International Journal of Industry and Sustainable Development (IJISD), Volume 6, Issue 1, Jan 2025

Print ISSN 2682-3993
Online ISSN 2682-4000

Enhancing solar still productivity: Dealing with design parameters

A. M. Tayeb[a,1], **H. M. Geddawy**[2]

[1]Chemical Engineering Department, Faculty of Engineering, Minia University, Minia, Egypt
[2]Water Plant, New Valley, Egypt
*Corresponding author: agharid.tayeb@mu.edu.eg

Received 11 Sept. 2024 – Revised 01 Oct. 2024 – Accepted 11 Oct. 2024

Abstract:

Water desalination processes have become of prime importance due to the increasing demands for fresh water. Due to the rapidly increasing prices of fossil fuel and caring about environmental safety, use of solar energy has drawn the interest of many researchers in the last few years as a means of an environmentally-friendly process for water desalination. The present study is an investigation of the effects of operating and design parameters on the performance of single-slope basin-type passive solar stills. A series of stills with the same external dimensions are used. Modifications are limited to the still basin by changing either the water depth or the shape of the still basin. The amount of water distillate, ambient temperature, vapor temperature, basin temperature, glass temperature and solar intensity were recorded. The results showed that water depth 0.4 cm gives the highest productivity of 2096 ml /m^2/day. The effect of the material of construction was studied. The results showed that the productivity of the stills increases by 16.7% when using metal as a construction material; compared to glass. Use of energy absorbing materials in the basin of the solar still increased the still productivity by 4.1%. Using a corrugated metal sheet in the bottom of solar still reduced the active area of evaporation to half its original value but the productivity was higher than half the productivity of the reference still.

Keywords: Solar Still, Desalination, Construction, Enhancing, Design

I. INTRODUCTION

Desalination is the process of purifying salt water into drinkable fresh water. Most of the modern interest in desalination has focused on providing fresh water for human consumption at low cost [1]. Since the desalination of water by evaporation requires a great deal of energy, solar desalination has recently been the subject of much research work [2]. Water is desalinated in several ways: reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), membrane distillation (MD), and solar desalination [3]. Solar desalination remains the most cost-effective method for supplying water to small communities in remote villages [4].

Solar stills fall into two broad categories: passive and active stills [5]. Passive stills heat water directly, without active elements such as heaters or boilers, and do not add preheated water from other sources [6, 7]. They are simple in design and do not require an additional heating element [8]. Active stills, on the other hand, have active heating elements. Preheated water can also be used [9]. Passive and active stills can be further divided into efficient and conventional designs [10].

The actual amount of water that can be distilled depends on a whole range of factors, including geographic location, position of the sun, general meteorological conditions, solar still design, and operating technique [11, 12]. There are many operating parameters that affect solar still productivity such as: Water depth, coloring of water with dye, water mass flow rate, salt concentration, use of phase change material (PCM) and absorption and storage materials [13]. There are several reviews dealing with the research and development of solar distillation systems [14-17].

The major limitation of solar distillation systems is their low productivity compared to conventional desalination processes [18]. Thus, the aim of this work is to investigate the factors increasing the yield of solar distillation systems. This is attained by changing the shape of the bottom of the basin, the depth of water in the basin or the construction material.

II. Experimental Work:

A. *Experimental setup:*

All experiments were conducted at the Solar Energy Laboratory of the Faculty of Engineering, Minia University, Egypt (30 45' east longitude). The present study is an investigation of the effects of operating and design parameters on the performance of basin type passive solar stills. A series of stills (all with the same basin area of 1 m^2) were used (**Fig. 1**). Some stills are made of galvanized iron with a glass cover, while others are made of glass. Design parameters included: type of construction material (metal or glass), evaporation area, shape of the basin (flat or fluted), and use of a heat-absorbing material. Series of experiments were conducted with two different passive solar tanks, one with glass walls and the other with metal walls, to investigate the effects of the construction material on improving the productivity of the solar still during the day.

Fig. 1: Photo of the solar stills used

B. Material and method:

1. Material:

Sodium chloride (NaCl, Analytical grade) and distilled water are used for the preparation of salt water required for the desalination experiments.

Print ISSN 2682-3993
Online ISSN 2682-4000

2. Method:

All experiments are carried out in batch at room temperature. Synthetically prepared salt water is used in the experiments by adding an appropriate amount of salt to distilled water to simulate saline seawater. Sodium chloride at a concentration of 35,000 ppm is used to simulate Mediterranean Sea water. Saline water is introduced into the distillation pool, and the distillation unit is left under sun rays to help evaporating the water in the pool. The productivity of the distillation unit is monitored hourly (V, in ml) and other variables are also recorded. The variables recorded are ambient temperature, pool temperature, glass cover temperature, and solar intensity. Temperature is measured with thermocouples connected to a digital multipoint meter (Fluke) "2166A", and the solar intensity is measured with a digital millimeter (HAENNI) "solar 130". The daily productivity is the total amount of desalinated water collected during the experiment hours. The daily thermal efficiency for stills is calculated using the relationship (Kabeel et. al, 2016) [19]:

$$E = \frac{Q \times h}{A \times I}$$

Where:
E = overall thermal efficiency
Q = daily output (liter)
h = latent heat of vaporization (2.260 MJ/l)
A = area of the glass surface of the solar still (m^2)
I = average daily solar radiation (MJ/m^2)

III. Results and Discussion:

Experiments were conducted in April, July and August of 2020.

A. Effect of the material of construction:

Series of experiments were conducted on:
1. Passive solar system with glass walls
2. Passive solar system with metal walls; to study the effect of construction material on performance.

