ENHANCED SOLAR STILL PERFORMANCE USINGA CONVEX LENS ON THE GLASS COVER

S. A. El-Agouz

Department of Mechanical Power Engineering, Faculty of Engineering, Tanta University, EGYPT
elagouz2011@yahoo.com, el-sayed.abdelazim@f-eng.tanta.edu.eg

ABSTRACT

This paper presents a modification of solar still using a convex lens on glass cover, tocollect the solar radiation at the focus on surface water. Thecomparison between modified solar still with a convex lens and conventional solar still is carried out to evaluate the enhanced performance system under the same climate conditions.The effect of modified solar still using a convex lens with and without black stone on the distillate productivity is investigated. The results indicate that the productivity of the modifiedstill with convex lens is higher than that for conventional still approximately by 26.64%, while 35.55 % with a convex lens and black stone at mass water 30 kg. Also, the maximum productivity of the modified still with a convex lens and black stone is 51.85% at mass water 20 kg.Total dissolved solids (TDS) and pHof salt water desalination are22 mg/l and 8.08.

Keywords: Solar still; Solar radiation; Desalination; convex lens

INTRODUCTION

Clean drinking water is a basic human need. Many people, especially in developing countries, do not have access to clean drinking water. Water that is dirty or salty is undrinkable, and untreated water that looks clean is likely to have bacteria and organisms that cause sickness and disease. A solar still is a device that produces clean, drinkable water from sea water using the energy from the sun. This inexpensive device can easily be built using local materials.
The water film type of a solar still is simple in construction, a cheap and easy method for providing fresh water. It consists of a basin, glass cover having thickness 5 mm and cooling film thickness 1.3 mm.

Al-Hinai et al. [1] studied the effect of design, climatic, and operational parameters on the productivity of a simple solar still. The results show that the daily productivity increased by 8.2% with a rise in ambient temperature from 23 to 33 °C. The water depth is batter in the range of 0.02–0.06 m. The effect of wind speed on the daily productivity of some designs of basin type, vertical, active and passive solar stills was investigated by El-Sebaii [2, 3]. The results showed the value of wind speed is independent of the still shape and heat capacity of the brine. The wind is more effective in summer and at higher water masses. Gude et al. [4] developed and evaluated the performance of the two-stage operation of the low temperature desalination process using a low-grade heat source. The results show that in a double stage configuration, the specific energy consumption of the process was less than 3.6 kJ/kg of mechanical energy and 1500 kJ/kg of thermal energy.

Xiong et al. [5] designed a new multi-effect solar still with enhanced condensation surface, which applied the corrugated shape, structure to decrease the condensation resistance and increase the freshwater yield. The results showed that, the seawater temperature change of the model reveals the existence of a reverse temperature difference in the second stacked tray, which can make the seawater temperature increase quickly and was advantageous for enhancing the freshwater yield in the subsequent process. Abdallah et al. [6] studied three design modifications to improve the performance of a traditional single slope solar still. First, addition of internal reflecting mirrors on all interior sides of still, secondly, using stepwise water basin instead of flat basin and thirdly coupling the solar still with a sun tracking system. The results showed that, coupling of the stepwise basin with sun tracking system gives the highest efficiency thermal performance with an average of its 38% efficiency. Khalifa et al. [7] studied some modifications of single and double slope stills on productivity and efficiency. The results showed improvements in the output and efficiency of the solar stills due to the employment of the above modifications. Velmurugan et al. [8] compared the performance of ordinary single basin solar still and wick type still. The enhance evaporation of the still basin water, fins and sponges were integrated at the basin of the still. It was found that productivity increased about 29.6%, when wick type solar still was used, productivity increased about 15.3%, when sponges were used and it increased about 45.5%, when fins were used.

Several improvements have been proposed such as the use of forced convection, a dye, and external condensers. The authors found drawbacks, i.e. the need for a controllable air supply, the effect of dye on distillate quality and the need for an electric power supply.

The efficiency is still further improved by utilizing a part of water used for cooling in the form of preheated makeup water to the still. The cooling film also performs the important function of continuous self-cleaning of the glass cover. The presence of dirt and other types of filth on the glass cover greatly reduces the still efficiency. Continuous cleaning of the glass cover maintains high levels of efficiency. Proper use of film cooling parameters may increase the still efficiency up to 20%. Mousa et al. [9] have focused in achieving high efficiency with respect to the temperature difference between the water in the basin and glass cover.

