EXPERIMENTAL STUDY FOR ENHANCING THE PERFORMANCE OF AN EVACUATED TUBE SOLAR COLLECTOR WITH METALLIC CONDENSER DESALINATION UNIT

Nabil H. Mostafa, Mohamed H. Gobran, Mohamed A. Essa, Estabrak N. Eewayed

Department of Mechanical Power Engineering, Faculty of Engineering, Zagazig University, 44519 Zagazig, Egypt: email: nabil@eng.zu.edu.eg , mhgobran@yahoo.com , eng1182@gmail.com , geuk270@gmail.com

ABSTRACT

Solar desalination is needed for the scarcity of fresh water in the world. An experimental investigation was performed on a desalination unit of evacuated tube collector and a steel condenser. Three modifications for the enhancement of this unit were studied. The first parameter is the water film thickness beside the absorber tube. This water film thickness was applied using a core insertion tube with different diameters to apply three values of the water film thickness of 2, 4 and 6 mm. The smallest water film thickness found to give the best performance of the system over the day reaching an efficiency of 23.2%. The second considered modification is the diameter of the condenser steel tube of values 80, 120 and 160 mm. It was found that the performance of the largest diameter is the highest achieving an overall efficiency of 51%. However, the smallest diameter found to give fast condensation. The third modification considers the inclination angle of the condenser with the horizontal with values of 80°, 62° and 45°. It was found that the 45inclination achieves the best performance with overall efficiency of 37.6%.

Keywords: Evacuated tube solar collector, passive desalination, metallic condenser.

1 INTRODUCTION

Water in oceans, polar region and in rivers are the three-water source available around the world. The need for efficient water desalination becomes very important due to the leakage of fresh water supply. The fresh water that can be used by humans represents about 0.36% of available water on the earth (Xiao et al. 2013). Solar desalination system become more efficient due to the availability of the main power source. Sun is the main power source that used to operate the solar desalination system (El-Sebaii and El-Bialy 2015). Solar desalination system can be divided in two main categories which are direct and indirect. The direct system also can be divided to different categories, active and passive (M and Yadav 2017). The passive one can be defined as the system that depends on the sun as the only source of energy. However, the active one uses an auxiliary source of thermal energy as mentioned by (Manokar, Murugavel, and Esakkimuthu 2014). The traditional passive solar desalination system is composed of two main part, basin and cover. The Basin contains the water to be desalinated while the cover is usually made from glass. This cover allows the sun rays to pass through it and evaporates water inside the basin. then the water vapor condenses on the cover's inner surface (El-Sebaii 2004). The effect of various type of solar desalination system on the fresh water productivity can be found in (Durkaieswaran and Murugavel 2015). Evacuated tube collector (ETC) is one of the promising techniques that used in solar still as a collector. ETC consist of two glass tubes are placed concentric and having one open end. There is a vacuum zone between the two-glass tube in which this zone used to reduce heat losses by conduction and convection dramatically. The inner glass tube is painted by a special absorber material to increase its absorption to solar radiation (M.A. Essa and Mostafa 2017) and (Mohamed A Essa, Mostafa, and Ibrahim 2018). The effect of ETC on the production of solar sill was experimentally studied by (K. Sampathkumar, T.V. Arjunan 2011). Results showed that the yield increased from 2.7 L/m^2 in convectional one to 5.1 L/m^2 in ETC solar still with average increase up to 72%. The cost of fresh water production was decreased by using ETC with solar still (Omara, Eltawil, and ElNashar 2013). The productivity of solar still coupled with ETC when the inclination angle of ETC and glass cover is 15º is increased up to 70% (Praveen T Hunashikatti, KR Suresh, B Prathima 2014). The Production rate of solar still with and without ETC at different water depths was studied by (Agrawal and Nema 2016). Results showed that the average thermal efficiencies of active solar still without ETC considering water depth as 1, 2, 3, and with EGT water depth 1, 2, 3 cm were, 15, 41, 45 and 35% respectively. Double basin solar still with and without ETC was studied by (Panchal 2015). Result showed that distillate output increased to 56% with adding ETC. The production efficiency of different configuration of ETC integrated with solar still was introduced in (Yadav et al. 2017). A comparison between simple solar still and solar still equipped with ETC was performed by (Sampathkumar, et al 2013). Result showed that the maximum daily production of 3.225 kg is obtained from passive solar stills at a water depth of 0.04 m. A pyramid solar still integrated with ETC was studied by (Sharshir et al. 2019). An experiment was performed with and without ETC and results showed that the thermal efficiency increased up to 50% by using ETC with solar still. The performance of a solar still equipped with thermoelectric modules and ETC was experimentally studied by (Mohammad Behshad Shafii et al. 2016). Results showed that the thermal efficiency increased up to 60% due to using ETC. Solar ETCs were used to heat the saline water and vacuum pump created vacuum conditions at system startup only (Abbaspour, Faegh, and Shafii 2019). The thermal efficiency increased up to 47.6%. A system consist of basin, 5 ETC thermosyphon heat pipe was studied by (Mamouri et al. 2014) to investigate it productivity. Results showed that a huge amount of heat was transferred from ETCs and het pipe to the solar still basin. The cost of fresh water production was lowered to 0.0092 $/l by using ETC and thermosyphon. The performance of ETC was decreased by 60% when the glass tube transmission reduced from 0.98 (clean glass) to 0.6 (very dusty glass) (El-Nashar 2009). A performance of a solar still integrated with ETC in natural mode was investigated by (Singh et al. 2013). They claimed that the use of ETC increases the temperature of water as well as yield. Also, they mentioned that the use of ETC with 10 tubes is preferable than a single larger size ETC. A solar still integrated with ETC and heat pipe was experimentally studied by (Elsheniti, Kotb, and Elsamni 2019). Result showed that there is an increase in efficiency due to heat pipe. A modified solar desalination system using ETC as a basin and cover was introduced by (M B Shafii et al. 2016). They studied the effect of changing ETC inclination angle on solar still productivity. This study performed at latitude angle 35° 43' and the inclination angles used were 25°, 35° and 45°. The results showed that the productivity increased up to 35.5% at inclination angle equal to 35° which is near the latitude of the test location. A comparison between the productivity of solar still integrate with ETC and FPC was investigated by (Ali et al., n.d.). Results showed that the production of solar still with FPC increased up to 7.62% . While it increased up to 13.25% for solar still with ETC. From the above literature, The ETC is preferred as a solution for efficient solar desalination system. Data from three days experiments show that evacuated tubes have better water production when they are full of water in comparison with the case in which they are half empty (Shahmohamadi M., Shafii 2015). According to the presented literature, the present study will investigate experimentally the performance of the ETC systems integrated with a steel condenser under the effect of three different parameters. These parameters are: The water film thickness inside the ETC on the fresh water productivity, the condenser inclination angle, the condenser diameter on the desalinate productivity and the system's efficiency.

2 EXPERIMENTAL SETUP

2.1 System's Components

The systems consists of an evacuated tube collector, coupler and condenser. Each evacuated tube consists of two glass tubes made from borosilicate glass. The outer tube is transparent allowing light rays to pass through with minimal reflection. The inner tube is coated with a special selective coating (Al-N/Al) which features excellent solar radiation absorption and minimal reflection properties. The top of the two tubes are fused together and the air contained in the space between the two layers of glass is pumped out while exposing the tube to high temperatures. This "evacuation" between the two glass tubes makes a perfect thermal insulator for conduction and convection heat transfer.

The proposed solar still desalination system (ETCs with condenser) is installed on steel frame. The steel frame was provided by many reflectors to concentrate the sun rays on the evacuated tube as well as reducing the heating time. The brackish water provided to the system through a tank installed in high level to provide smooth water flow without pump. The lay out of the system is shown in figure 1. The system consists of two main parts connected with a special coupler. The first part is ETC (vacuum tube collector). The used ETC have inner and outer diameters of 42mm and 58 mm, respectively. The length of this tube is 1800 mm.