Fig. 2a shows the hourly productivity for two stills; one is made of glass and the other is made of galvanized iron. Experiment is carried out on 3/4/2020. It is observed that the productivity is higher near noon (for both stills). However, the productivity of the galvanized iron still is always higher than that of the glass still.

The accumulated productivity (daily productivity) of the two stills is shown in **Fig. 2b**. During the experimental period (from 10:30 am to 4:50 pm), the total productivity was 1330 and 1107 ml for the metal and glass stills, respectively. The use of galvanized iron in the sidewalls of the stills increases the productivity of the solar still by 20% compared to that made of glass. This agrees with the results of Kabeel et al., 2014 [20]. The efficiency of the still is 20.5% and 24.6% for the glass and metal stills, respectively.

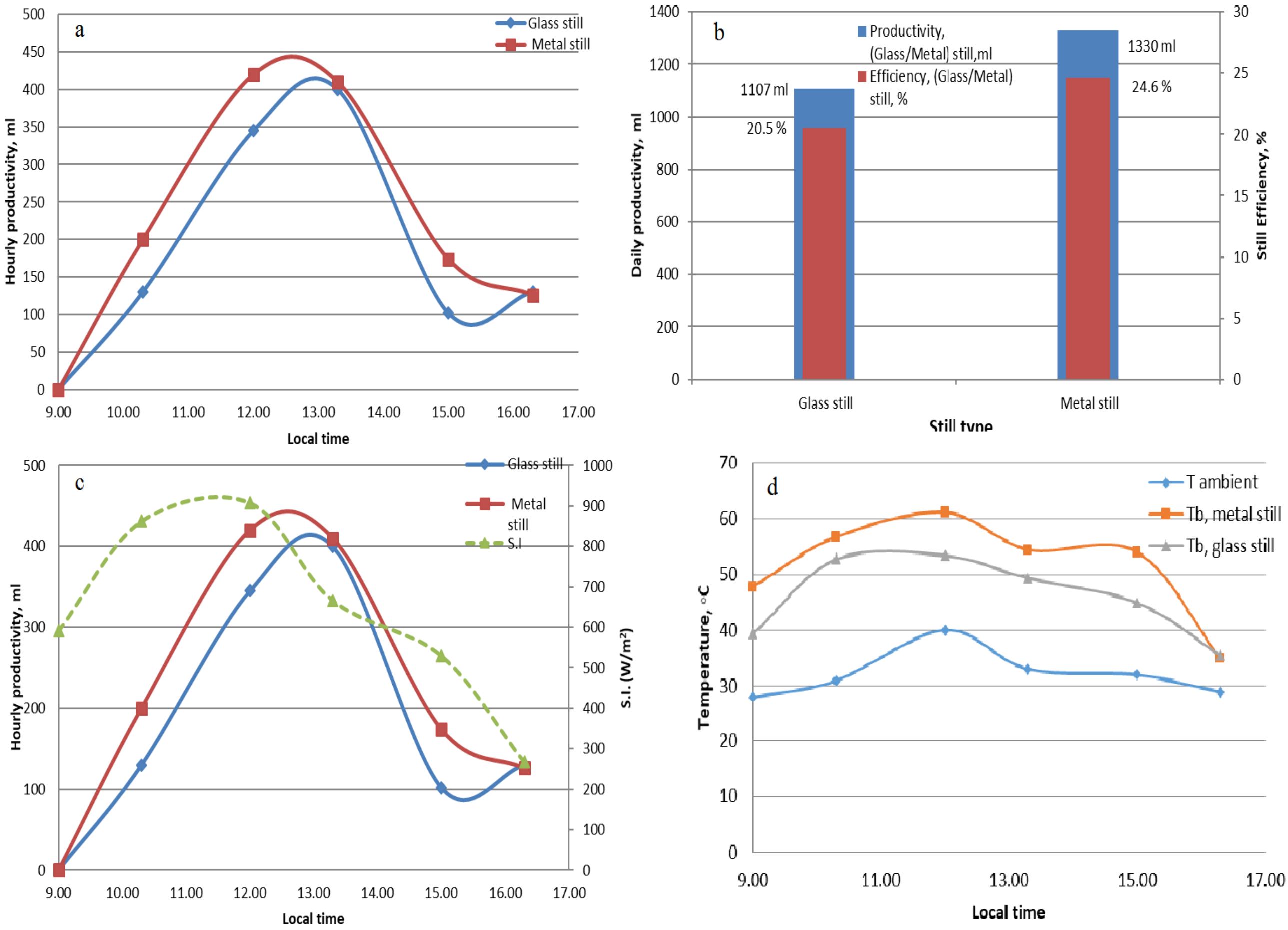

Fig. 2: (a) Hourly productivity of metal and glass stills, (b) Daily productivity and efficiency of glass and iron stills, (c) Change of hourly productivity of glass and metal stills with solar intensity and (d) Change in pool temperature for metal and glass stills (Tb, metal still & Tb, glass still) and ambient temperature over time of experiment

Fig. 2c shows the change in hourly distillate productivity as a function of solar intensity. It is clear that both curves show the same tendency, i.e. the productivity of the stills increases with the solar intensity. **Fig. 2d** shows the variation of the basin (Tb) and ambient (Tambient) temperature with time of the day. It can be seen that the basin temperature of the metal still is higher than that of the glass still, and both are higher than the ambient temperature but have almost the same trend. This explains the higher productivity of the metal still compared to the glass still, as shown in **Fig. 2a and b**. At midday, the ambient temperature was 40°C, while the pool temperatures for the metal and glass stills were 61.1 and 53.5°C, respectively. At sunset, the basin temperatures of both stills are almost the same (35 and 35.6°C for metal and glass stills, respectively (but still higher than the ambient temperature of 29^{O}C), which is due to the higher thermal conductivity of metal compared to glass and the associated higher heat loss from the basin [21].