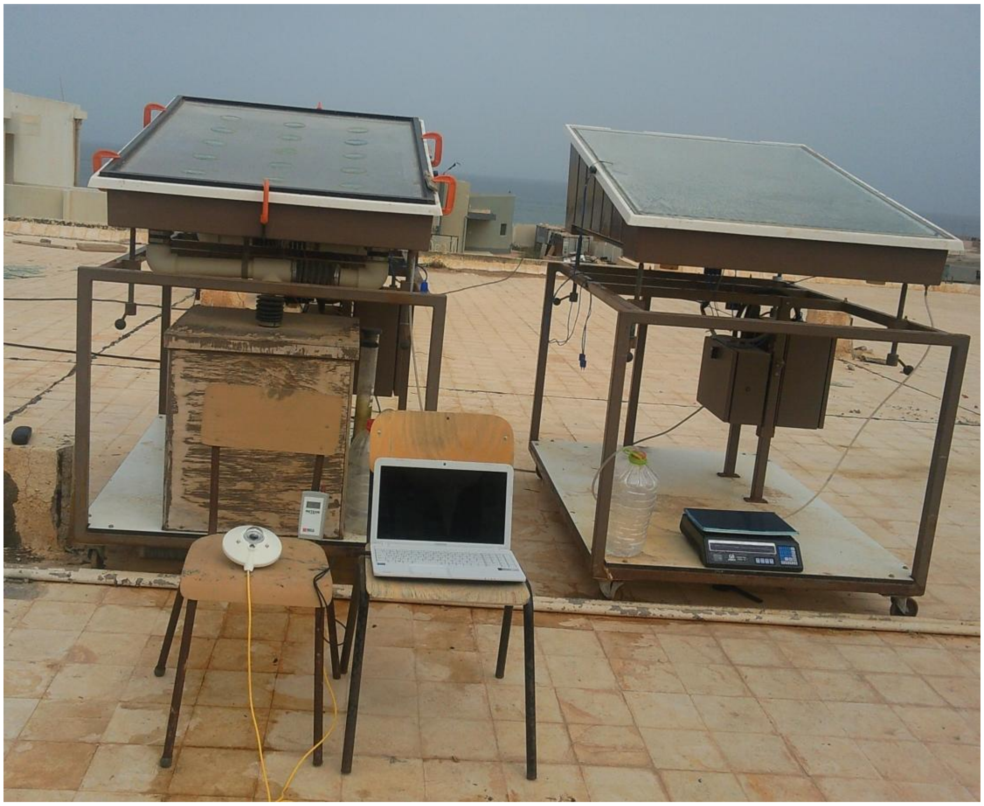
One of the solar devices which can be used for fresh water production is single slope solar stills. Due to the low amount of distilled water produced by the single basin still, it is not accepted in some instances. Consequently, the performance of single slope solar stills is a need to improve. Murugavel et al. [10] reviewed different passive methods to improve the effectiveness of the single basin solar still. They reported that, the direction and inclination of the transparent cover, cover material, thickness and temperature are responsible for the performance of the still. Water depth and materials used in the basin also affect the performance of the still. In order to minimize the convective and radiation losses, double-basin type still is fabricated. It possesses an additional transparent sheet of material fixed in between the basin liner and the glass cover [11]. Ghoneyem and Ileri [12] carried out experiments with different thickness glass covers and reported 16.5% more production in 3 mm thickness cover plate

Increasing the temperature difference between the water-glass cover is the main focus when trying to improve the rate of condensation, and consequently the productivity of the still is increased. This can be done by either decreasing the glass cover temperature or increasing the water temperature. Continuous supply of water film is fed over the glass cover in order to reduce the glass temperature. But this method requires raising the water container to the level of the highest part of the still or using pump water. Therefore, the using convex lens on glass cover does not need any modification of the still. The paper presents a modification of solar still using a convex lens on glass cover, to collect the solar radiation at the focus on surface water. The comparison between modified solar still with a convex lens and conventional solar still is carried out to evaluate the enhanced performance system under the same climate conditions. The effect of modified solar still using a convex lenses with and without black stone on the distillate productivity is investigated.

