4ème Conférence Internationale des Energies Renouvelables (CIER-2016)
Proceedings of Engineering and Technology – PET
Vol.17 , pp. 117 - 123

Experimental study of New Design of Solar Still with an internal condenser and Coupled with Solar Water and Air Heater and humidifier

K. Zarzoum[1], H. Ben Bacha[2] and K. Zhani[1]

[1]*LASEM (Electromechanical Systems Laboratory), National Engineering School of Sfax, B.P. 3038, Sfax University, Tunisia*
kamelissat@hotmail.com

[2]*College of Engineering at Alkharj, Mechanical Engineering Department – Prince Sattam Bin Abdulaziz University P.O.Box 655, Alkharj 11942 – Kingdom of Saudi Arabia*

***Abstract*—This paper tackles an optimization of a new design of a solar still which is located at Sfax engineering national school in Tunisia. This optimization approach is based upon the above mentioned design's improvement by coupling the conventional solar still into at a condenser, solar air and water collector and humidifier. The productivity in a solar still mainly depends on the temperature difference between the evaporation tower water of the modified solar still and the condenser for a given surface area. The results clearly show that the performance of the new disgn of solar still increases with the increase of solar radiation and with the increase of feed water temperature of solar water collector. The performance of the modified solar distiller using different operational parameters is studied experimentally, to find out best factors enhancing still productivity. The variation of different parameters of the new design of the solar still has been studied.**

***Keywords*— Solar still; desalination; air and water solar heater; condenser; humidifier.**

I. Introduction

Today, fresh water demand is increasing continuously because of the industrial development, intensified agriculture, improvement of standard of life and increase of the world population. At depletion of non-renewable energy resource namely, fossil fuels, renewable sources of energy such as tidal, geothermal, solar, wind etc. are going to play an important role for our energy requirement. To solve these problems, new drinking water sources should be discovered. Solar distillation process is the use of solar energy resource to evaporate sea and/or brackish and collect its condensate in the same closed system like conventional solar still. They are classified as passive and active solar stills and various scientists throughout the world have carried out research works on design of solar still, fabrication methods and performance study, etc. Desalination of sea and/or brackish water is an important alternative, since the only inexhaustible source of water is the ocean. A lot of research work is undertaken to improve the performance of solar desalination systems, particularly solar stills. Omar Ansari (2013) [1] has described that the solar desalination system used brackish water in passive solar still with a heat energy system put under the basin liner of the desalination device. It shows the whole excess energy generated during sunshine time and stored in PCM for later use during night time and rainy day. Sampathkumar et.al., (2012) [2] have studied the performance of the single basin solar still augmented with evacuated tubes and inferred that the daily production rate of the solar still is increased by 49.7% and increased by 59.48% by using black stones incorporated with evacuated tubes. R. Kannan a, et al. (2014) [3] designed and tested a vapor adsorption type solar still and the experimental and analytical results were compared to the energy equation for both conventional and vapor adsorption type solar still, hence found that theoretical results performed well with experimental results (R. Kannan et al. 2014) [3] . Omar et al. (2014) [4] had taken various parameters like storage bed and water depth with different sand materials (yellow and black) used experimentally. It indicated that the heat storage sends enhanced productivity. Maximum productivity was achieved at sand bed heights of 0.01m and above the sand bed layers to zero height of saline water compared to conventional style. The condensing cover made-up of glass cover is replaced with a PVC material. Sampathkumar et al. (2013) [5] have made an attempt to investigate a newly deign solar still coupled with an evacuated tube collector experimentally. It was found that the maximum productivity of the still is increased when coupled with evacuated tube collector. H.N.Panchal et al. (2013) [6] performed a single slope, solar still 2- phase, 3D model made for evaporation conduct a condensation process in still by using ANSYS CFX method. Proved that ANSYS CFX method is a powerful instrument to diagnose solar still. A. E. Kabeel performed an experiment about solar still with various parameters of glass cover and evaporative surface area. Average distillate productivity during the day time is approximately 4 L/m² with a system efficiency of 0.38 at solar noon. It is more eminent than the conventional type solar still (A. E. Kabeel, 2008). Juan et al. (2008) [7] developed a new humidification and dehumidification system. In this system, the air worked in a closed loop and the evaporator prepared of treated cellulose paper substratum. This system is designed to improve the heat recovery at the condenser. Prof.Nilamkumar S Patel et al. (2003) [8] compared different solar stills which are stepwise basin solar still, pyramid solar still and concave/convex basin solar still ,due to different designs of solar still, its parameter changes and to find out that which one is the bestest designs compare to others Prof. (Nilam kuma r S Patel 2013). Ben Bacha and Zhani (2013) [9] designed a new solar still with an energy storing material, where in the basin, a flat plate solar collector and a separate condenser that