Throughout the day, there is a temperature difference between the cover of the still and the temperature of the water basin. This temperature gradient is the driving force for evaporation and condensation of water, which in turns affects the productivity of the still [22].

Print ISSN 2682-3993
Online ISSN 2682-4000

The relation between the temperature gradient (between basin temperature Tb and glass temperature Tg) for both stills and its productivity are shown in **Fig. 3**. It is noticeable that a maximum hourly productivity of 400 ml/h/m^2 is reached at noon (at 13:30) for the glass still, while for the metal still it is 420 ml/h/m^2 at 12:00 (SI = 908 W/m^2).

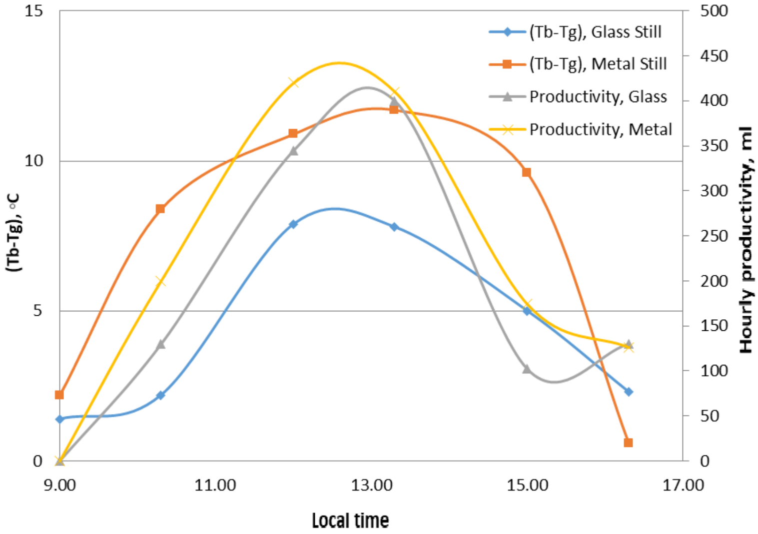

Fig. 3: Change in hourly distillation output with the temperature gradient (3/4/2020)

B. Effect of still basin shape on its productivity:

Two solar stills with different basin shapes were used in this test. One still has a flat basin, and the other has a basin made of galvanized corrugated sheet metal, so the area filled with water (evaporation area) is almost reduced to half compared to the other still (only the deep areas are filled with water). Although both stills have the same condensing area, the results shown in **Fig. 4** indicate that the still with shallow basin (larger area) has higher productivity. Thus, the productivity of the still is proportional to the evaporation area (area of the still). However, it is interesting to note that even though the area filled with water of the corrugated basin is almost half that of the flat basin, the productivity is more than half that of the flat basin. This could be because the higher metal parts of the corrugations act as absorbers of solar energy, increasing the basin temperature and consequently the distillation productivity [23].

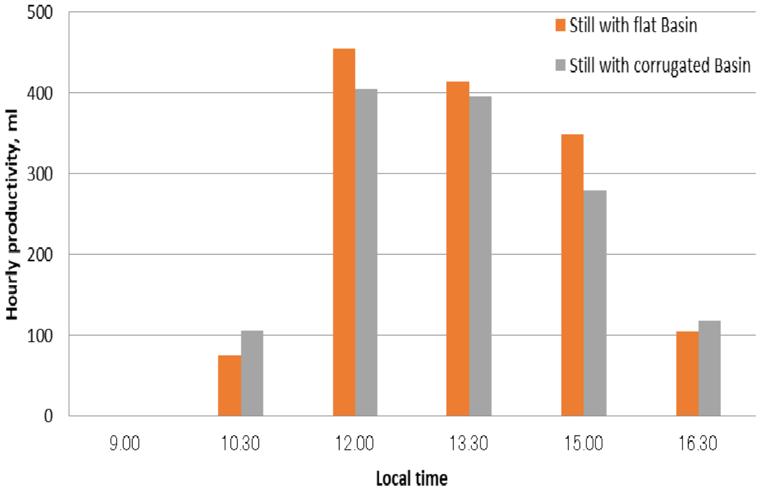

Fig. 4: Change in hourly still productivity with the shape of the basin (4/4/2020)

As shown in **Fig. 5a**, the daily productivity of the still with flat basin is 1400 ml/m^2/day, while the corresponding daily productivity of the still with corrugated basin is 1304 ml/m^2/day. Thus, the productivity of the flat basin still was increased by 7.4% even though the water-filled area of the flat basin is almost twice that of the corrugated basin, and the system efficiency was 25.9% and 24% for the flat basin still and the corrugated basin still, respectively.