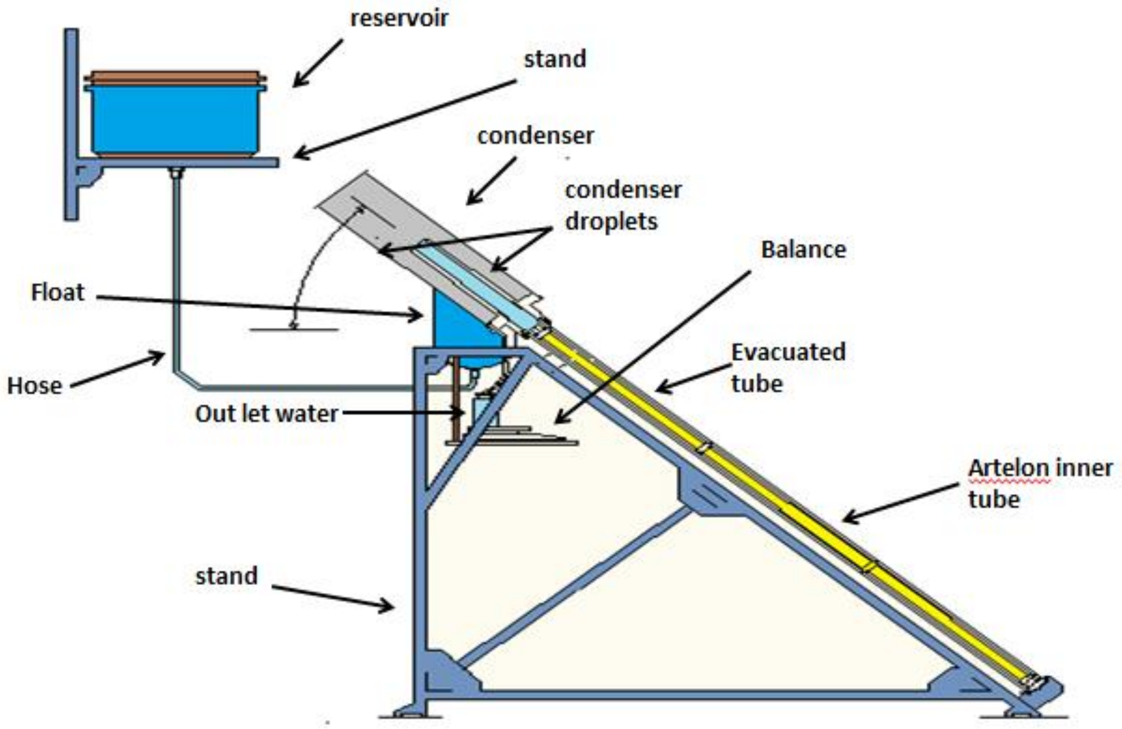
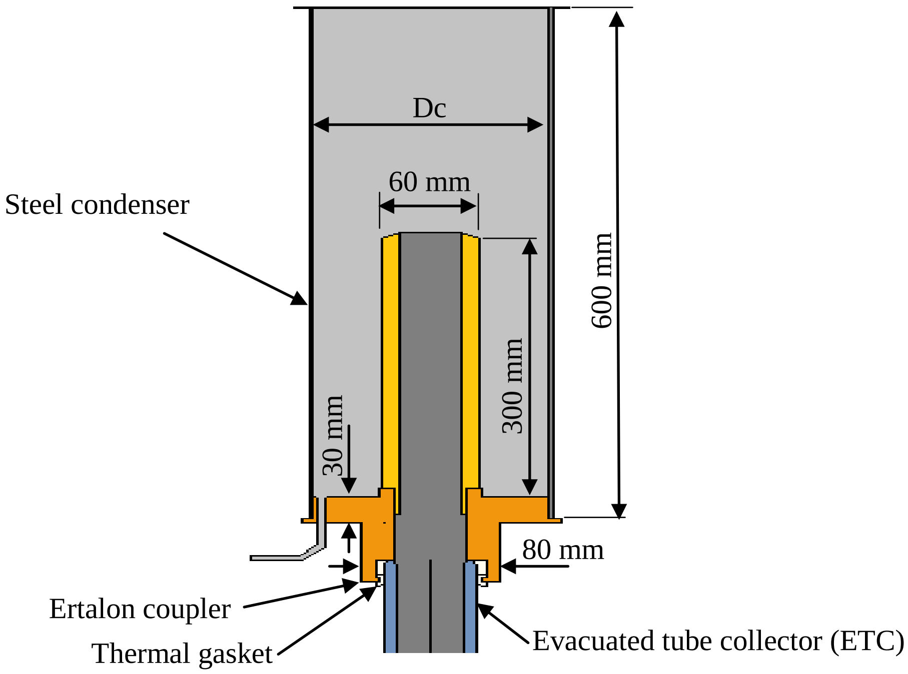


Figure 1. A layout of the experimental setup

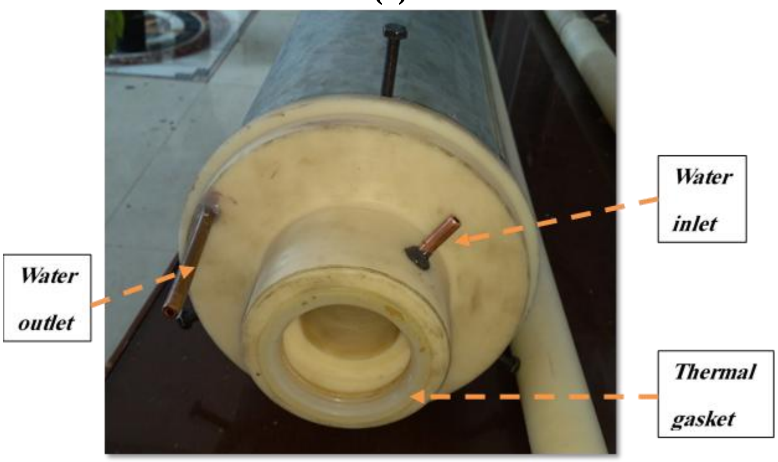
The second part is the steel condenser with 600 mm length and 0.7 mm thickness. Its diameter is generally equals to 160 mm and was varied as a study parameter in one of the experiments having values of 80, 120 and 160 mm as shown in figure 2.

Figure 2. The used steel condenser

The coupler that connects these two parts is shown in figure 3(a). It is made of high temperature Ertalon 66 SA-C to withstand the high temperature vapor generated in the ETC. In the condenser, the heat absorbed from water vapor and the water condenses on the condenser inner surface. The purified water droplets were getting out from condenser through a hole connected to small copper tube as shown in figure 3(b).



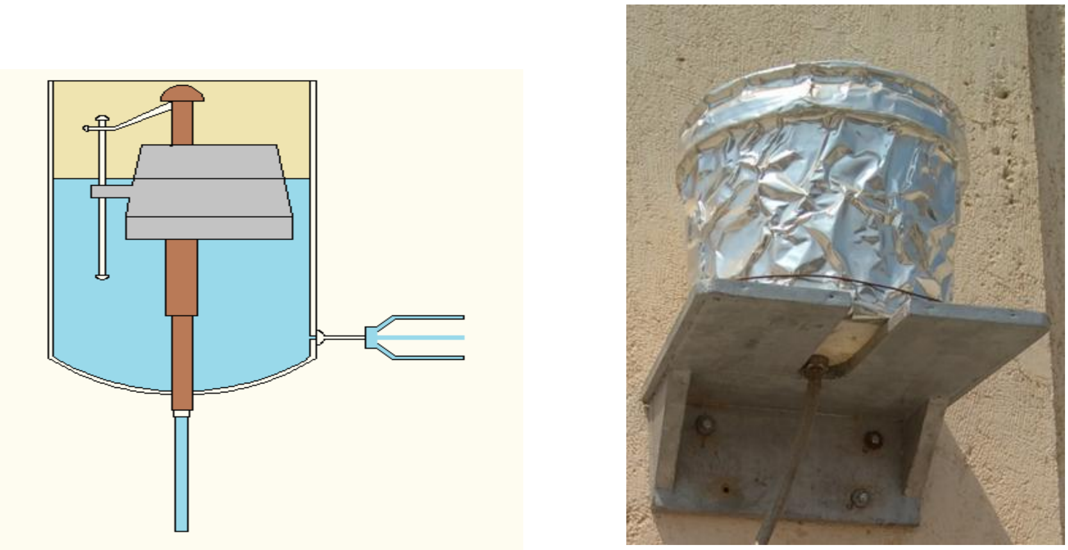
(a)



(b)

Figure 3. schematic diagram for the coupler that connects the ETC with the steel condenser.

The tube is filled by the water that to be desalinated through tank provided with plastic float-valve and a hose as shown in figure. 4(a). The tank was made of PVC to prevent rust formation inside brackish water tank. The plastic float-valve used to regulate the water flow inside the tube. This plastic tank is supplied with water from a 2m from ground level height main tank as shown in figure 4 (b)



(a) (b)

Figure 4. schematic drawing for water tank with float valve.

2.2 Measuring Devices

T-type thermocouples were used to measure temperature of the condenser internal wall. The uncertainty of this thermocouples is ±1°C. NI Compact DAQ with NI-9211 Module was used for temperature measurement and recording with 0.1 frequency. PASCO Xplorer GLX (uncertainty of ± 0.5 °C) with wind speed detector were used to easily measure ambient temperature, wind speed. This device used to record wind speed every 200 seconds and the ambient temperature every 10 seconds and sent it to computer device. PYR1307 pyrometer (uncertainty of < 10 W/m2) is used to measure solar radiation intensity and located parallel to the evacuated tube collector. A 1gm sensitive balance was used to weight the collected fresh water from condenser.