ISSN 2356-5608

4ème Conférence Internationale des Energies Renouvelables (CIER-2016)
Proceedings of Engineering and Technology – PET
Vol.17 , pp. 117 - 123

coupled with the solar still to increase the daily productivity by increasing the temperature of the water during the day and to store the excess hot water that would extend water desalination beyond sunset. This paper is therefore an attempt to experimentally investigate the performance of a solar still at different water depths in the basin under the prevailing weather condition in Tunisia. The distilled water productivity, the water basin temperature, vapor temperature air temperature and ambient temperature were measured. In our parts, to ameliorate the production of the solar still, we have added to this latter:

•A flat plate solar collector to increase the temperature gradient between the water and the glass cover.

• A humidifier to increase the exchange surface and the residence time of air and water inside the solar still to increase the heat and mass transfer, and thereafter improve the production of freshwater system.

• A plane air solar collector.

• A separate condenser for the solar distiller where condensation is produced at a temperature below that of the glass cover.

II. THE EXPERIMENTAL SETUP

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

A. Design of the system:

Figs. 1 and 2 illustrate respECTIVELY A SIDE AND FRONT VIEWS photograph of the experimental setup .Solar distillation system is useful especially in summer season when the solar radiation attends its high values. So, it is of interest to investigate the experimental behaviour of the modified solar still during summer season. Experimental measurements were carried out using the solar distillation prototype located at the National Engineering School of Sfax, Tunisia (34 N, 10 E) and tested on several sunny days. This system was built in the climatic conditions of city in Tunisia. Data obtained included environmental condition (solar intensity radiation, ambient temperature and humidity), design parameters (basin absorptivity), and operational procedure (initial saline water temperature, air temperature, glass cover temperature) indicated that these decisively influence the still performance. Energy collection is performed by means of the solar collector and of the solar distiller. A black rubber mat, placed at the bottom of the still was used to enhance the amount of solar energy absorbed within the system and, thus, increase the amount of distilled water produced. The glass cover of thickness 4 mm is used as the condensing surface. The solar desalination system under study differs from the previously explored published works by using a humidifier, on the one hand, and a field of flat-plate air solar collector and a field of flat-plate water solar collector on the other, which makes the system more flexible and increases the fresh water production. Sea or brackish water which is preheated in the condensation tower of the solar still , by the latent heat of condensation, and heated in the water solar collector is pulverized into the humidifier . Due to heat and mass transfers between the hot water and the heated air stream in the humidifier in case of working in open air loop and between the hot water and the dehumidified air stream, coming from the condensation tower in case of working in closed air loop, the latter is loaded by moisture. To increase the exchange surface and the residence time of air and water inside the solar still to increase the heat and mass transfer, and thereafter improve the production of freshwater system ,and therefore to raise the rate of air humidification, packed bed is implanted in the tower of the humidifier. The saturated moist air is then transported toward the tower of condensation where it comes in contact with a surface the temperature of which is lower than the dew point of the moist air. The condensed water was collected from the bottom of the condensation tower of the solar still , while the brine (the salty water exiting the humidifier) at the bottom of the humidifier will be either recycled and combined with the feed solution at the entry point or rejected in case of increase of saltiness rates. The detailed descriptions of the solar still main components are as follows: Most liquid collectors use a sheet-and-tube absorber with the tubes in front of, behind, or as an integral part of the sheet. The water solar collector device used by the present distillation prototype is composed of 2 collectors 2 m in length and 1 m in width. The water solar collector use a sheet and tube, in copper material, absorber with the tubes as an integral part of the sheet, the inner diameter of the tubes is 10 mm and the outer one is 12 mm. The air gap between the absorber and the glass cover is 0.1 m. The rear and sides insulations were provided by polyurethane to reduce heat loss. A silicon sealant was used between the different components of the water solar collector to ensure insulation from the environment. The current solar distillation prototype employs 8 m to reduce heat loss. A silicon sealant was used between the different components of the air solar collector to ensure insulation from the environment. In order to achieve the maximum yield from the system, the still orientation should be the direction at which the highest average incident solar radiation is obtained. The operating principle of this system is as follows: the brackish water or the cold sea water returning in the condensation stage undergoes preheating by the latent heat of condensation. Then, water will be heated in a solar water plan. Water will be sprayed in the form of small particles by means of atomizing nozzles with high pressure or a compressed air nozzle or a piezoelectric transducer generating ultrasound. The water vaporizes in the distiller and is injected into the condensation stage to ensure the dehumidification of the vapor obtained. By cons, in packed columns, the liquid is sprayed on the packed bed between grids. The liquid phase, which contains the absorbent, forms a film on the packing elements (wetting zone). The humidified air exiting the distiller will be conveyed to the condensation stage, where it condenses when it comes in contact with the outer walls of the tubes that circulate cold water. The amount of the condensed air (The distilled water) produced will be collected in a tray placed below the condensation chamber and on the inner surfaces of the glass cover. The condensation chamber was equipped with a ferry of a size 0.5 x 0.7 x 0.4 m to collect the produced fresh water. The latter was evacuated outside the solar still by an immersed water pump. It runs along the lower edge of the glass cover. The amount of evaporated water that condenses will not be injected back to the solar distiller. The amount of evaporated water which is not condensed will be injected again to the solar still. The solar desalination system under study differs from the previously explored published works by using a humidifier, on the one hand, and a field of

