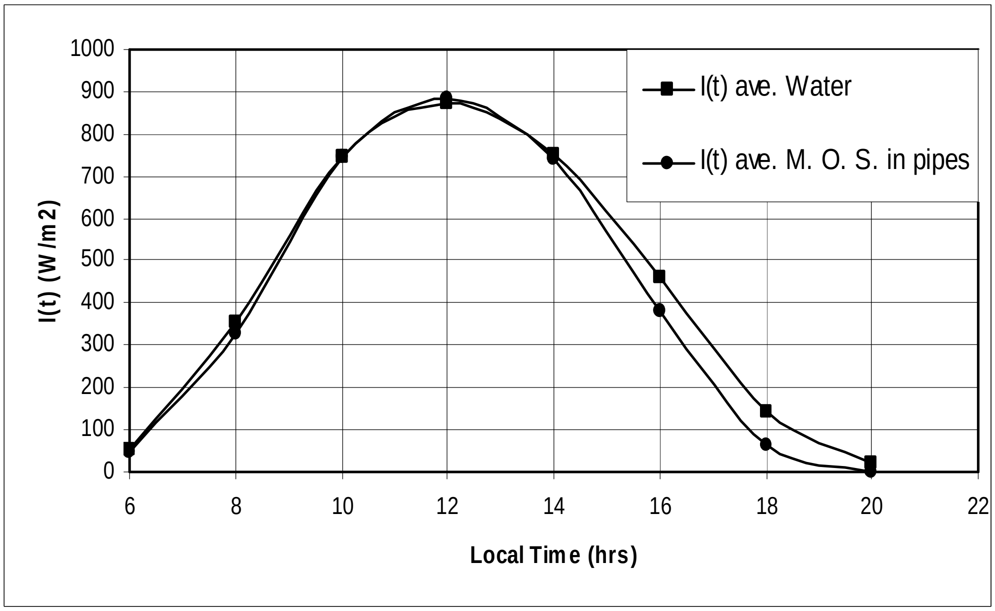


Figure (5) Shows the solar radiation intensity versus time of the day in cases with and without using Methyl Orange solution in glass pipe.

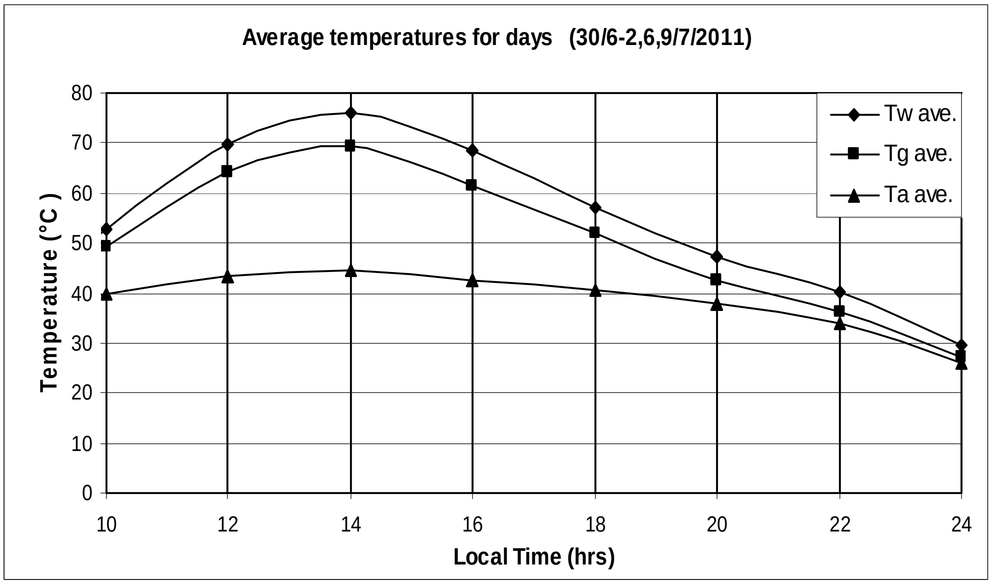


Figure (6) Shows the hourly variation of average water, glass and ambient temperatures when using water only for days 30/6- 2, 6, 9/7/2011.