2.3 Study Parameters setup

In this study, three parameters were investigated to study its effect on fresh water productivity. The setup of each parameter will be described in the following sections. In the first parameter, the water film thickness was changed from 2 to 4 and 6 mm. ERTALON 66SA-C bars with different diameters was inserted inside the ETC to control the water film thickness. ERTALON rings were inserted between the ETC and ERTALON column to make sure the column was centered inside the ETC. Figure 5 shows the ERTALON bars and the ETC. this experiment was conducted in 25 of May 2019.

Figure 5. pictures of ERTALON columns inside the ETCs.

The second parameter was the condenser's diameter. The condenser diameter was changed in the range of 8, 12 and 16 cm. This experiment was conducted in 15 of June 2019. The last parameter is the condenser inclination angle on the horizontal. The inclination angle is 45, 62 and 80. This experiment was conducted in 4th of July 2019.

2.4 Experimental procedure:

Before performing the experiment, all instrumentation is set up on the experiment. Then a special cover on ETC was removed before water from tank entering the ETC. First of all, a plastic tank was put in 2-meter height and filled with brackish water. This tank is connected to secondary tank fitted with float valve to control the water flow to evacuated tube. Then the water gets in the evacuated tube by the coupler which is sealed with thermal gasket to avoid hot water leakage. The water takes some time to boil and evaporate to the condenser where the vapor condensate to water droplets. The solar radiation, wind speed, ambient temperature and wind direction are measured.

In the first experiment, the ERTALON bars with different diameters to control the water film thickness (2, 4 and 6mm). Three ETCs is used in the same time to ensure the same conditions are applied to all water film thickness. Figure 6 shows a top view of evacuated tube fitted with ERTALON bar and ring that used in this experiment (2,4,6) Water film . Then the ERTALON bar are removed and three condensers with different diameters (8,12 and 16 cm) are used as mentioned before. Also, the experiment with three different condensers are performed at the same time. In the last experiment, the three different condensers are replaced with three identical condensers. The condensers angel was changed (45º,62º and 80º) to study its effect

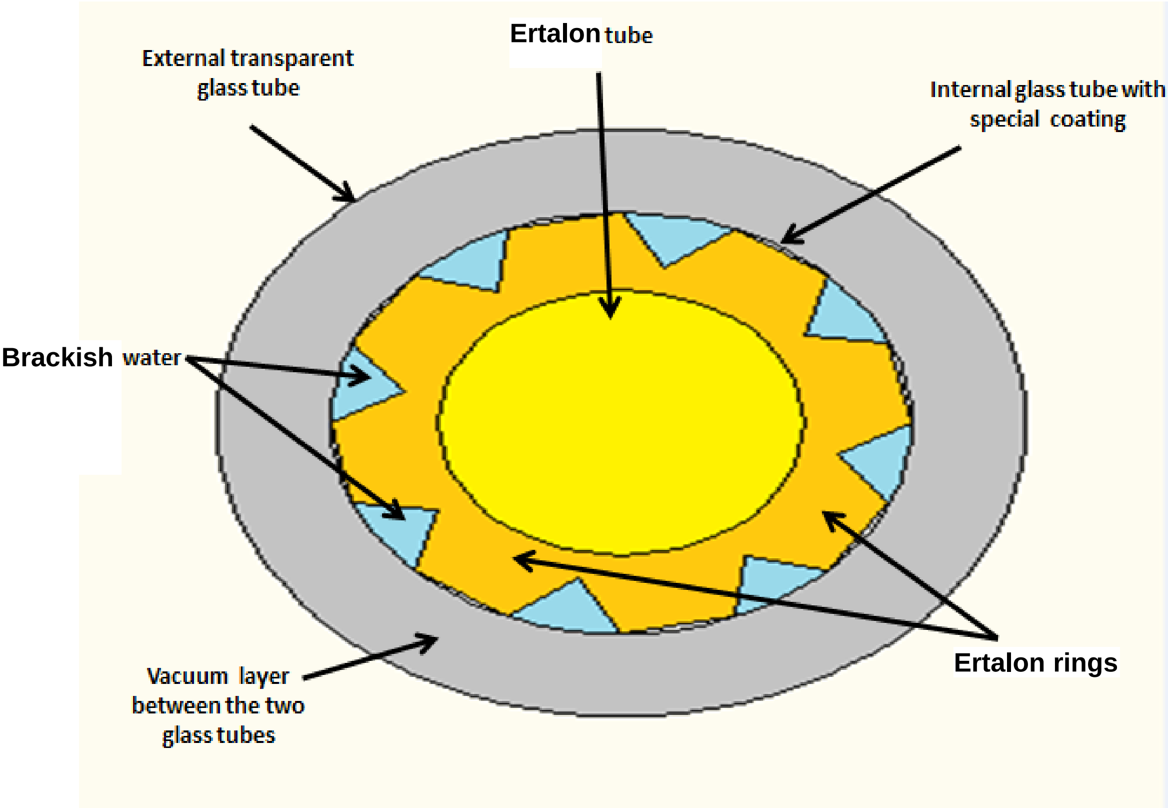


Figure 6. Top view of the evacuated tube with the inner tube

3 RESULTS AND DISCUSSION

According to the study parameters presented in the present research, the effect of the water film thickness, condenser diameter, and condenser inclination angle will be discussed in the following sections. The first parameter proposes an enhancement in the evaporator of the desalination system. however, the other two parameters propose enhancement in the condenser part.

3.1 Effect of water film thickness on the system's performance

The water film thickness in the evacuated tube was varied in the range of 2,4 and 6mm. The variation of the ambient temperature and the wind speed over the day are as shown in figure 7. In that day, the ambient temperature varied in the range from 25 to 38 °C over the day with the maximum values after 12:00 hr. The wind speed varied from 0.1 to 3.5 m/s with the maximum values biased between 11:00 and 12:00 hr.

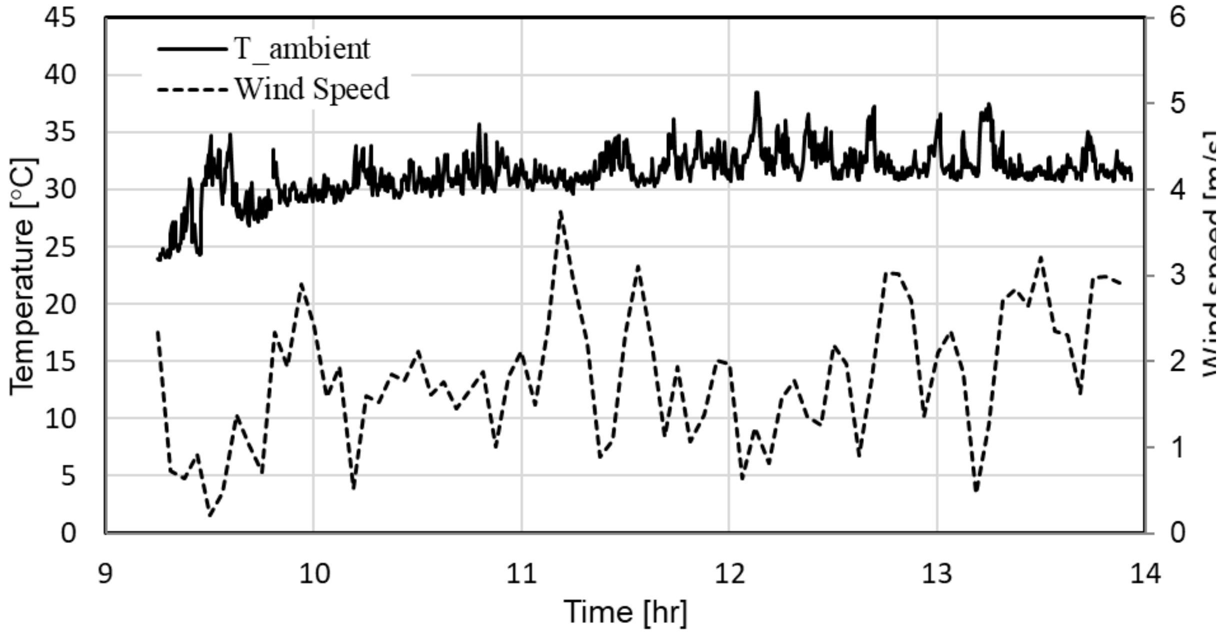


Figure 7. The variation of the ambient temperature and wind speed in the water film thickness experiment

The distribution of the global inclined solar radiation (Ig) is shown in figure 8. It can be observed that the solar radiation values in that day have a maximum value of 690 w/m2 with average value of 564.5 w/m^2.