ISSN 2356-5608

flat plate air solar collectors and a field of flat-plate water solar collectors on the other, which makes the system more flexible and increases the fresh water production. The humidifier used in the distillation prototype is a pad one is presented in Fig 3. The cross sectional area of the pad is 0.6 m x 0.8 m, while its height is 0.56 m. at the top, there is a liquid distributor, which can feed the pad with hot brackish water coming from water solar collectors, while at the bottom there is a liquid collector, where brine is collected as it drains down the pad. Thus, the hot brackish water flows downward, while the air passes in a cross-flow direction. Textile (Viscose) of a $14\ m^2$ ($52\ m^2/m^3$) surface is used as packing to increase the interface area between the air and water, which form the wetted surface. On the outside, the humidifier is covered with a polyethylene sheet of thickness 15 mm and insulated with a layer of armaflex. The pyranometer is used to measure solar Insolation with 1% accuracy and 12.29 µV/Wm sensibility placed in a horizontal plane adjacent to the collector. Thermocouples were located in different places of the solar still and the water and air solar collectors. They record the different temperatures, such as outside glass cover, solar basin water, water and air temperature and ambient temperature. Temperature sensors (Thermocouples) measures temperatures and store the values in data logger. The data logger is connected with laptop hence readings were recorded in a Laptop. Temperature sensors having a least count of 0.1°C. Various thermocouples are attached to measure the temperature of particular place and connected with the overtime data recorder (Data Logger) that is simply fixed with some program software and plug in with computer. Computer records data with it and works during a sunny day. These thermocouples are mounted with logger and fixed with different channels, and indicates the channel wise simulation of temperature. Those channels are measured different input and output parameters. The view of channel and program run on computer are show in Figs. 1 and 2. A view of the condensing chamber and photograph of the experimental setup are shown in figure 4.

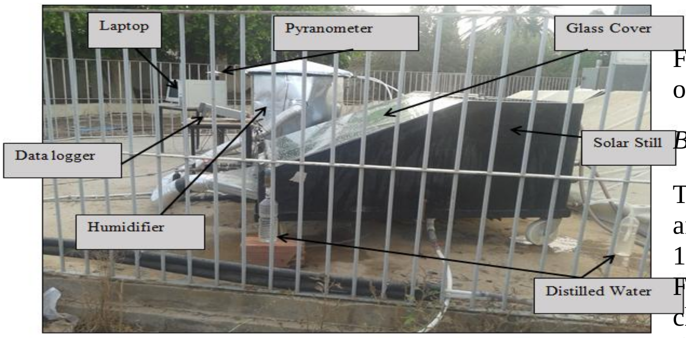

Figure.1. Photograph of the experimental still (side view).