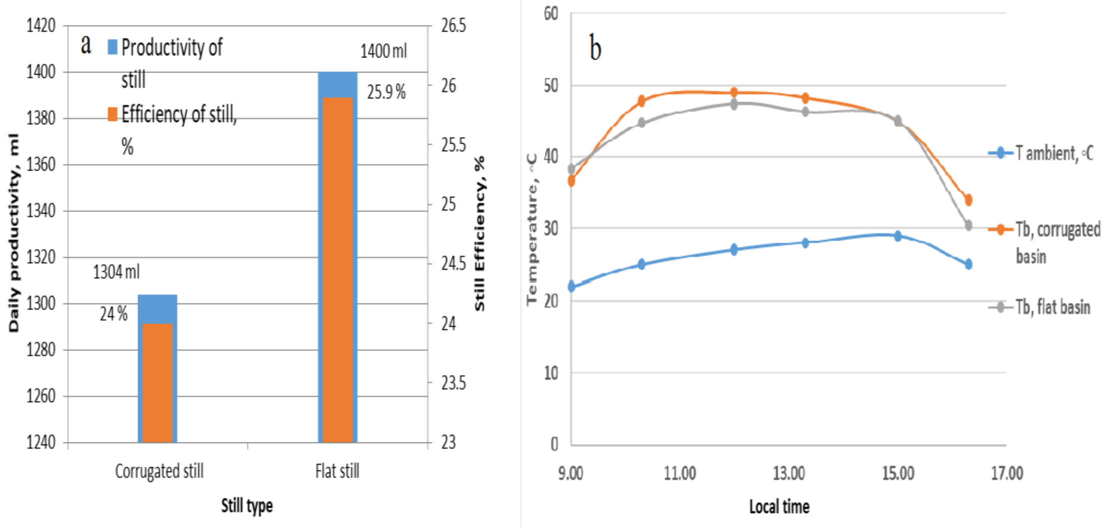

Fig. 5: (a) Change in daily productivity and efficiency with the shape of still basin (b) Change of the basin temperature in stills with flat and corrugated basins with time and ambient temperature

Fig. 5b shows the change in pool temperature for both types (with flat and corrugated basin) with ambient temperature. It can be seen that the temperature of the wavy pool is higher than that of the flat pool, and both are above and almost parallel to the ambient temperature curve. This is because the higher areas of the corrugations are exposed to the sun's rays and act as an extended surface or fins that absorb more solar energy, increasing its temperature [24]. However, the solar still with a flat basin is more productive than the one with a fluted basin because it has a larger evaporative surface area [25]. Although the temperature gradient (Tb-Tg) is larger for the corrugated basin (**Table 1**), the daily productivity of the shallow basin is higher due to the larger evaporation area. Thus, evaporation area is a predominant factor in increasing productivity [26].

Table 1: Temperature gradient and productivity of flat and corrugated stills

Local Time	Tb-Tg, Flat Basin	Tb-Tg, Corrugated Basin	Hourly productivity, Flat Basin	Hourly Productivity, Corrugated Basin
9:00	1.7	3.3	0	0
10:30	3.8	4.3	75	106
12:00	4.6	6.1	455	405
!3:30	3.3	5.6	415	395
15:00	3.0	5.7	350	280
16:30	1.9	3.3	105	118

Fig. 6a shows that hourly still productivity changes with solar intensity (S.I.) values. It is clear that productivity is higher around noon when higher values of solar intensity are reached. The maximum hourly productivity at noon time was 455 ml/m^2 and 405ml/m^2 for the flat and corrugated basins, respectively, and this was at a solar intensity of 690 W/m^2.

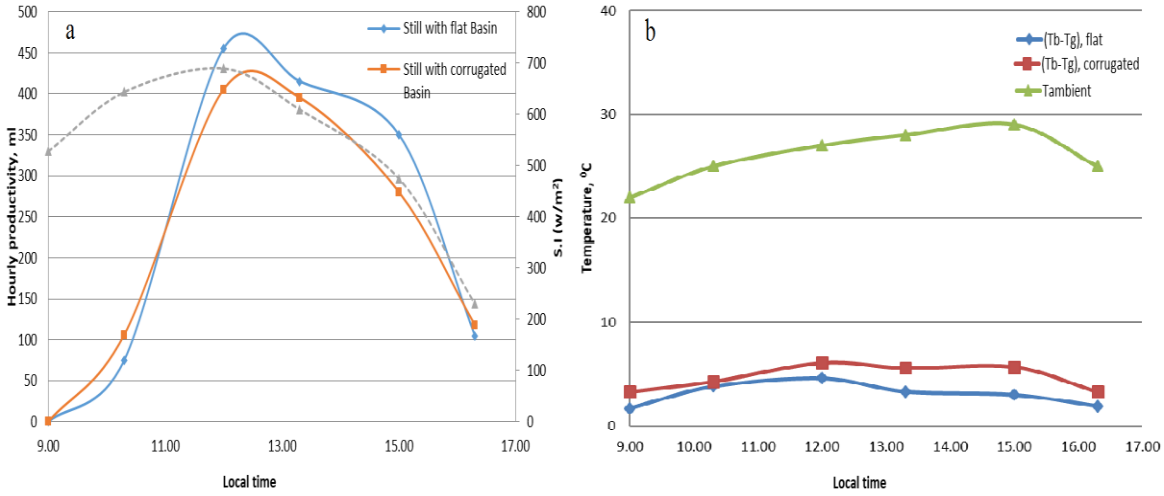

Fig. 6: (a) Hourly productivity of stills as a function of solar intensity (SI) (4/4/2020)
(b) Change of temperature gradient and ambient temperature with time

Fig. 6b shows the temperature gradient between the glass cover and the pool temperature for the flat and corrugated pool stills. It is clear that even at sunset there is still a temperature difference, resulting in low production of desalinated water at sunset. Although the temperature gradient is higher for the corrugated basin, its productivity is lower than that of the flat basin. This is because the evaporation area of the flat basin is larger and therefore the amount of water evaporated is higher [27]. Therefore, it can be said that the temperature gradient between the glass cover and the distillation basin is not the only factor that increases the productivity of distillation, unless it is supported by a large evaporation area. The efficiency was increased by 35% when a corrugated basin was used.