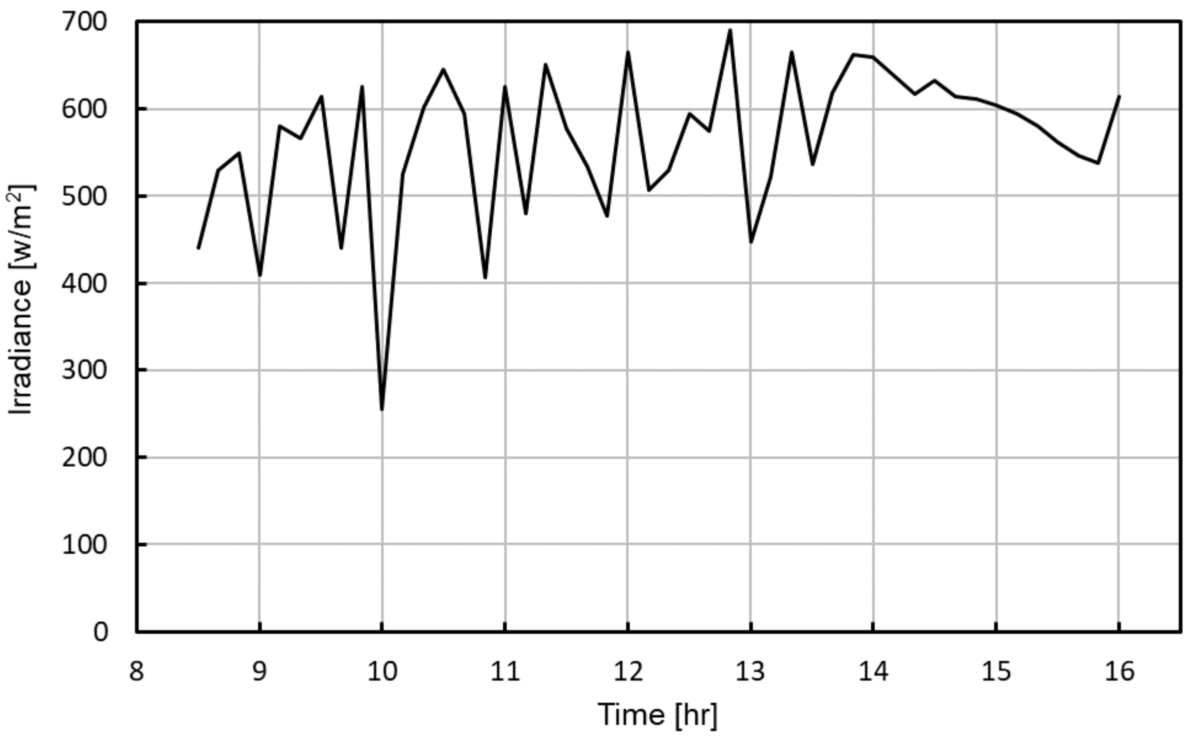


Figure 8. The distribution of the global inclined solar radiation for the water film thickness experiment.

The distribution of the system's productivity over the day for the three WFT values is as illustrated in figure 9. As can be observed, The low radiation intensity led to the time lag between the systems start of production and solar cover removal of about 2.5 hours. This effect exists in all the test due to the small values of solar radiation in that period of the year. It can be observed that the highest production rate of the system occurs at the 2mm water film thickness with a value of 0.85 kg/m^2.hr at 16:00 hr. Moreover, it can be observed that the maximum production rate is not fixed for a specific WFT value. However, the 2mm WFT gives the maximum production rate over most the measuring period. This unstable productivity rate can refer to the small and fluctuating values of the solar radiation acting on the evacuated tubes over the day which controls the vapor generation rate. This in turn changes the evaporation rate from the tubes over time.

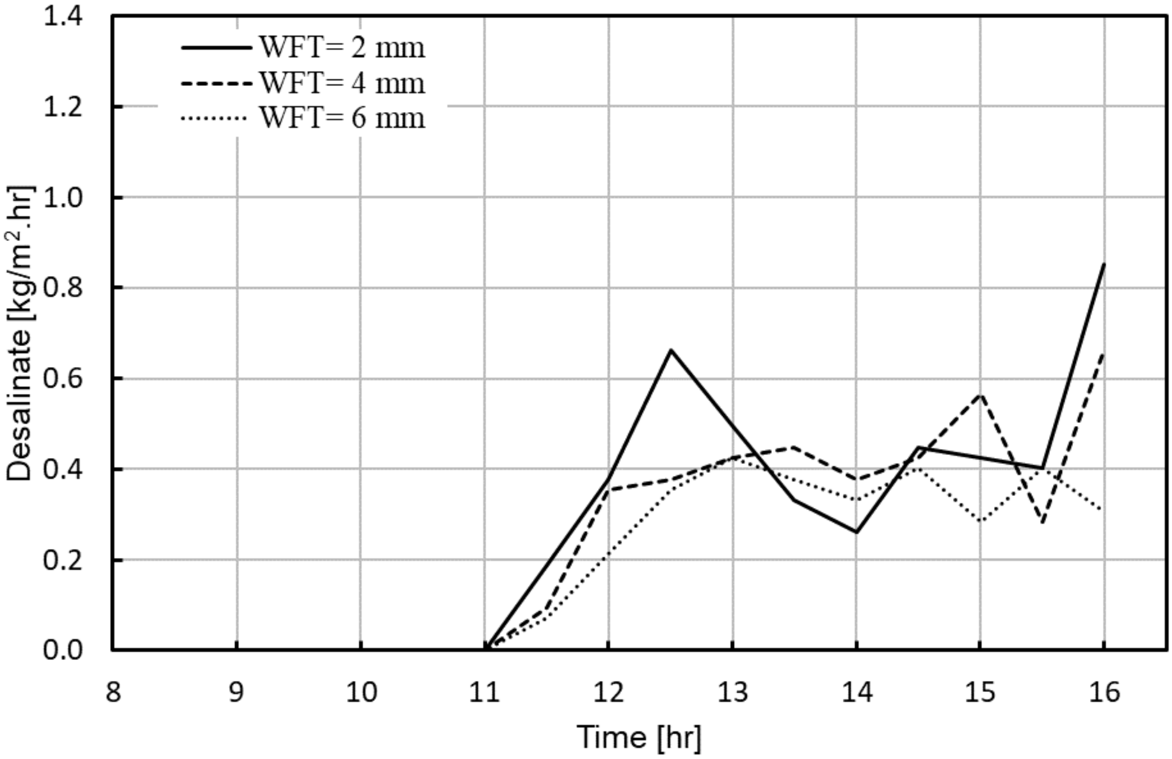


Figure 9. The distribution of the systems productivity of the desalinate over the day for the water film thickness values of 2, 4, and 6 mm.

As a result of the variation of the evaporation rate and the change of the wind speed which controls the condensation rate over the day, the system performance makes asynchronous productivity of the yield for the different values of the WFT. For that reason, these systems can be judged using the cumulative productivity over the day. The variation of the cumulative yield among the three WFT values is illustrated in figure 10. It can be observed that the water film thickness of 2mm gives the maximum productivity of 2.22 kg/m^2 in that day. This behavior refers to the smaller heat capacity of water with smaller WFT. This in turn increases the evaporation rate of the water and as a result, increases the condensation rate and the desalinate productivity.