Figure.2. Photograph of the experimental still (front view).

Figure.3. Humidifier used in the solar desalination system.

Figure.4. Photograph the condensing chamber and photograph of the experimental setup.

B. Experimental results of the solar distillation system

The weather conditions (respectively solar radiation and air ambient temperature) for various days (01/09/ 2014, 17/08/2014 and 19/08/2014) of July and August is shown in Fig 5 and Fig 6 at the city of Sfax, Tunisia. These days are characterized by clear sky conditions. It is made clear from these figures that the highest value of solar radiation thereabouts $1050\ W/m^2$ occurred at noon in August (19/08/2014) and the highest air ambient temperature was obtained in the same day of August (19/08/2014). It is seen that during these days from sunrise to sunset, the solar radiation and ambient temperature increases gradually and reaches a maximum value at around noon period and then it decreases. Variations of the accumulated distillate during the day for different days are shown in Fig. 7. It is clear therefore that the use of the preheater (water solar collector) and black absorber combined with a solar distiller is very beneficial for production of distillate, because the water temperature in the

ISSN 2356-5608

4ème Conférence Internationale des Energies Renouvelables (CIER-2016)
Proceedings of Engineering and Technology – PET
Vol.17 , pp. 117 - 123

modified solar still is mainly due to the effect of this preheater system with the aim of increasing the heat exchange surface and absorption of the radiation. It can be seen that the highest productivity thereabouts 9, 8 L/day occurred in August (19/08/2014). We note that the curve of the total production is almost zero at the beginning of the days. The productions of solar distiller freshwater increases when the brine temperature rises. This is because of the minimum convective and radiation heat losses dealing with the mass flow rate of circulating brackish water. Also, the lowest feed water flow rate gives minimum thickness of water film moving over the stepped surface of the solar still (basin of the modified solar still) and hence gives maximum surface water temperature and subsequently improves the evaporation process. The effect of water depth on the condensate produced is shown in Fig. 8 for a solar flux can reach almost 1050 W/m2 occurred in August (19/08/2014). From the graphs, it is clear that the distillate output decreases with increase in the depths of water. So, the objective of the present work have successfully achieved as shown on the performance of the modified solar system. The maximum distillate collected were 8, 9 L/day for the water depths of 0.01 m. We note that the distillate flow increases with decrease in water depth of the solar still. We can conclude that it is interesting to work with low water depths in the solar distiller to increase the production of distilled water. Also, the lowest feed water flow rate gives minimum depth of water film moving over the stepped surface of the modified solar still and hence gives maximum surface water temperature and subsequently improves the evaporation process. Similarly, Fig. 9 shows the changes in temperature profiles for the basin, water, ambient and the glass cover for the modified solar distillation system in the function of time throughout for the days August 17, August 19 and 01 September except in the evening, which is also due to the higher thermal capacity of the basin water mass. During these days, the first thing that can be drawn from the figure that follows is that all the temperatures showed similar trends of increasing with the respective increasing of solar radiation of respective during the day. These results indicate that solar radiation has a greater influence on the thermal performance of the solar still. The curves increase gradually at the beginning of the day, reaching a maximum between 12h and 14h, then decrease gradually. It is also observed that the water temperature and the absorber (pelvis) are almost the same because of the contact with the last two heat transfer by convection directly. The temperature of the absorber reaches a maximum value of 67 ° C.The temperature in the modified solar still has reached a temperature of 66˚C; the temperature is mainly due to the effect of the preheater (water solar collector) and black absorber with the aim of increasing the heat exchange surface and absorption of the radiation. The maximum solar radiation value witch shown in this figure is recorded between (12-13) hour, while the glass cover temperature (25°C-45°C) and the basin water temperature 67 °C reach their maximum values and after 14 hour the temperature of the glass cover begin decrease as a result of decreasing the amount of solar radiation falling on the solar still a shadow effect due to a decrease of energy.