C. . Effect of using energy storage material on the productivity of solar still: **(Use of copper tubes in still basin):**

An important parameter affecting distillery productivity is the use of a heat absorbing material. In this test, two similar stills were used with copper tubes (in the form of a serpentine) added to the basin of one still as an energy storage material. **Fig. 7a** shows that the effect of the copper tubes on increasing the productivity of the stills is visible just after midday and before sunset. This can be explained as follows: Around noon, the copper tubes begin to heat up due to solar radiation, which is not the case in the morning because the tubes are immersed in water [27]. Before sunset, the water in the basin starts to cool down, but the copper tubes still have some stored energy, which helps to increase the productivity of the still during this time. The maximum productivity of the still with copper tubes was 470 ml and it was reached around noon, while the maximum productivity of the still without copper tubes was 400 ml and it was reached shortly after noon.

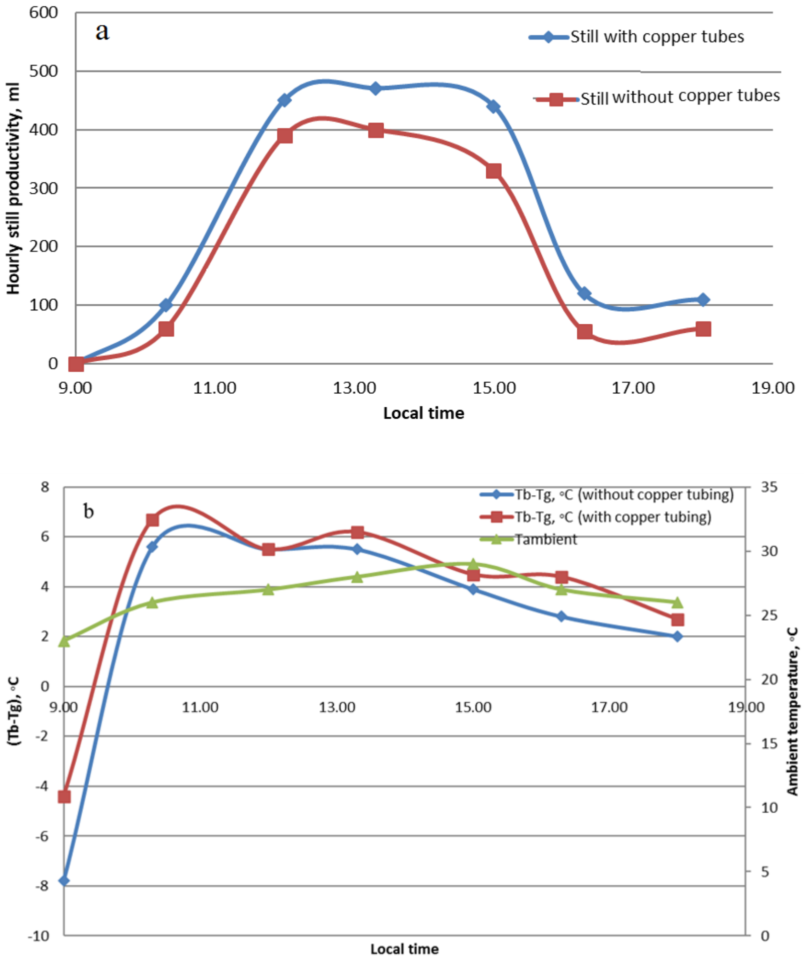

Fig. 7: Change in hourly productivity over time for stills with and without copper tubes (a) (23/4/2020) and (Tb-Tg) versus local time for stills with and without copper tubings (b)

However, the temperature of the pool with copper pipes does not show this variation between the morning and afternoon periods and is always slightly higher than the temperature of the pool without copper pipes. This is noticed when recording the driving force for evaporation (T_b-T_g); as shown in **Fig. 7b**. The maximum temperature gradient was 7.5^{O}C and it is reached at 11 am. It is interesting to note that the temperature gradient is negative at the beginning of the day. This could be due to the glass cover being exposed to solar radiation at the beginning of the day and therefore heating up to a higher temperature than the temperature of the pool, resulting in a negative temperature gradient [22]. As time progresses, the pool begins to warm up, increasing its temperature and thus yielding positive values for the temperature gradient. This is consistent with the results in Figs. **7a**, b where no yield was obtained at the beginning of the day when a negative temperature gradient prevails.

Change of ambient temperature with time is also shown in **Fig. 7b**. Besides, the higher hourly productivity of the still with copper tubes is related to the higher solar intensity, as shown in **Figs. 8a**. This is due to the effect of the copper tube as an energy storage material [25], and it is noticed at maximum solar intensity (around solar noon). The change in hourly distillation productivity with solar intensity shows the same trend as before (in sections 3.1 and 3.2), i.e., an increase in distillation productivity with higher values of solar intensity. The maximum hourly productivity of the still with copper tubes was 470 ml and it is reached at noon (at mtximum value of solar intensity). This compares to 400 ml for the still without copper tubes at the same time. Although the difference between the productivity of the two stills is not large in the morning, it becomes more evident in the afternoon period, which can be attributed to the effect of the copper tubes as an energy storage medium [28- 30]. This effect continued until the hour of sunset, when the solar intensity recorded its minimum value of 100 W/m^2. The daily production of desalinated water for the still with copper tubes was 1530 ml compared to 1470 ml for the still without copper tubes **(Fig. 8b**). Thus, an increase of 4.1% due to the copper tubing is accomplished. The system efficiency was 37% and 35% for stills with and without copper tubing, respectively.