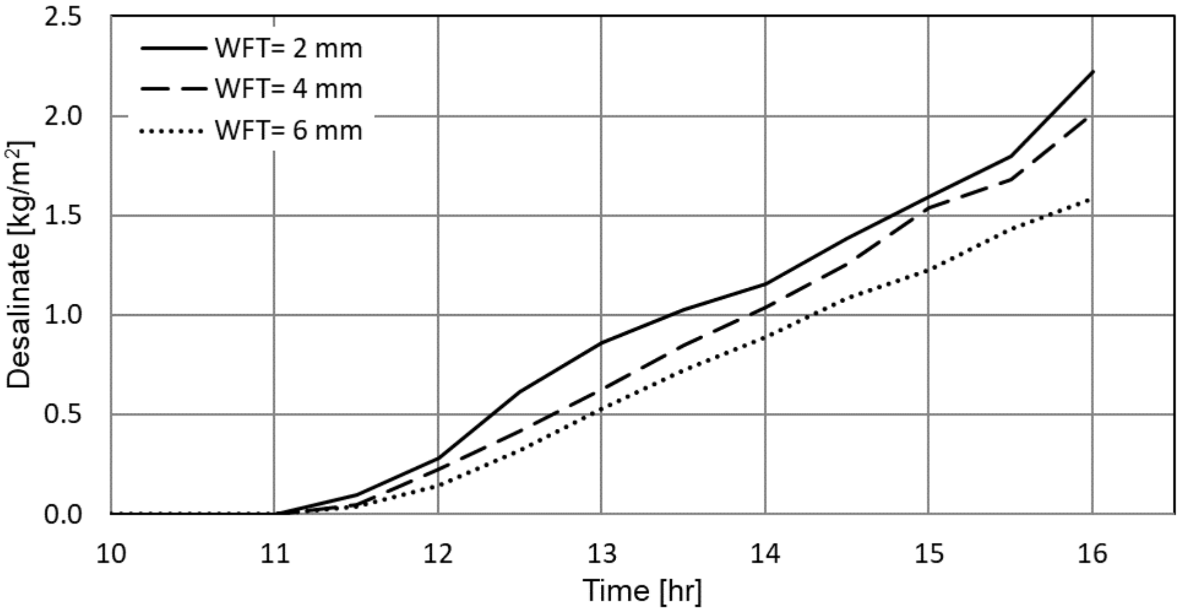


Figure 10. The variation of the systems cumulative productivity of the desalinate for the water film thickness values of 2, 4, and 6 mm.

This behavior emphasis that the use of the core inserts inside the evacuated tube enhances the evaporation rate as the heat is absorbed by a smaller thickness of water (smaller heat capacity) leading to faster evaporation. As the system behaves with unsteady performance of evaporation and condensation, and because of the low solar radiation intensity, the instantaneous efficiency may lead to miss information. So, the overall system performance is judged through the over day efficiency. The over day efficiency of the systems is illustrated in table 1.

Table 1. system's efficiency variation according to WFT

WFT	Efficiency [%]
6 mm	22.9
4 mm	29.1
2 mm	32.2

3.2 Effect of the condenser’s diameter on the system’s performance

The second test investigated the effect of varying the condenser’s diameter in the range of 80, 120 and 160 mm on the system’s performance. figure 11 shows the variation of the ambient temperature and wind speed over the day for the present test. it can be observed that the ambient temperature variation in that day was from 27 to 37 °C, over the test period. The wind speed varied from 0.0 to 2.4 m/s in that day.

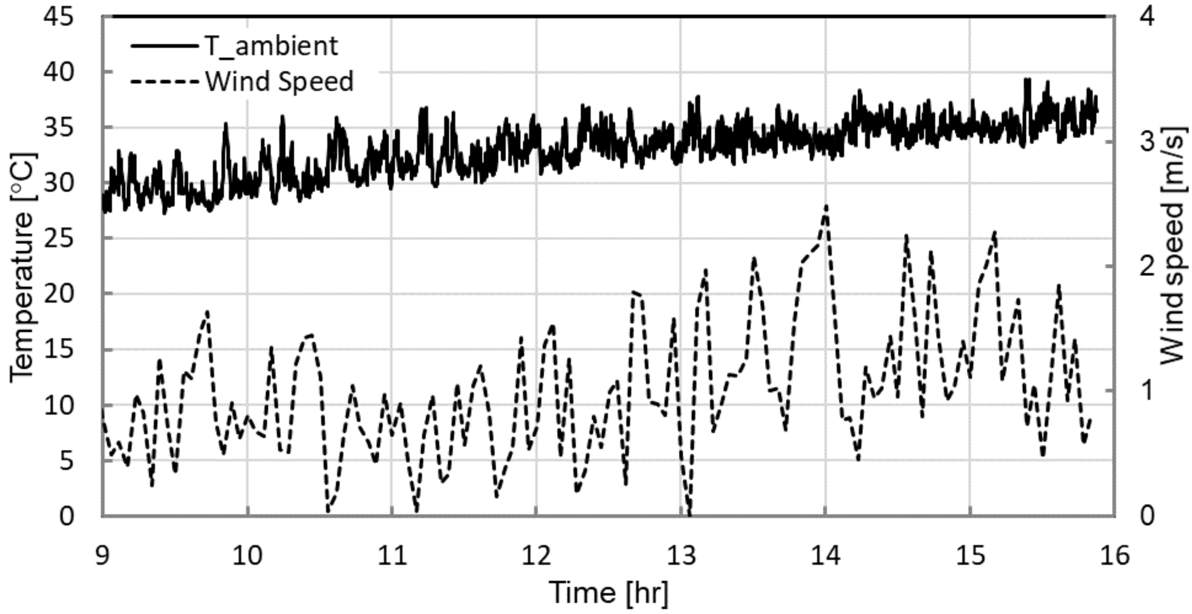


Figure 11. The variation of the ambient temperature and wind speed in the condenser's diameter experiment.

Figure 12 shows the distribution of Ig over the test day. It can be observed that the solar radiation in that day is fluctuating with an average value of 558 w/m^2.

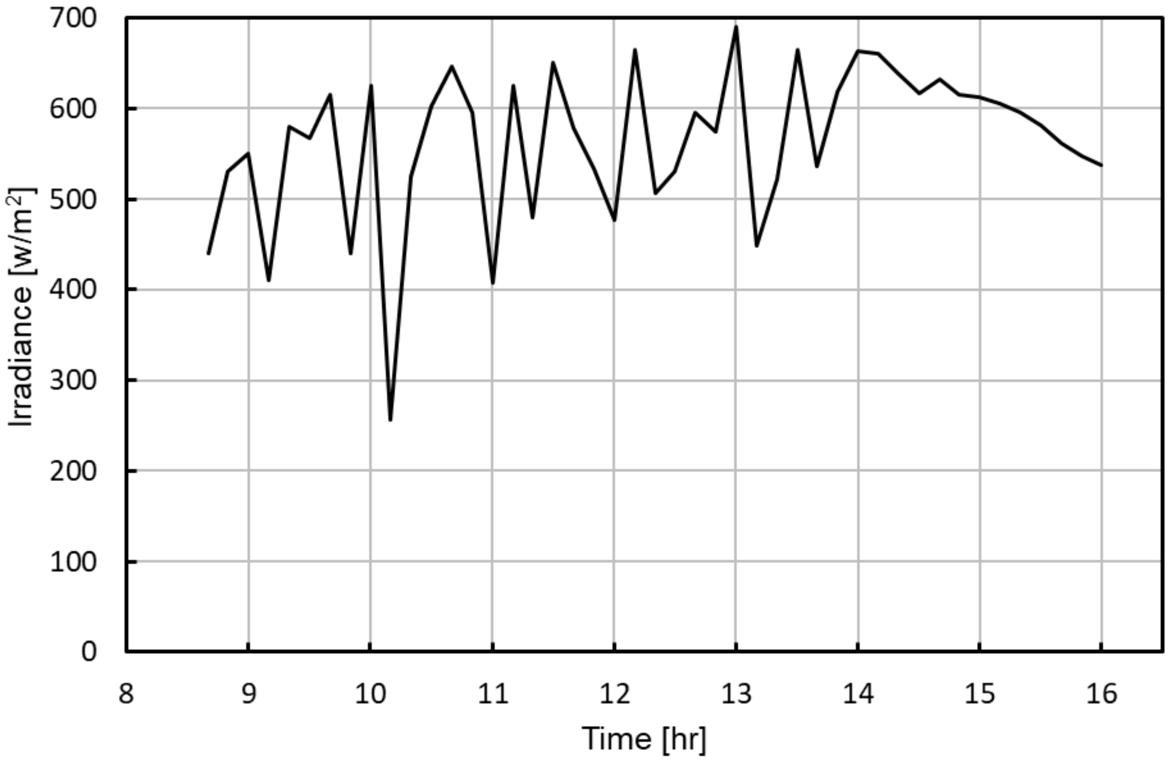


Figure 12. The variation of the global inclined solar radiation over the day for the condenser's diameter experiment.

In the present test, the distribution of the systems yield at different condenser's diameters are as shown in figure 13. It can be observed that the minimum condenser's diameter of 80 mm started the production of the condensate at 11:00 hr. Then the 120 mm diameter condenser started at 11:30 hr. The latest diameter of the desalinate production was the 160 mm diameter condenser at 12:00 hr.