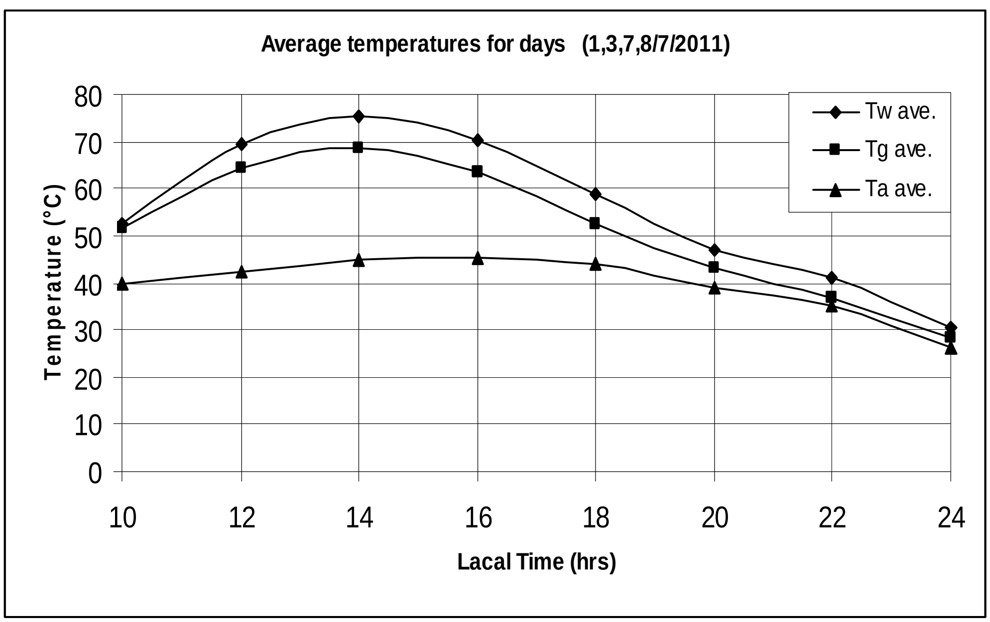


Figure (7) Shows the hourly variation of average water, glass and ambient temperatures when using Methylene blue solution in glass pipes.

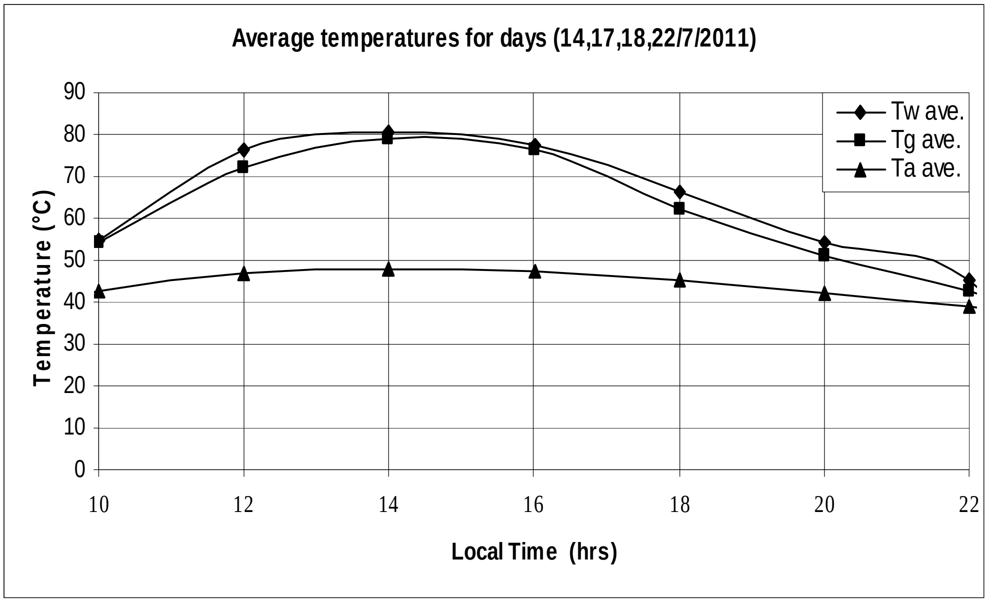


Figure (8) Shows the hourly variation of average water, glass and ambient temperatures when using water only for days 14, 17, 18, 22/7/2011.