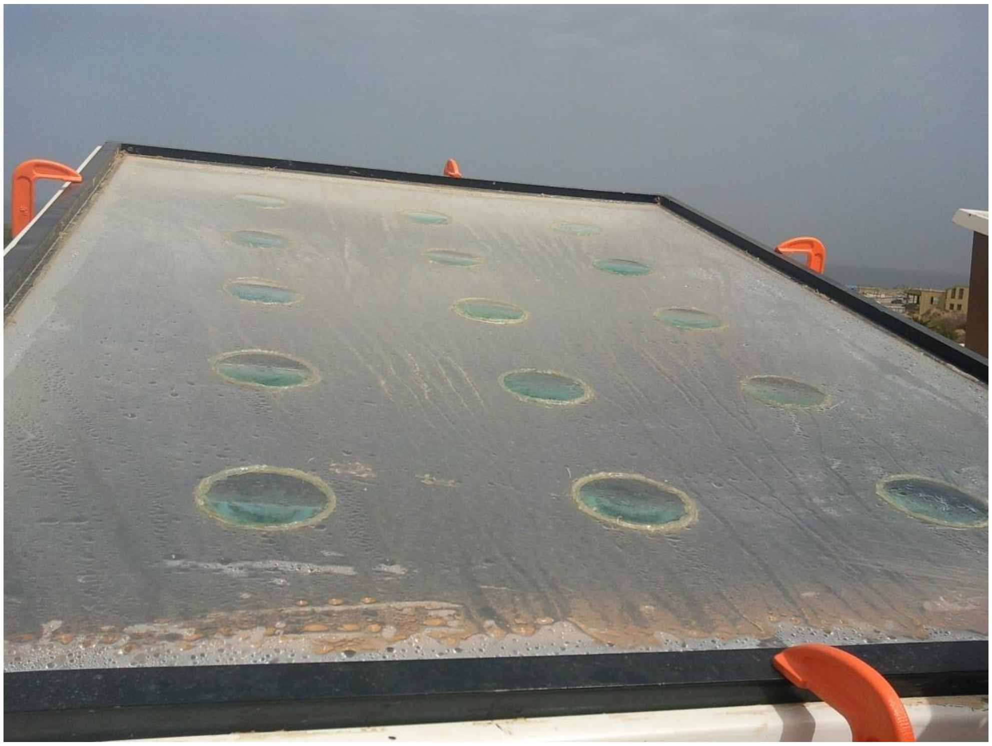
2. EXPERIMENTAL SETUP AND INSTRUMENTATION

The two solar stills have an effective horizontal surface area of 1 m^2. The basin liners are covered with black rubber in order to improve the solar energy absorption. The glass cover is mounted at an angle of 30°to the base of the shallow tray to ensure that condensate on its inner surface will drain down the glass into the condensate collecting channel and its thickness is 6 mm. Silicon rubber is used to prevent leakage from any gap between the glass cover and the still box. The still box is made from fiberglass in order to reduce heat losses from the walls and the bottom of the basin and prevented corrosion. A photograph of the experimental setup,cover with lenses and distribution lines are shown in Fig. 1. Three cases are studied: case 1 (Conv. still) conventional still, case 2 (Conv. still-lens) conventional still with lenses, and case 3 (Conv. Still-lens-BS) conventional steel with lenses and black stone.