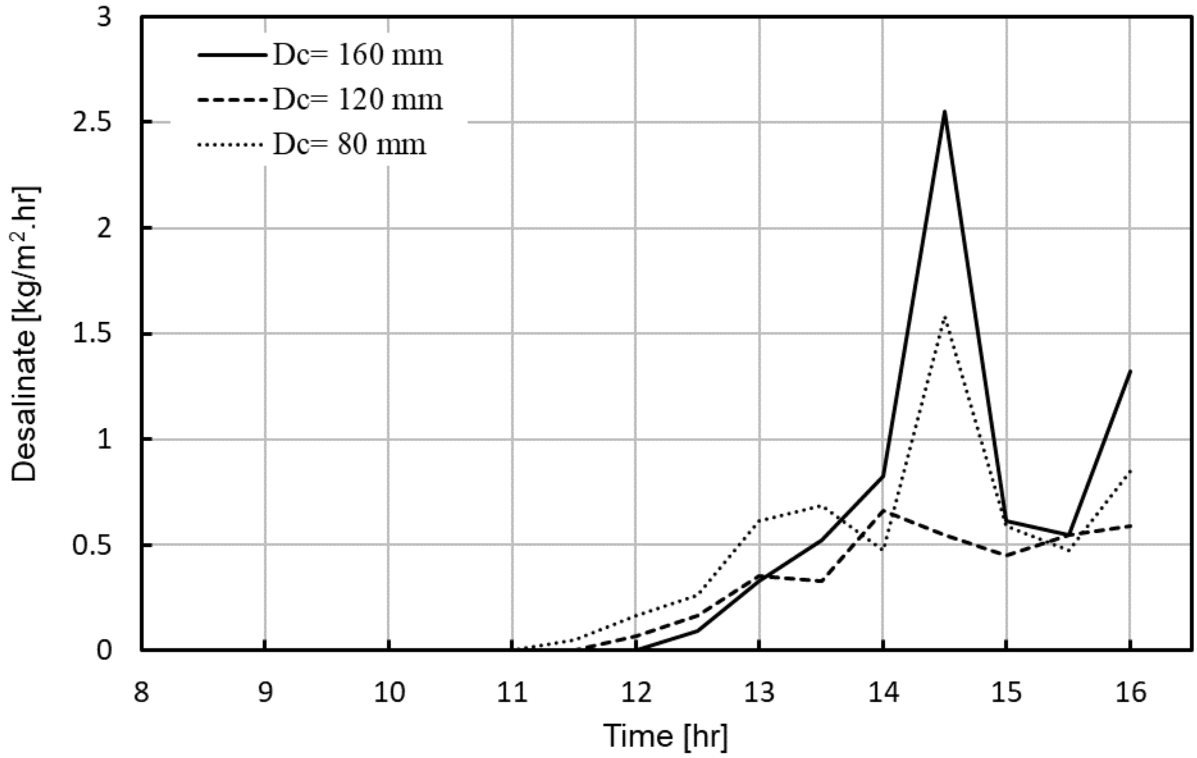


Figure 13. The variation of the systems productivity of the desalinate over the day for the condenser's diameter of 80, 120 and 160 mm.

This time lag between the three systems refers to the different diameter of the condensers which causes different volumes. The condenser with the minimum diameter have the smallest volume which is filled with the vapor from the evaporator before the other two condensers and hence starts condensation before them. This indicates the advantage of the smaller diameter condenser in starting condensation before the other two condensers. However, considering the production rate, it can be observed that the condenser with diameter of 160 mm reaches a production rate of 2.5 $kg/m^2.hr$ at 14:30 hr. It can be observed that in that test also the highest production rate is not guaranteed to the maximum diameter condenser over the day. The heights production rate takes place sometimes in the 80 mm diameter and in other times to the 120 mm diameter. This can also refer to the small values of the solar radiation which also creates asynchronous condensation among the three condensers which causes no clear behavior for the best diameter.

For analyzing the difference between the three systems in this test, the internal surface temperature Tc,s of the three condensers were recorded and illustrated in figure 14. It can be observed that Tc,s of the condensers fluctuates in cycles of variable periods for the three systems. This indicates that the condensation process occurs in cycles as stated before. It can be observed that Tc,s have inverse proportionality with the condenser's diameter. Which means that the 80mm diameter condenser have the highest temperature most of the time, and the 160 mm diameter condenser have the lowest temperatures. This indicates that the diameter of the condenser plays an important role in the condensation process which is related directly to the value of Tc,s and the area of condensation. Moreover, it can be observed that the time periods at which the condensation rate increases follows directly the low Tc,s values periods as illustrated by the red arrows in figure 14.

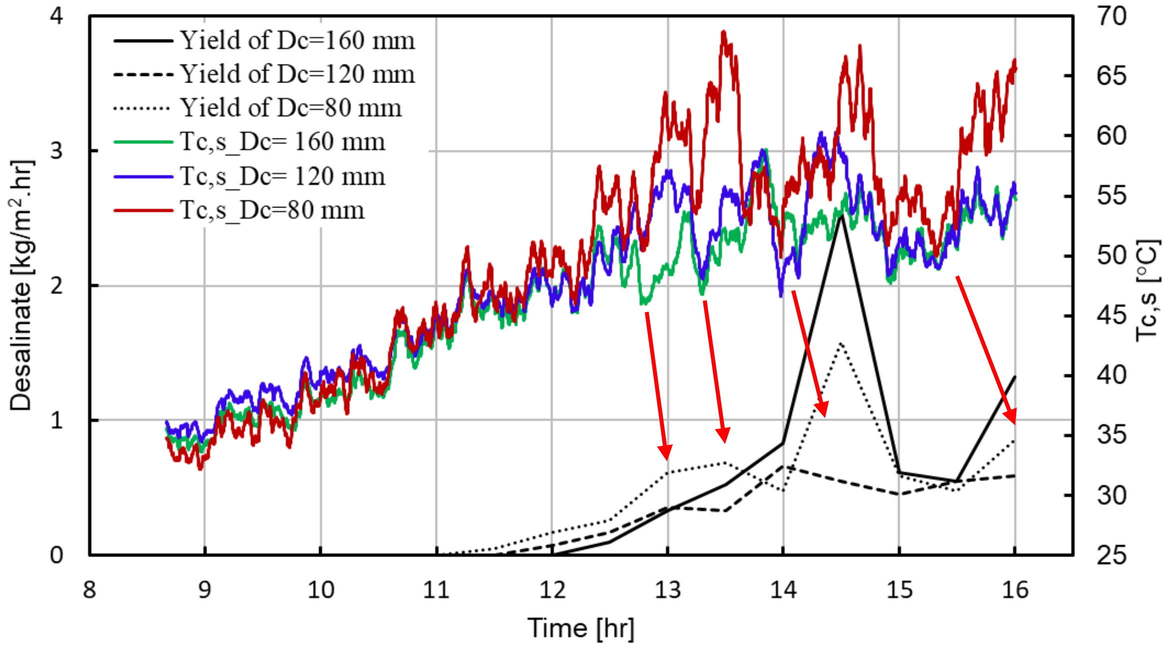


Figure 14. The distribution of the internal surface temperature of the condensers with diameters of 80, 120 and 160 mm.

Comparing the small and large diameter condenser's according to their performance, it can be found that the small diameter lads to fast condensation for its small surface area. This fast condensation have two advantages. The first is that it starts condensation over the day faster. The second is that the rate of condensate drops collection from the surface is high. This is emphasized by the high difference in the Tc,s temperature which reaches 14°C in some cycles. However, the large diameter condenser have an important property which is the surface area. The large are is considered an advantage as it permits large area for heat disposal to ambient and condensation. However, the rate of condensate collection from the large are is lower than that in the small area. Moreover, the large area collects more thermal energy from the solar radiation. Although these disadvantages of the large area of the 160 mm diameter condenser, it still achieves the highest condensation rate. It can be observed that the condensation rates achieved by the 80 mm condenser is higher than that of the 120 mm. this means that the fats condensation for the 80 mm achieves higher rates than the larger are of the 120 mm condenser. However, it can be judged over the best performance from the over day productivity which usually agree with the maximum production rate over the day. Figure 15 shows the distribution cumulative desalinate of the three systems over the day. This indicates that the 160 mm diameter condenser gives the highest desalinate of 3.4 kg/m^2 over the day.