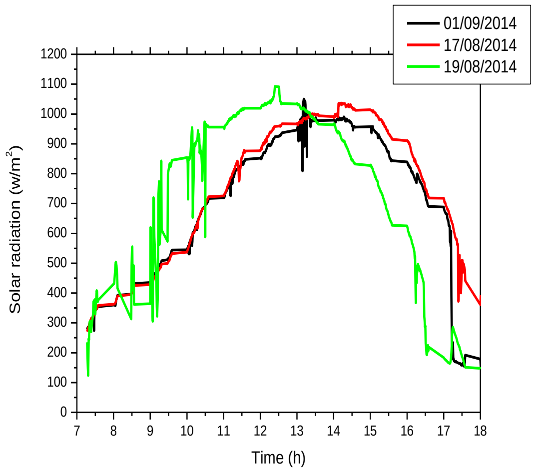

Figure.5. Solar radiations measured during various days.

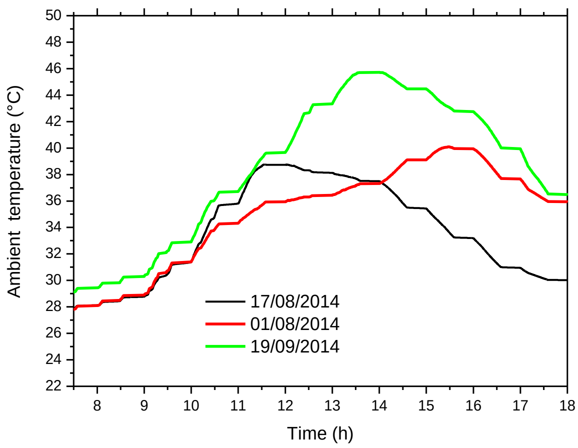

Figure .6. Ambient temperature measured during various days.

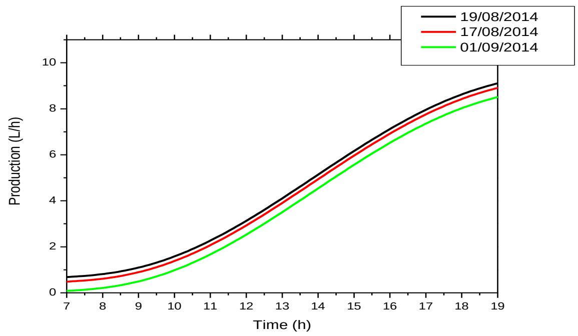

Figure.7. Daily production of Solar Still vs Time for different days.

ISSN 2356-5608

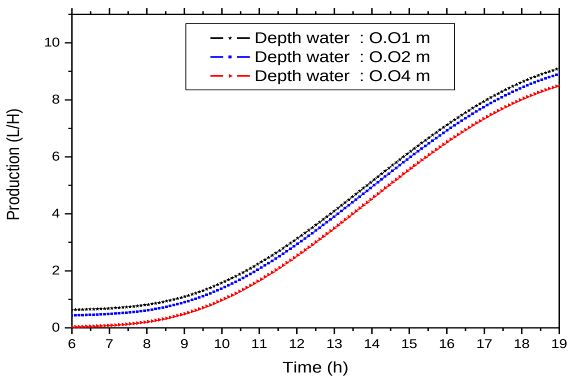

Figure .8. Daily production of Solar Still vs Time for different depths of water.

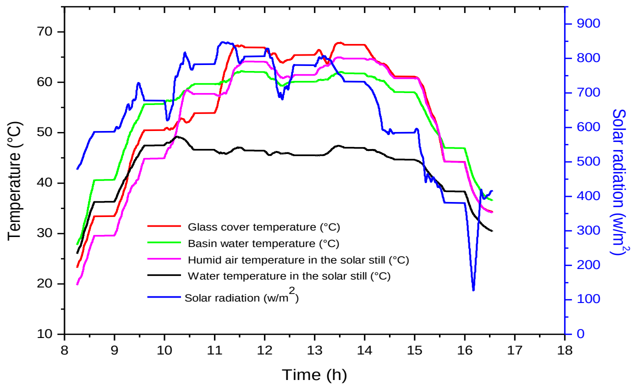

Figure .9. Hourly variation of various temperatures of the solar still with local time (19.08.2014).