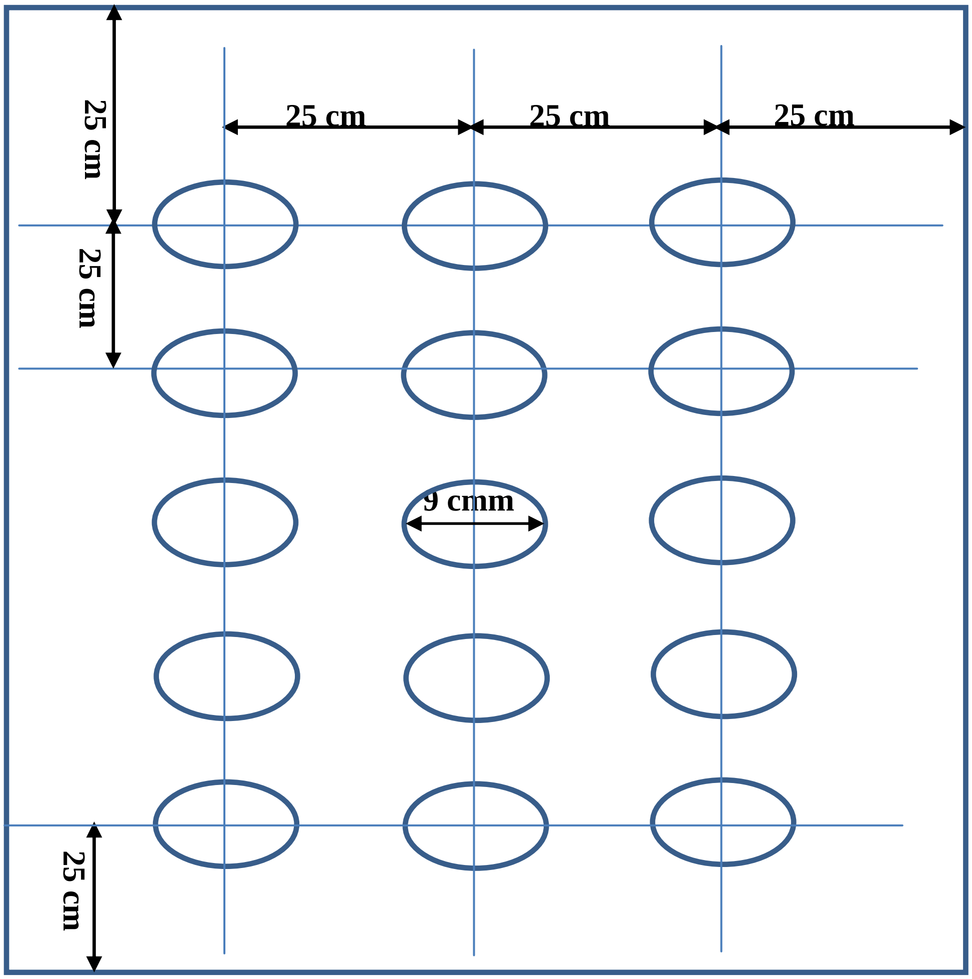
The temperatures of water, glass cover, and ambient temperature are measured continuously every 15 mins by copper–constantan thermocouples with the accuracy of 0.1 °C and saved on a computer using a data logger. A Kipp-Zonen pyranometer with an accuracy of 3% is used for measurement of solar irradiance every 15 mins and saved on a computer using a data logger. The produced distilled water is measured on an hourly basis using an electronic balance with the accuracy of 3 cm. TDS (Total dissolved solids) of salty and fresher water is measured by YSI model 556 MPS with a range (0–42000 mg/l) and accuracy of ± 1 mg/l. The wind velocity of the air is measured by using air velocity meter TM-401 with a range (0–15 m/s) and accuracy of ± 0.1 m/s.