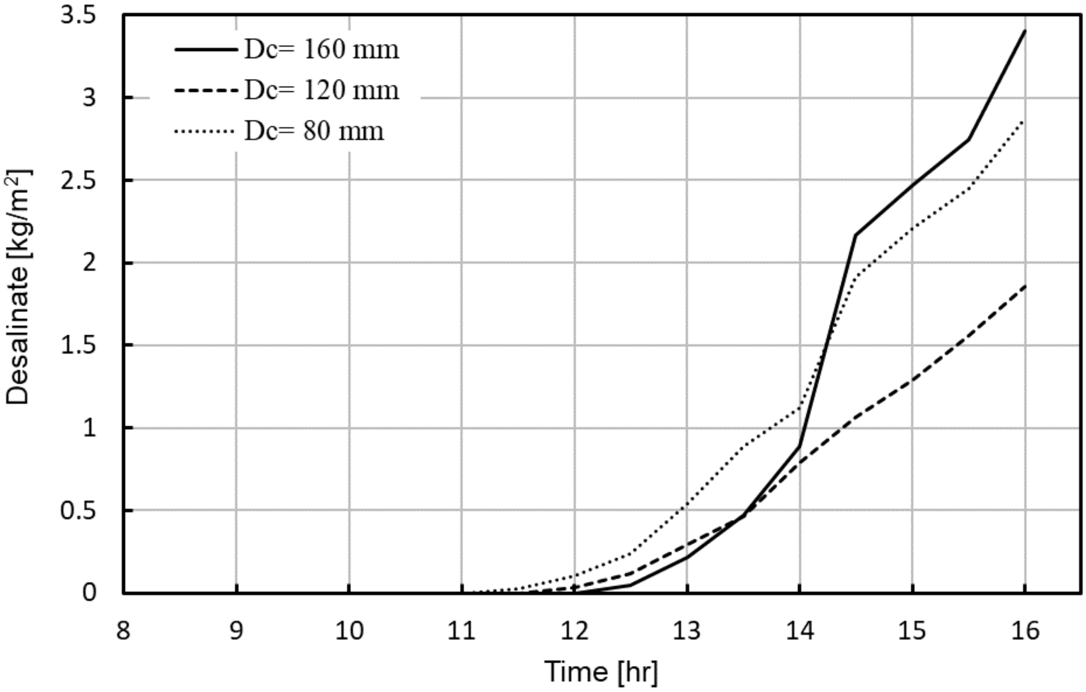


Figure 15. The cumulative desalinate distribution of the 80 mm, 120 mm, and the 160 mm diameter condensers over the day.

Due to the fluctuating production of condensate which considers some storage of the vapor generated tile the removal of the condensate layer, the instantaneous efficiency can give erroneous values. The over day efficiency was calculated and illustrated in table 2.

Table 2. System's efficiency variation according to condenser's diameter

Dc	Efficiency [%]
80 mm	43.0
120 mm	27.8
160 mm	51.0

3.3 Effect of the condenser's inclination angle on the system's performance

The third test parameter was the inclination angle of the condenser. The test took place one three different inclination angles of the condenser on the horizontal of values 80°, 62° and 45°. In that day, the distribution of the ambient temperature and the wind speed are illustrated in figure 16.

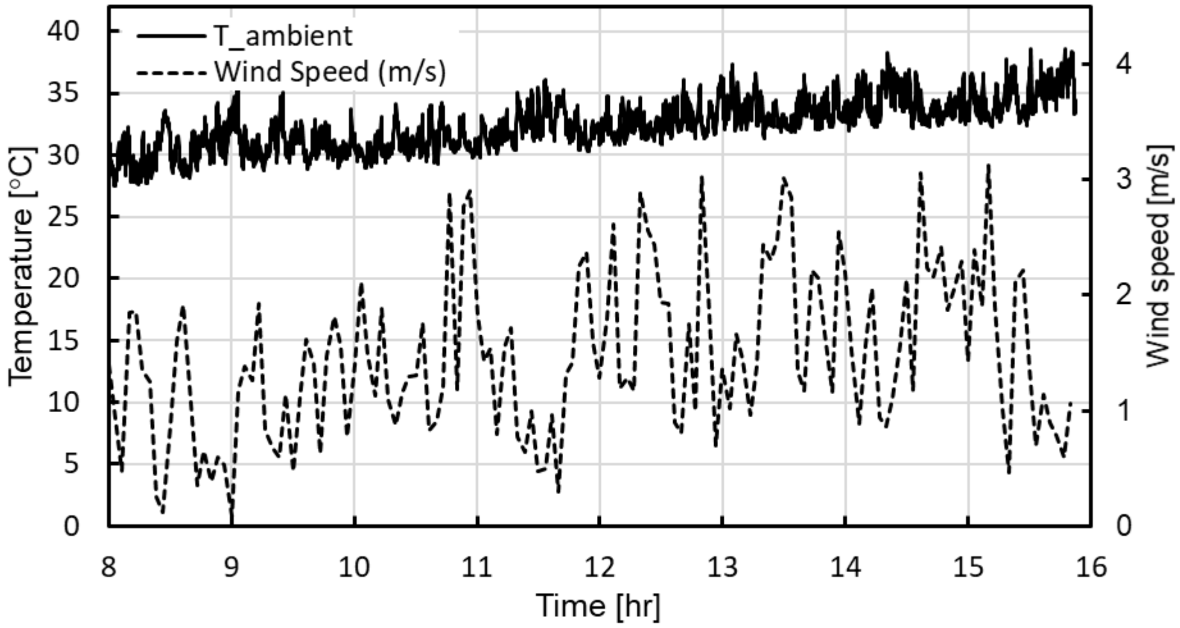


Figure 16. the distribution of the ambient temperature and the wind speed in the condenser's inclination angle test day.

It can be observed that the ambient temperature in that day have an average value of 32.4 °C with an average wind speed of 1.46 m/s. The distribution of Ig is illustrated in figure 17. The solar radiation in that day have an average value of 650.8 w/m2 over the test period.

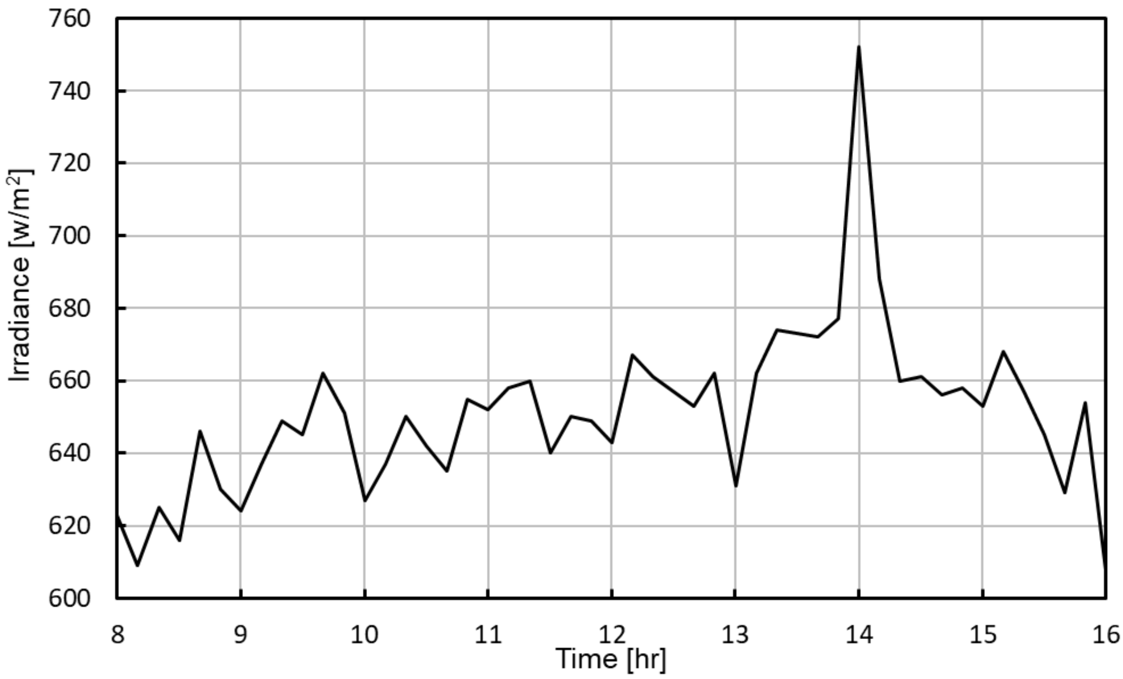


Figure 17. the distribution of the global inclined solar radiation Ig in the day of condenser's inclination angle test.

The distribution of the desalinate yield for the three inclination angles of the condenser are illustrated in figure 18. It can be observed that the maximum production rate of 1.08 kg/m^2.hr is achieved by the 62° inclination condenser.at 15:00 hr. The large inclination angles help in the collection of the desalinate more rapidly than the lower inclination angles. However, the inclination effects on two important parameters that can increase the condensation rate. The first is the opposition acted by the condenser's surface on the natural direction of the vapor upwards. In this parameter, when the condenser tends to be horizontal, this factor increases and hence increases the condensation rate. The second parameter is the distribution of the wind speed around the surface of the condenser which tends to be more convective for vertical orientation of the condensers. According to these three parameters, the three systems behaves and the condensation rate varies among them.