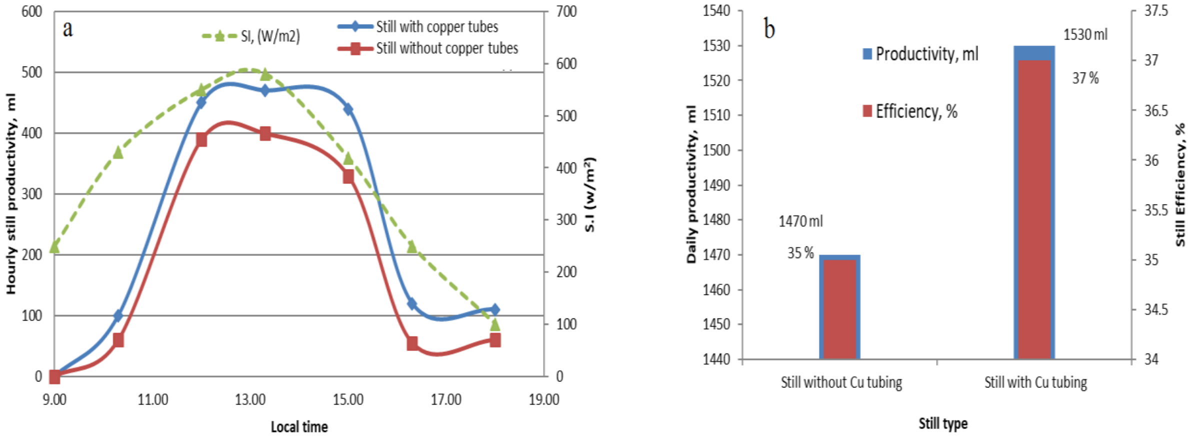

Fig. 8: (a) Hourly productivity with solar intensity, (b) Daily productivity and still efficiency

3.4. Effect of the brine depth in basin:

Under the weather conditions of 7/4/2020, an experiment was conducted with four similar stills with different values for the brine depth in the still. Values of 0.4, 0.5, 0.6, and 0.8 cm of water depth were used to study the effect of varying the water depth on the productivity of the solar still. The results of this test are shown in **Fig. 9a** as hourly productivity as a function of local time and in **Fig. 9b** as accumulated productivity for the stills (daily productivity) with different water depths in their basins.

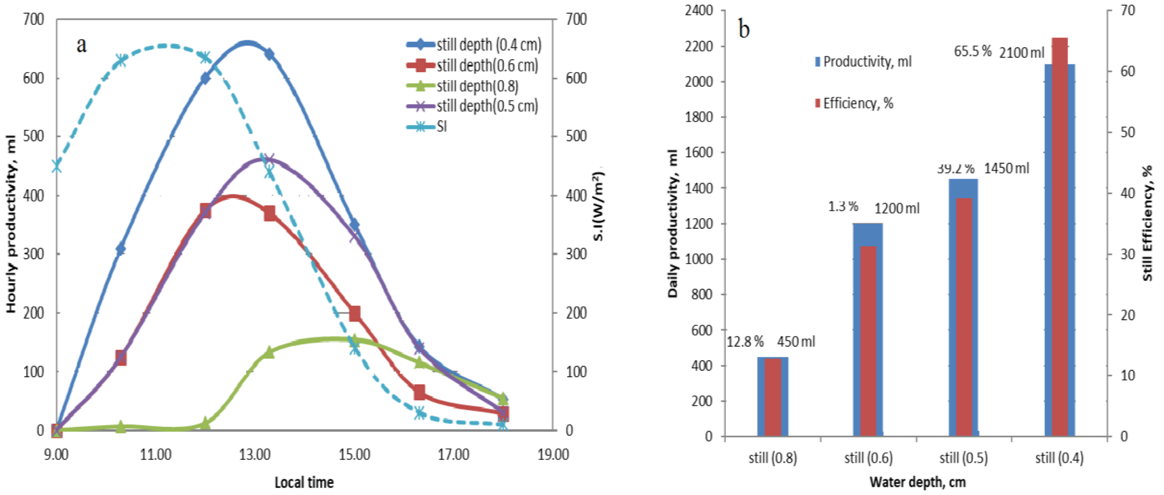

Fig. 9: (a) Change of hourly still productivity with water depth in basin (7/4/2020)
(b) Cumulative distillation output and distillation efficiencies for distillation units with different water depths (7/4/2020)

It is clear from Figs. 9a and b that as salt water depth increases, distillate productivity decreases. As sunset hour approaches, the pool temperature and solar intensity decrease, and the productivity decreases rapidly. The distillate output of the solar system varies with the intensity of solar radiation, which is usually highest at midday (around 12 noon) and then decreases towards sunset (sunset on the experimental day was at 18:27). As shown in Fig. 9a, although the still with a water depth of 0.8 cm had the lowest productivity during the day, its productivity exceeded that of the 0.6 cm pool at the end of the day and even after sunset. This could be because greater water depth means greater water volume, i.e., greater heat capacity for water, which helped to increase the productivity of the 0.8 cm water depth still compared to the other stills; at the end of the sunny day [23]. However, the production of the still with 0.8 cm water depth is delayed compared to the other stills because it takes a while for the water to heat up and reach evaporation due to the larger mass of the still water compared to the other stills [21]. Fig. 9b shows that the accumulated amount of water per day reaches 2096, 1455, 1163 and 476.5 ml/m^2 after 10 hours of distillation operation for stills with 0.4, 0.5, 0.6 and 0.8 cm water depth, and the corresponding efficiencies are: 56.5%, 39.2%, 31.3% and 12.8%, respectively. Thus, the maximum daily yield is 2096 ml/m^2 for the still with 0.4 cm depth. This indicates that the performance of a solar still is high when the water depth of the pool is shallower. A 77% decrease in the distillation unit efficiency was achieved when the water depth was increased from 0.4 to 0.8 cm. The distillate output of the solar still varies with the intensity of the total solar radiation. It increases to a maximum value at 12 noon and then decreases with time. The maximum yield is 2096 ml/m^2 for the still with 0.4 cm depth. It should be noted that the basin temperatures decrease with increasing water depth in the basin. This is evident from the results in Fig. 10a (along with ambient temperature) and is an explanation for the fact that still productivity increases with increasing water depth. Despite the lower daily productivity, the still with a water depth of 0.8 cm reached almost the same pool temperature at the end of the day (39°C). This is the same as for the stills with 0.4 and 0.5 cm water depth), which can be attributed to the relatively higher heat capacity [29].