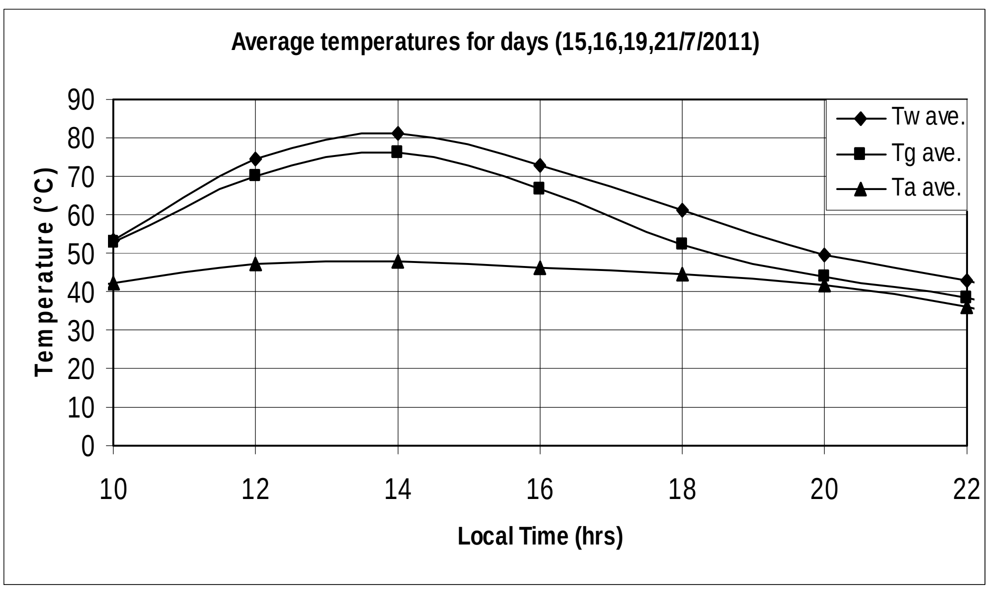


Figure (9) Shows the hourly variation of average water, glass and ambient temperatures when using Methyl Orange solution in glass pipes.

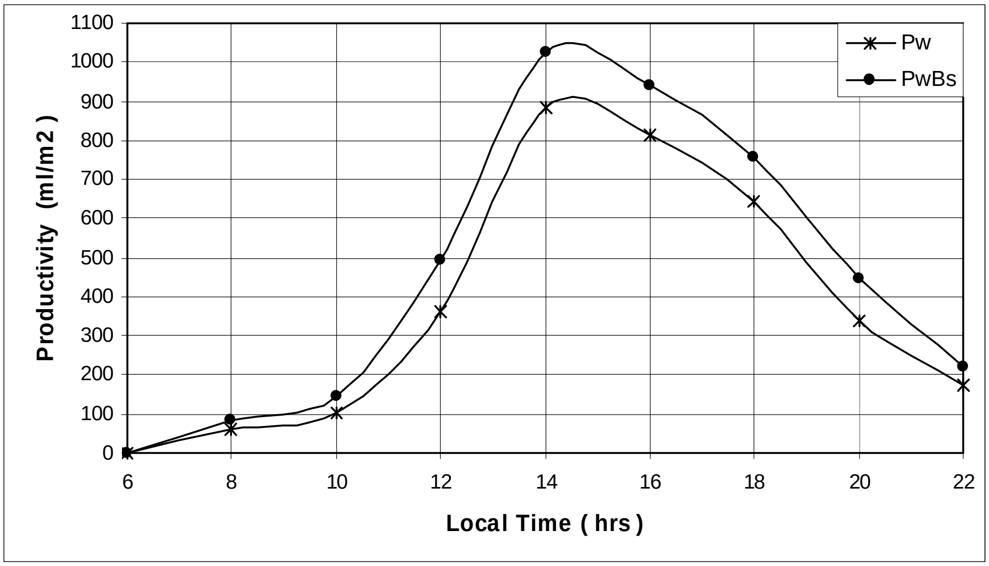


Figure (10) Shows the still productivity with the local time in cases when using MethyleneBlue solution in glass pipes compared with use of water only water only.