III. CONCLUSIONS :

In the present study, the performance of the modified solar still coupled to a condenser, solar air and water heater and humidifier was designed, fabricated and experimentally tested during daytime for topical day at the city of Sfax, Tunisia climatic conditions. The newly designed system presented in the current work exhibited a number of attractive attributes that might open new promising opportunities for the advent of freshwater to environments with limited water resources and high solar radiation rates. Based on the obtained results, the following conclusions can be drawn:

- The various temperatures like outside glass cover, solar basin water, water and air temperature initial saline water temperature, air temperature, and ambient temperature of the stills are recorded by using thermocouples and the data is plotted. Thermocouples were located in different places of the solar still and the water and air solar collectors.
- The Indeed, the productivity of our distiller increases with decrease in water depth of the solar still. The possibility of increasing the water productivity could be reached by lowering the water depths on the basin- absorbing plate.
- Decreasing the inlet water temperature to the condenser of solar still leads to increasing the still productivity.
- The solar intensity shows similar variation during the days of the analysis.
- The lowest feed water flow rate gives minimum depth of water film moving over the stepped surface of the modified solar still and hence gives maximum surface water temperature and subsequently improves the evaporation process.
- It was found that the geographical location may having a significant positive effect on the increased water productivity of the modified solar still, especially for those locations with an abundant weather conditions (solar radiation and air ambient temperature), which the reduced boiling point of water and the corresponded saturation pressure are below the standard atmosphere.
- The concept of using the preheater (water solar collector) was found to be very attractive method for obtaining the fresh water, because of improving the evaporation process.
- The periodic variation of the solar intensity for the days of analysis is also plotted. Their average value shows a similar variation in these days.

ACKNOWLEDGMENT

The authors wish to thank the Ministry of Higher Education, Scientific Research and Information and Communication Technologies MESRS-TIC for its financial support to the R&D project entitled “Solar Driven membrane distillation for resource efficient desalination in remote areas”, and the Fraunhofer Institute for Solar Energy Systems ISE for its collaboration

REFERENCES

[1] O. Ansari et al, 2013. “Desalination of the brackish water using a passive solar still with a heat energy storage system” Des alination 324 - 10–20.

[2] Sampathkumar, P., Mayilsamy, K., Shanmugam, K. and Senthilkumar, P, 2012. “An experimental study on single basin solar still augmented with evacuated tubes”, Thermal science, Vol. 16, pp. 573 – 587.

[3] R. Kannan et al, 2014. “Solar still with vapor adsorption bas in: Perfor mance analysis” Renewable Energy 62 - 258-264.

[4] Omar and Kabeel, 2014. “The Performance of different sand beds solar stills” International Journal of Green Energy,” 11: 240–254.

[5] Sampathkumar, P., Arjunan, V. and Senthilkumar, P., 2013. “The experimental investigation of a solar still coupled with an evacuated tube collector”, Energy Source, Part A: Recovery, Utilization and Environmental effects, Vol. 35, pp. 261 – 270.

[6] Panchal HN, Shah PK , 2013. “Modeling and verification of s olar s till us ing ANSYS CFX” International journal of Energy and Environment 4 -13-28.

[7] A. E. Kabeel, 2008. “Performance of a solar still with a wick concave evaporation surface” Twelfth International Water Technology Conference, IWTC12 Alexandria, Egypt.

[8] Prof. Nilam kumar S Patel, 2013. “Effect of various parameters on different types of solar still: Case Study” International Journal of Innovative Research in Science, Engineering and Technology, ISSN: 2319-8753 MAY , VOL. 2, ISSUE 5.

[9] H. Ben Bacha, K. Zhani, 2013. Contributing to the improvement of the production of solar still, Desalin. Water Treat. 51(4–6) 1310–1318.

4ème Conférence Internationale des Energies Renouvelables (CIER-2016)
Proceedings of Engineering and Technology – PET
Vol.17 , pp. 117 - 123

ISSN 2356-5608