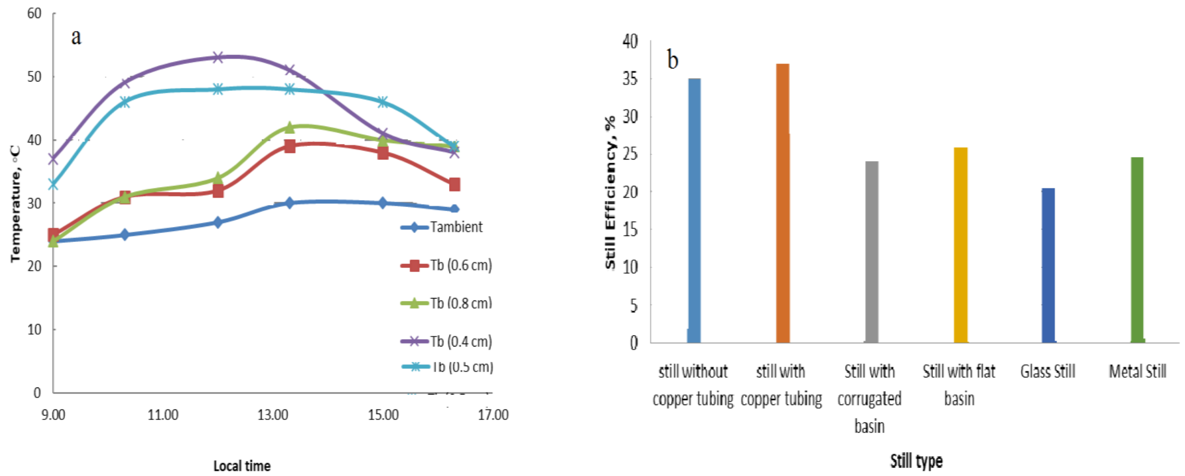

Fig. 10: (a) Change of the basin temperature with water depth in the basin (7/4/2020)
(b) Efficiencies of the different stills considered in the study

Fig. 10b shows the efficiencies of the different stills considered in this study. It is clear that the highest efficiency (37%) is achieved by the still with copper pipes. This is followed by the stills without copper pipes (35%) and the stills with flat basin (25.9%). The stills with metal walls and the stills with corrugated basin have almost the same efficiency (24.6% for the first and 24% for the second), while the still with glass walls has the lowest efficiency (20.5%).

IV. CONCLUSION

In this study, the effect of design and operating parameters of solar stills on their productivity and efficiency was investigated.

- The use of galvanized iron in the stills increased the productivity of the stills by 20%. The efficiency of the stills is 20.5% for the glass stills and 24.6% for the metal stills. The total productivity was 1330 ml/m2/day and 1107 ml/m2/day for the metal and glass stills, respectively.

- The productivity of the still with corrugated basin is higher than half the value for the flat basin still. The maximum hourly productivity at noon was 455 ml/m^2 and 405ml/m^2 for the flat and corrugated basins, respectively, and this was at a solar intensity of 690 W/m^2.
  - The maximum productivity of the still with copper tubes was 470 ml and it was reached at noon, while the maximum productivity of the still without copper tubes was 400 ml and it was reached shortly after noon.
- The accumulated water per day reached 2096, 1455, 1163, and 476.5 ml/m^2 after 10 hours of distillation operation for stills with depths of 0.4, 0.5, 0.6, and 0.8 cm, and the corresponding efficiencies were 56.5%, 39.2%, 31.3%, and 12.8%, respectively.
- The maximum daily yield is 2096 ml/m^2 for the still with 0.4 cm depth.
- The highest efficiency (37%) is achieved by the still with copper pipes. It is followed by the stills without copper pipes (35%) and the stills with flat basin (25.9%).
- The stills with metal walls and the stills with corrugated basin have almost the same efficiency (24.6% for the first and 24% for the second), while the stills with glass walls have the lowest efficiency (20.5%).

References:

[1] N. Rahbar, J.A. Esfahani, Productivity estimation of a single-slope solar still: Theoretical and numerical analysis, Energy 49 (2013) 289-297.

[2] S.Z. Heris, S.G. Etemad, M.N. Esfahany, Convective heat transfer of a Cu/Water nanofluid flowing through a circular tube, Exp. Heat Transf. 22(2009) 217-227.

[3] B. Xiao, Y. Yangc, L. Chen, Developing a novel form of thermal conductivity of nanofluids with Brownian motion effect by means of fractal geometry, Powder Technology 239(2013) 409–414.