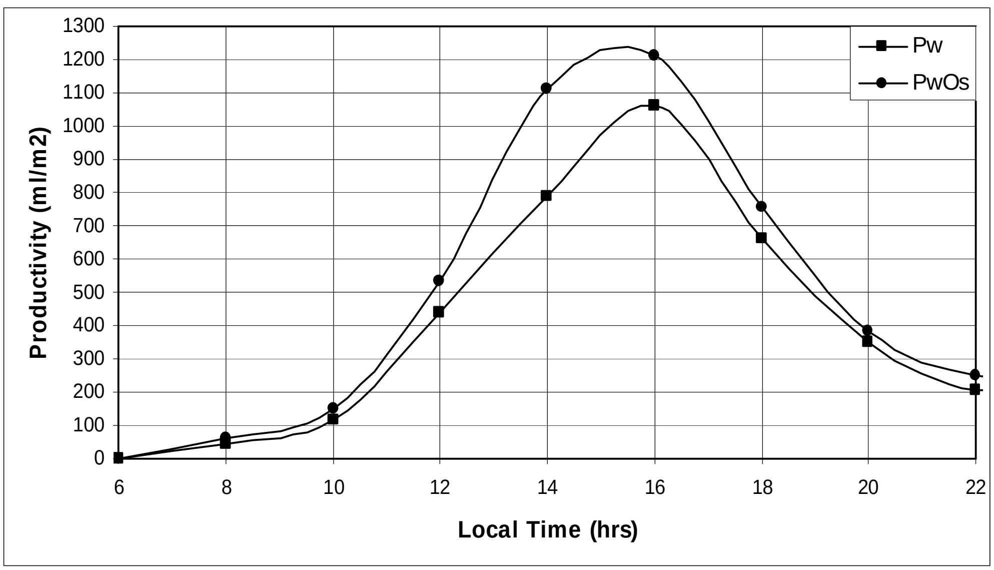


Figure (11) Shows the still productivity with the local time in cases when using Methyl Orange solution in glass pipes compared with use of water only.

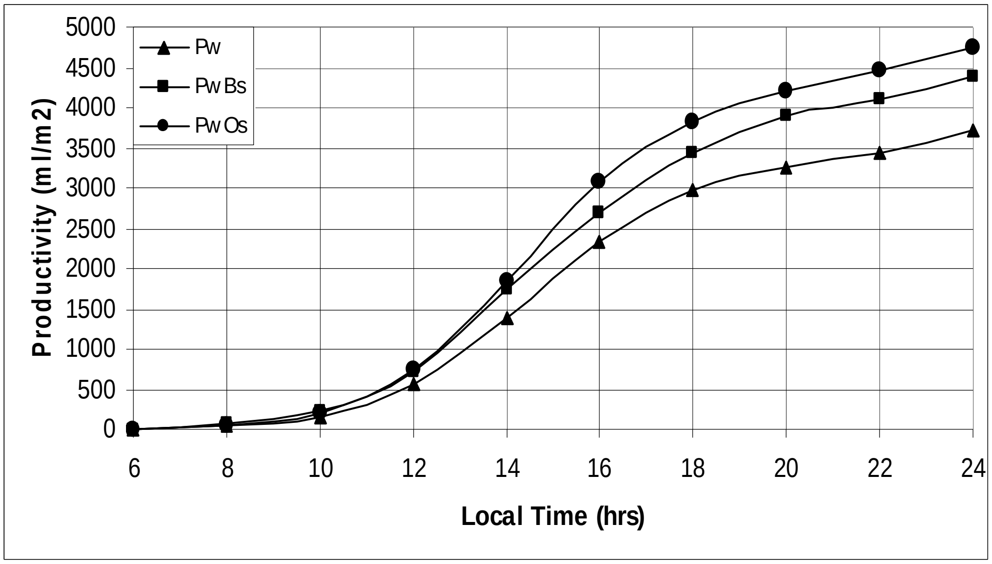


Figure (12) Variation of accumulative productivity for 24 hour for cases using (a)water (b) Methylene Blue and solution in the pipes (c) Methyl Orange and solution in glass pipes.