(a) Experimental setup



(b) Cover with lenses



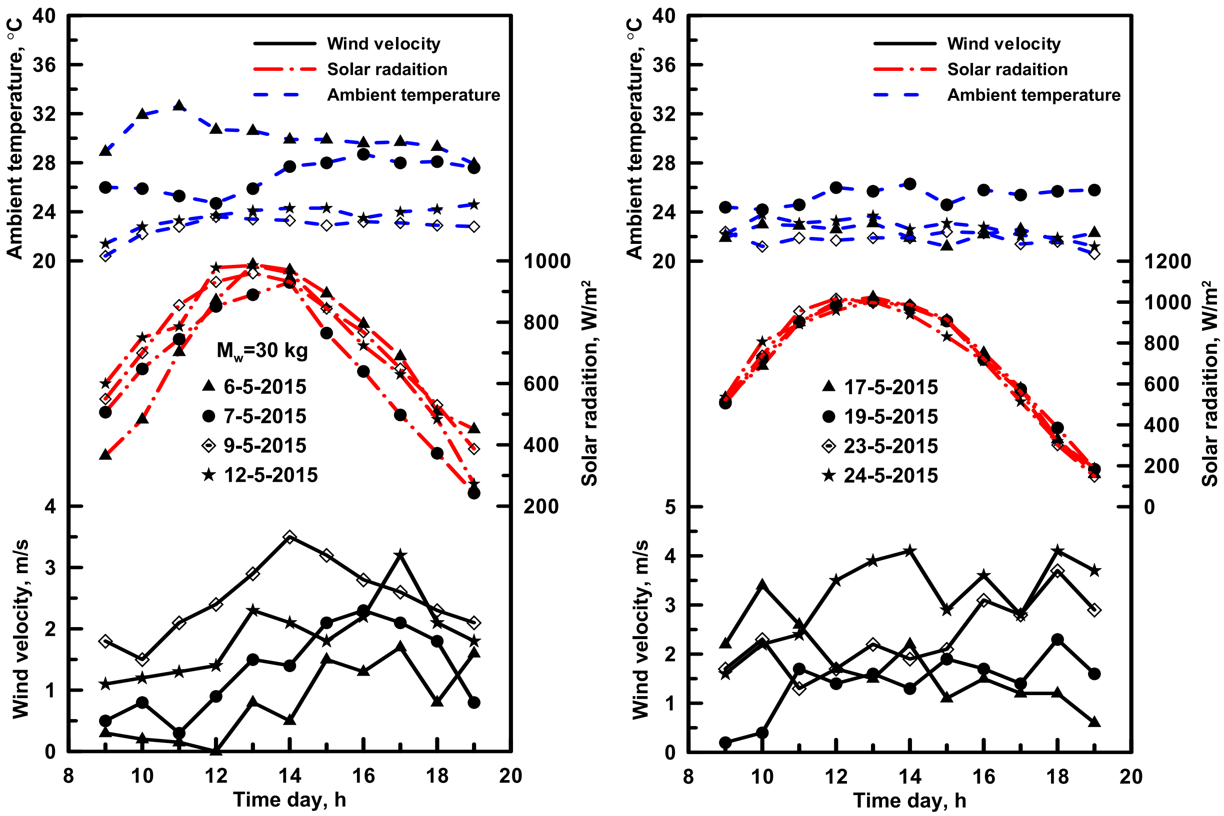
(c) Distribution lenses

Fig. (1). Experimental setup, cover with lenses and distribution lenses.

3. RESULTS AND DISCUSSION

The variation of wind velocity, solar radiation, and ambient temperature for different days is shown in Fig. 2. It is observed that the ambient temperatures at all points increase as the time increase till a maximum value at noon and start to decrease after that. This is due to the increase of solar radiation intensity in the morning and its decrease in the afternoon and it is dependent on the wind velocity. The variation of ambient temperature is between 20–32 °C, the wind velocity is between 0–4 m/s, and solar radiation received during the study is between 200–1000 W/m2.

Fig. 3 presents the water and glass cover temperatures for all studied models at different days. In all models, it can be seen that the temperature of water and glass cover increases in the morning hours, reaching its maximum values around midday, and then decreases in the afternoon. This is due to the effect of solar radiation intensity value during day time. The convex lenses collects the solar radiation at the focus on surface water, thus decreasing reflection from the basin, water, and glass cover therefore, the water temperature increasing and the glass cover temperature decreasing. Thus the temperature difference between the water and glass ($T_w - T_g$) increases. The results showed that the ($T_w - T_g$) of the modified still with lenses and black stone is higher than that of the conventional still.