[4] Y. He, Y. Jin, H. Chen, Y. Ding, D. Cang, H. Lu, Heat transfer and flow behavior of aqueous suspensions of TiO_2 nanoparticles (nanofluids) flowing upward through a vertical pipe. Int. J. Heat Mass Transf. 50(2007) 2272-2281.

[5] D. Gloss, H. Herwig, Wall roughness effects in laminar flows: an often ignored though significant issue, Exp. Fluids 49(2010) 461- 470.

[6] R. N. Wenzel, Resistance of solid surfaces to wetting by water, Ind. Eng. Chem. Res. 28(1936) 988.

[7] K.S. Hong, T.K. Hong, H.S. Yang, Thermal conductivity of Fe nanofluids depending on the cluster size of nanoparticles, Appl. Phys. Lett. 88(2006) 1-3.

[8] W. Wei, J. Cai, X. Hu, Q. Han, S. Liu, Y. Zhou, Fractal analysis of the effect of particle aggregation distribution on thermal conductivity of nanofluids, Phys. Lett. A 380(2016)2953-2956.

[9] J. Cai, X. Hu, B. Xiao, Y. Zhou, W. Wei, Recent developments on fractal-based approaches to nanofluids and nanoparticle aggregation, Int. J. Heat Mass Transf. 105(2017) 623-637.

[10] J. F. Orgill, K. G. T. Hollands, Correlation equation for hourly diffuse radiation on a horizontal surface. Sol. Energy 19(1977) 357–359.

[11] R. Foster, M. Ghassemi, A. Cota, Solar Energy: renewable Energy and the Environment, CRC Press, 2010.

[12] O. Mahian, A. Kianifar, A.Z. Sahin, S. Wongwises, Entropy generation during Al_2O_3/water nanofluid flow in a solar collector: effects of tube roughness, nanoparticle size, and different thermophysical models, Int. J. Heat Mass Transf. 78(2014) 64-75.

[13] O. Mahian, A. Kianifar, A.Z. Sahin, S. Wongwises, Performance analysis of a mini channel based solar collector using different nanofluids, Energy Convers. Manag. 88(2014)129-138.

[14] J. B. Puga, B. D. Bordalo, D. J. Silva, M. M. Dias, J. H. Belo, J. P. Araújo, J. C.R.E. Oliveira, A. M. Pereira, J. Ventura, Novel thermal switch based on magnetic nanofluids with remote activation, Nano Energy 31 (2017) 278-285.

[15] P. Nitiapiruk, O. Mahian, A. S. Dalkilic, S. Wongwises, Performance characteristics of a microchannel heat sink using TiO_2/water nanofluid and different thermophysical models, Int. Communications Heat Mass Transf. 47(2013) 98-104.

[16] A. Celen, A. Çebi, M. Aktas, O. Mahian, A. S. Dalkilic, S. Wongwises, A review of nanorefrigerants: Flow characteristics and applications, Int. J. Refrigeration 44(2014) 125-140.

[17] R. Saidur, K.Y. Leong, H.A. Mohammad, A review on applications and challenges of nanofluids, Renew. Sustainable Energy Reviews 15 (2011)1646-1668.

[18] M.K. Gnanadason, P.S. Kumar, S. Rajakumar, M.H.S. Yousuf, Effect of nanofluids in a vacuum single basin solar still, I.J.AERS 1(2011) 171–177.

[19] Kabeel AE, Abdelgaied M. Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions. Desalination. 2016 Apr 1;383:22-8.

[20] A.E. Kabeel, Z.M. Omara, F.A. Essa, Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach, Energy Convers. Manag. 78 (2014) 493-498.

[21] Z.M. Omara, A.E. Kabeel, F.A. Essa, Effect of using nanofluids and providing vacuum on the yield of corrugated wick solar still, Energy Convers. Manag. 103(2015) 965-972.

[22] T. Elango, A. Kannan, K. K. Murugavel, Performance study on single basin single slope solar still with different water nanofluids, Desalination 360(2015) 45-51.

[23] L. Sahota, G.N. Tiwari, Effect of Al_2O_3 nanoparticles on the performance of passive double slope solar still, Sol. Energy 130(2016) 260-272.

[24] L. Sahota, G.N. Tiwari, Effect of nanofluids on the performance of passive double slope solar still: A comparative study using characteristic curve, Desalination 388(2016) 9-21.

[25] S.W. Sharshir, G. Peng, L. Wu, N. Yang, F.A. Essa, A.H. Elsheikh, S. I.T. Mohamed, A.E. Kabeel, Enhancing the solar still performance using nanofluids and glass cover cooling: Experimental study, Appl. Therm. Eng. 113(2017) 684-693.

[26] Y. Ding, H. Alias, D. Wen, R.A. Williams, Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids), Int. J. Heat Mass Transf. 49(2006) 240-250.

[27] H. Xie, Y. Li, W. Yu, Intriguingly high convective heat transfer enhancement of nanofluid coolants in laminar flows, Phys. Lett. A: Gen., Atomic Solid State Phys. 374(2010) 2566-2568.

[28] J. A. Duffie, W. A. Beckman, Solar engineering of thermal processes, 2nd ed., 919. New York: John Wiley & Sons, 1991.

[29] A. K. Tiwari and G. N. Tiwari, Solar Distillation Practice for Water Desalination Systems, Anshan Publishers, India, 2008. 33
[30] R. Dunkle, Solar water distillation, The roof type still and a multiple effect diffusion still, Internat. Developments in Heat Transfer, ASME, Proc. Internat. Heat Transfer, Part V, University of Colorado, 1961, 895.