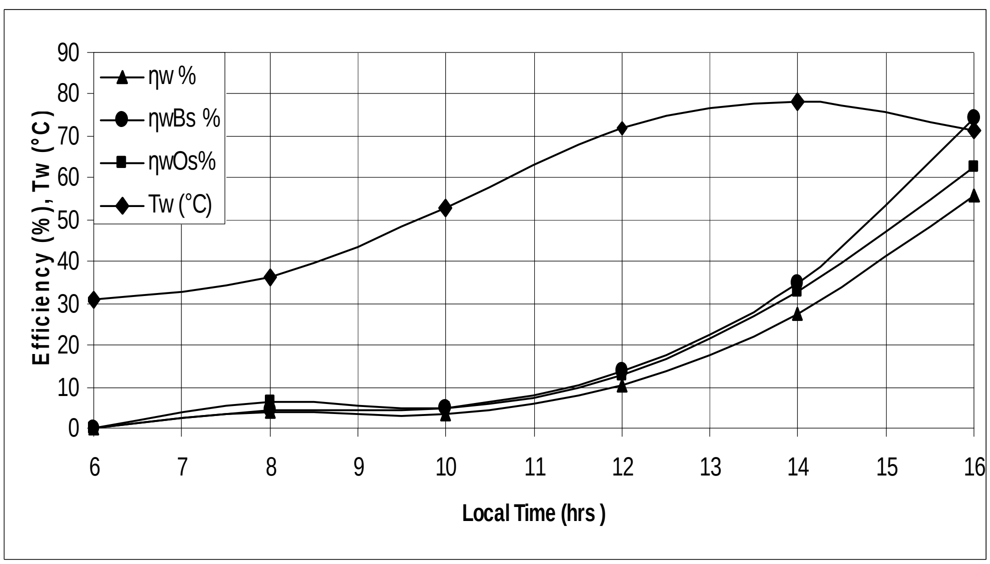


Figure (13) Presents variation of daily still accumulative efficiency and water temperature in case .

REFERENCES

[1] Dincer, I., Rosen, M. A. THERMAL ENERGY STORAGE, John Wiley & Sons, Ltd, England, 2002.

[2] . Khalifa, A. N., Ibrahim H. A. “Effect of inclination of the external reflector of simple solar still in winter: An experimental investigation for different cover angles”, International Journal of the science and technology of the desalting and water purification, Vol. 264, pp 129-133, 2010.

[3] Foster R. E., Amos W., Eby S. “Ten years of solar distillation application along the U. S. Mexico border”, Solar World Congress, International Solar Energy Society Orlando, Florida, August 11, 2005.

[4] Khalifa, A. N. “On the effect of cover tilt angle of the simple solar still on its Productivity in different seasons and latitudes”, Energy conversion and management, Vol. 52, pp. 431-436, 2011.

[5] Akash B. A., Mohsen M.S., O. Osta, Elayan Y. “Experimental evaluation of a single-basin solar still using different absorbing materials”, Renewable energy, Vol. 14, pp. 307-310, 1998.

[6] Abdullah S., Badran O.O. “Sun tracking system for productivity enhancement of solar still”, Elsevier Journal. Desalination, Vol. 220, pp. 669-676, 2008.

[7] El-Sebaii A. A., Al-Ghamdi A. A., Al-Hazmi F. S., Faidah A. S. “Thermal performance of a single basin solar still with PCM as a storage medium”, Elsevier Journal Applied Energy, Vol. 86, pp. 1187-1195, 2009.

[8] Naim M. M., Abd El Kawi M. A., “Non-conventional solar stills Part2. Non-conventional solar stills with energy storage element”, Elsevier Journal Desalination, Vol. 153, pp. 71- 80, 2002.

[9] Ighodalo O. A., Ebhodaghe F. A., “Performance Evaluation of a Solar Still for Salty Water Desalination”, Journal of Emerging Trends in Engineering and Applied Sciences, Vol. 2, pp. 338-341, 2011.

[10] M.Gowtham, M.Sharath Chander, K.V.Sri Saila Mallikarujanan and N.Karthikeyan, “Concentrated Parabolic Solar Distiller with latent heat storage capacity”, International Journal of Chemical Engineering and Applications, Vol. 2, pp. 185-188,2011.

[11] Khalifa A. N. and Hamood A. M., “On the verification of the effect of water depth on the performance of basin type solar still”, Solar Energy, Vol. 83, pp. 1312–1321, 2009.

[12] Badran O.O., “Experimental study of the enhancement parameters on a single slope solar still productivity”, Elsevier Journal, Desalination, Vol. 209, pp. 136-143, 2007.

[13] Medugu D. W., Ndatuwong L. G., “Theoritical analysis of water distillation using solar still”, International Journal of physical Sciences, Vol. 4 (11), pp. 705-712, November, 2009.

[14] Afrand M, Behzadmehr A., Karimipour A., “A Numerical Simulation of Solar Distillation for Installation in Chabahar-Iran”, World Academy of Science, Engineering and Technology, Vol. 71, pp. 515-520, 2010.

[15] Murugave K. K., Chockalingam K. S. K., Srithar K., “Modeling and Verification of Double Slope Single Basin Solar Still Using Laboratory and Actual Solar Conditions”, Jordan Journal of Mechanical and Industrial Engineering, Vol. 3, pp 228 – 235, 2009.

[16] Othmer K., “Encyclobedia of Chemical Thecnology”, John Wiley & Soins, Vol. 24, 1984.