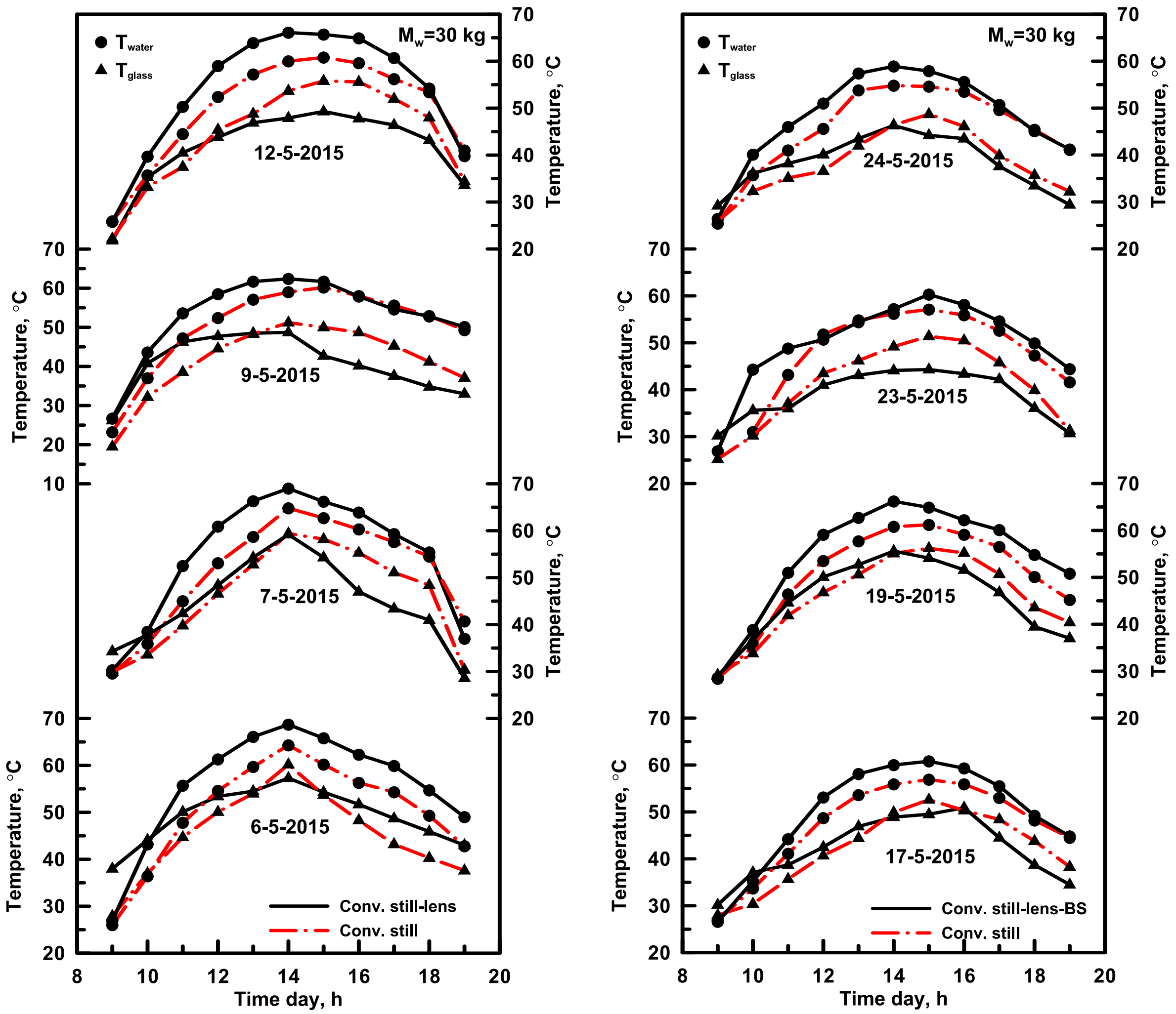


a) Conv. still-lens b) Conv. still-lens-BS

Fig. 2. The wind velocity, solar radiation, and ambient temperature for different days.

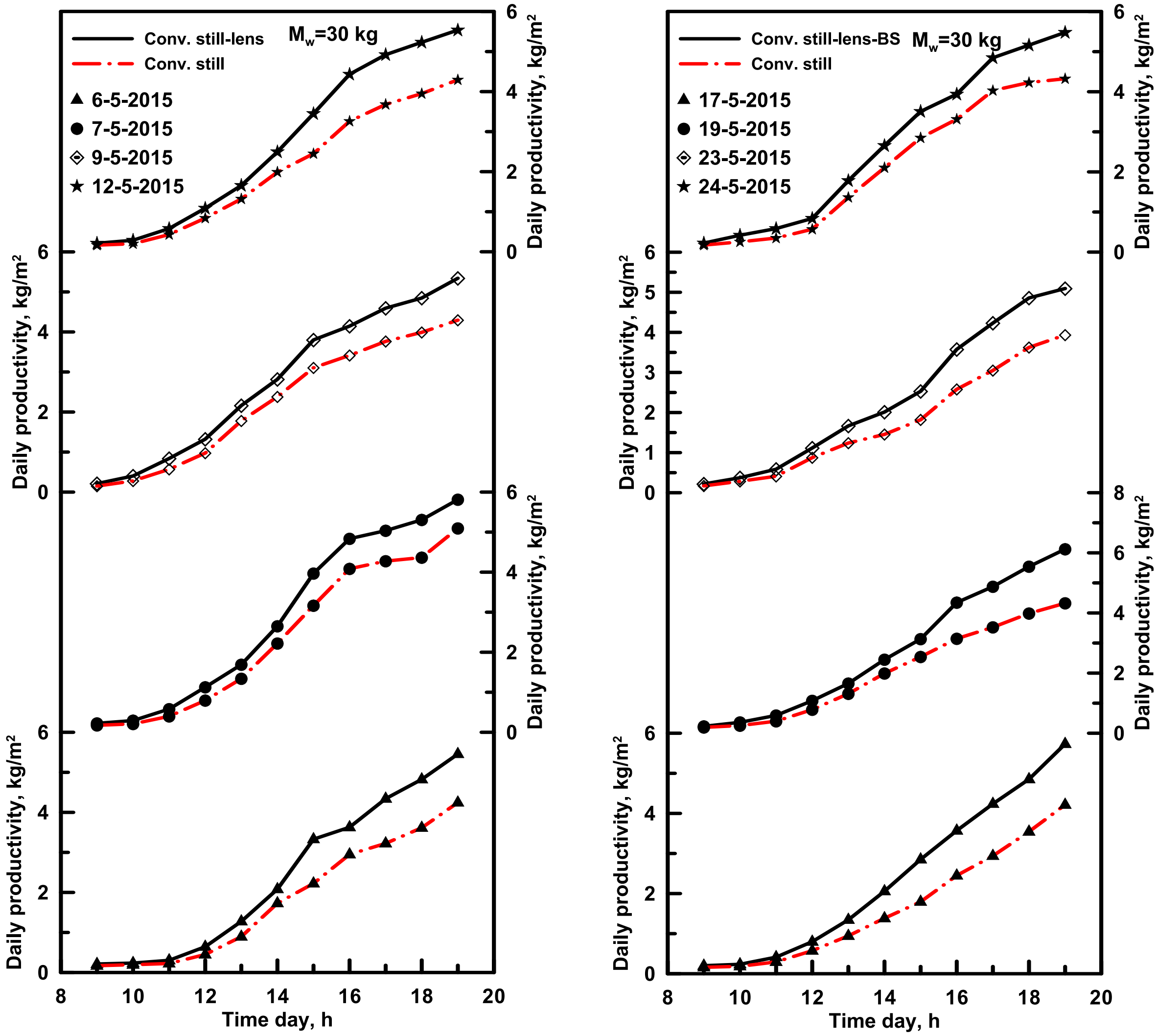
The variation of productivity for the modified and conventional solar stills is presented in Fig. 4. The results showed that the productivity of the modified still with lenses and black stone are higher than that of the conventional still due to high ($Tw - T_g$) as shown in Fig. 3.

Comparison of the average productivity for conventional still and conventional still with lensed is tabulated in Table 1. The results showed that the productivity of the modified still is higher than that for the conventional still, due to an increase in the water evaporation and condensation due to the water temperature increasing and the glass cover temperature decreasing as shown in Fig. 3a. The results indicated that the daily productivity for modified and conventional solar stills are approximately 5.97, 7.08 and 4.72, 5.54, respectively for day and day-night. The enhancement of productivity for modified solar stills are approximately 26.64 and 27.8%, respectively, for day and day-night.



a) Conv. still-lens **b) Conv. still-lens-BS**

Fig. 3. The water-glass temperatures for different days



a) Conv. still-lens **b) Conv. still-lens-BS**

Fig. 4. The daily productivity for different days

Comparison of the average productivity for conventional still and conventional still with lensed and black stone is tabulated in Table 2. The results showed that the productivity of the modified still is higher than that for the conventional still, due to an increase in the water evaporation and condensation due to the water temperature increasing and the glass cover temperature decreasing as shown in Fig. 3b.. The results indicated that the daily productivity for modified and conventional solar stills are approximately 5.857, 6.792 and 4.313, 5.058, respectively for day and day-night. The enhancement of productivity for modified solar stills is approximately 35.55% and 34.03%, respectively, for day and day-night.

Comparison of the average productivity of conventional still with lenses and conventional still with lensed and black stone is tabulated in Table 3. The results showed that the productivity of the modified still with lensed and black stone is higher than that for the modified still with lensed. The enhancement of productivity for modified still with lensed and black stone is approximately 51.85 at 20 kg of water in still.

Properties of salt water before desalination in experimental is 1505 mg/l for total dissolved solids (TDS). Total dissolved solids (TDS) of salt water after desalination is 22 mg/l and TDS of producing water is lower than that for the WHO guidelines. The Properties of salt water before and after desalination are presented in Table 4.

4. CONCLUSIONS

In the present study, the performance of the modified solar still using lenses and black stone has been experimentally investigated. The effects of mass water in a tank on the solar still performance have been considered. Based on the obtained results, the following conclusions can be drawn:

- The productivity of the modified still is higher than that for conventional still approximately by 27% and 35%, for still with lensed and still with lensed and black stone.
- The maximum productivity of the modified still with a convex lens and black stone is 51.85% at mass water 20 kg
- The productivity of the modified still with lensed and black stone is higher than that for the modified still with lensed.
- Total dissolved solids (TDS) of salt water after desalination is 22 mg/l.

Table 1 The comparison of conventional still and conventional still with lensed

Day	Conv. still-lens Productivity, kg/m^2		Conv. still Productivity, kg/m^2		Enhancement, %	
	Day	Day-night	Day	Day-night	Day	Day-night
6/5/2015	5.456	6.621	4.245	5.095	28.52	29.95
7/5/2015	6.181	7.351	5.095	5.865	21.31	25.34
8/5/2015	6.273	7.553	5.065	5.935	23.85	27.26
9/5/2015	5.342	6.352	4.295	5.065	24.38	25.41
12/5/2015	5.537	6.547	4.295	5.18	28.92	26.39
13/5/2015	5.951	7.026	4.575	5.435	30.08	29.27
14/5/2015	6.377	7.457	5.125	5.95	24.43	25.33
15/5/2015	6.63	7.72	5.035	5.785	31.68	33.45
Mean	5.97	7.08	4.72	5.54	26.64	27.8

Table 2 The comparison of conventional still and conventional still with lensed and black stone

Day	Conv. still-lens-BS Productivity, kg/m^2		Conv. still Productivity, kg/m^2		Enhancement, %	
	Day	Day-night	Day	Day-night	Day	Day-night
17/5/2015	5.733	6.783	4.215	5.205	36.01	30.31
19/5/2015	6.123	7.248	4.325	5.225	41.56	38.73
20/5/2015	6.854	7.739	4.760	5.475	43.99	41.35
23/5/2015	5.095	6.100	3.935	4.675	29.47	30.47
24/5/2015	5.480	6.090	4.325	4.710	26.70	29.29
Mean	5.857	6.792	4.312	5.058	35.55	34.03

Table 3 The comparison of conventional still with lenses and conventional still with lensed and black stone

Type	Conv. still-lens	Conv. still-lens-BS			
Mass water	30 kg	30 kg	25 kg	20 kg	15 kg
Enhancement, %	26.64	35.55	39.48	51.85	32.35

Table 4 Properties of salt water before and after desalination

Parameter	Before desalination	After desalination
TDS (mg/l)	1505	22
PH	6.95	8.08
Conductivity (dSm^{-1})	2070	32

REFERENCES

Al-Hinai H, Al-Nassari MS, Jubran BA. Effect of climatic, design and operational parameters on the yield of a simple solar still. Energy Convers Manage 2002;43:1639–50.

Abdallah S, Badran O, Abu-Khader MM. Performance evaluation of a modified design of a single slope solar still. Desalination 2008; 219: 222-230.

Abdallah S, Abu-Khader M M, Badran O, Effect of various absorbing materials on the thermal performance of solar stills, Desalination 242 (2009) 128–137.

El-Sebaii AA. Effect of wind speed on some designs of solar stills. Energy Conversion & Management 2000; 41: 523-538.

El-Sebaii AA. Effect of wind speed on active and passive solar stills. Energy Conversion and Management 2004; 45: 1187–1204.

Gude VG, Nirmalakhandan N, Deng S, Maganti A. Feasibility study of a new two-stage low temperature desalination process. Energy Conversion and Management 2012; 56: 192–198.

Ghoneyem A, Ileri A, Software to analyze solar stills and an experimental study on the effects of the cover, Desalination 114 (1997) 37–44.

Khalifa AJN, Al-Jubouri AS, Abed MK. An experimental study on modified simple solar stills. Energy Conversion & Management 1999; 40: 1835-1847.

Mousa A, Bassam A/K. Water film cooling over the glass cover of a solar still including evaporation effects. Energy 1997; 22: 43–48.

Murugavel K K,. Chockalingam Kn.K.S.K, Srithar , Progresses in improving the effectiveness of the single basin passive solar still, Desalination 220 (2008) 677–686.

Velmurugan V, Gopalakrishnan M, Raghu R, Srithar K. Single basin solar still with fin for enhancing productivity. Energy Conversion and Management 2008; 49: 2602–2608.

Xiong J, Xie G, Zheng H. Experimental and numerical study on a new multi-effect solar still with enhanced condensation surface. Energy Conversion and Management 2013; 73: 176–185.