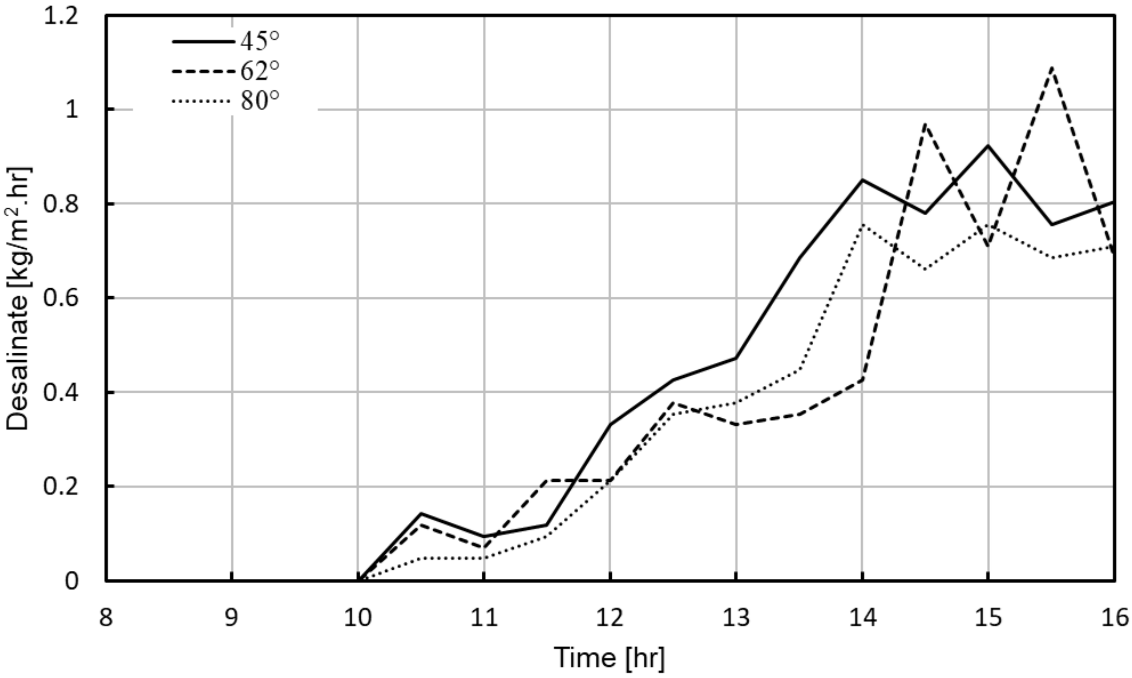


Figure 18. The distribution of the desalinate yield for the three inclination angles of the condenser of 80°, 62° and 45°.

The distribution of Tc,s for the three condensers is illustrated in figure 19. It can be observed that the desalinate production rate is related directly to the temperature Tc,s. As this temperature decreases, the desalinate rate increases as illustrated by the red arrows in figure 19. However, it can be observed that the 62° inclination condenser achieves high rates around 15:00 hr. It achieves an advantage of a moderate value of resisting the natural direction of the vapor that comes out from the evaporator. And also, a moderate inclination angle between the two other condensers which helps in collecting the condensate more rapidly.

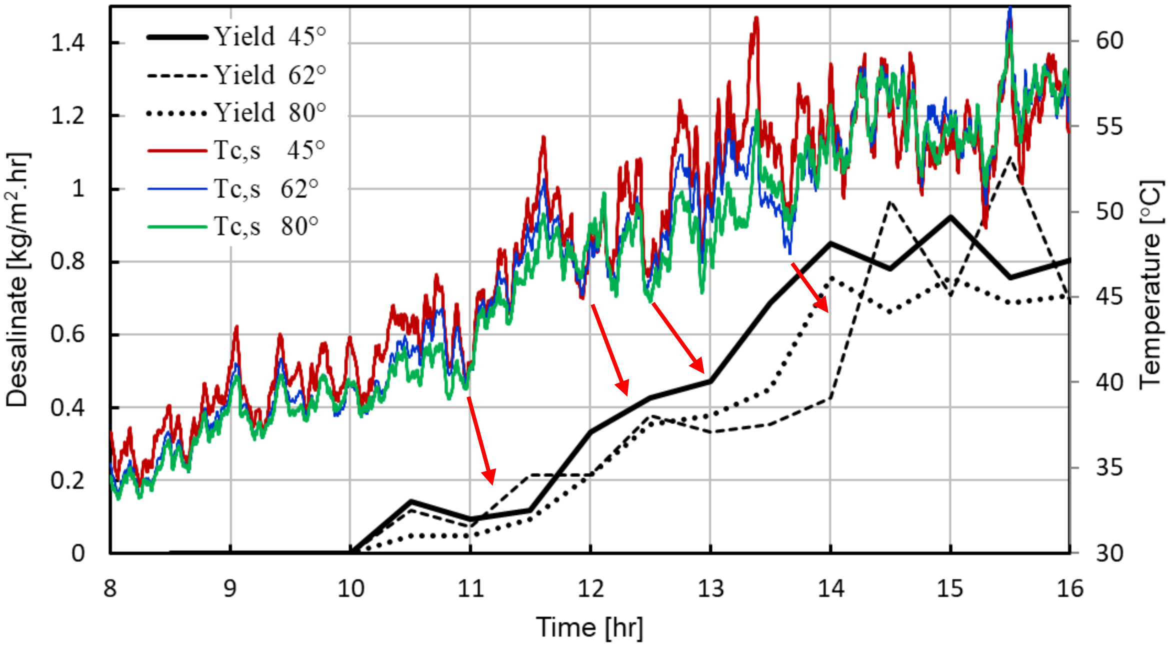


Figure 19. The distribution of the internal surface temperature of the condenser and the desalinate yield rate for the three inclination angles of the condenser of 80°, 62° and 45° .

However, the production rate is achieved by the 45° Inclination most of the day. This can be emphasized by the cumulative production distribution shown in figure 20. As can be observed, the maximum cumulative yield is achieved by the 45° inclination condenser with a value of 3.19 kg/m^2. This emphasizes that the inclination angles near horizontal acts better as a cumulative desalinate than higher inclination angles.

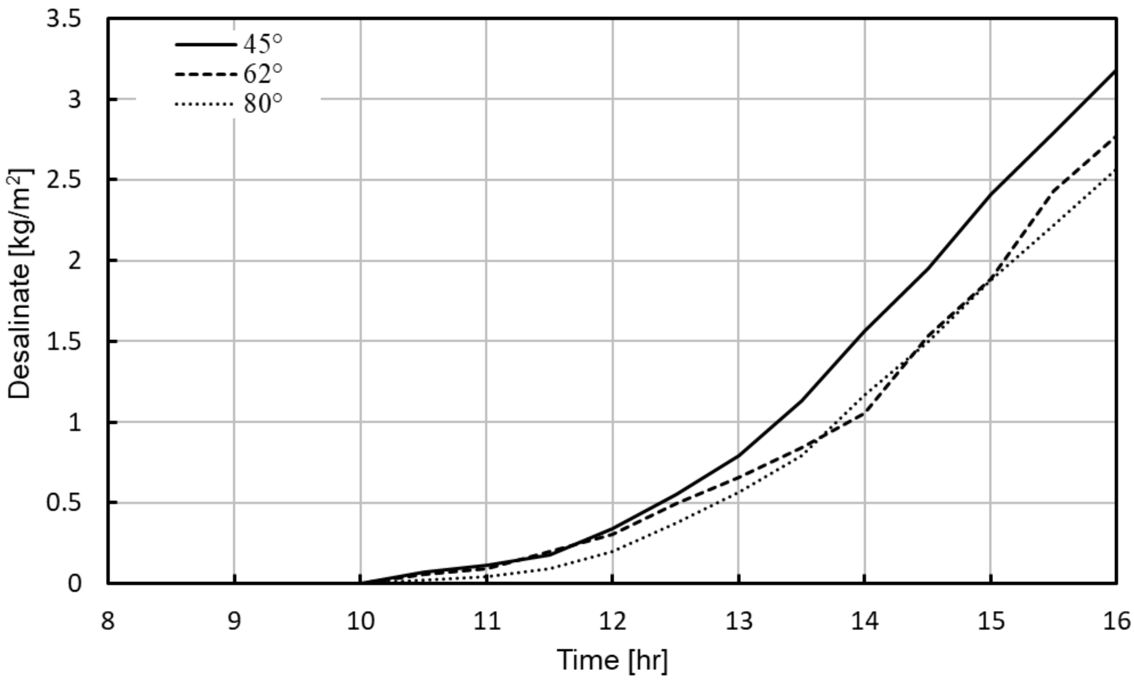


Figure 20. The distribution of the cumulative desalinate yield for the three inclination angles of the condenser of 80°, 62° and 45°.

Due to the fluctuating production of condensate which considers some storage of the vapor generated tile the removal of the condensate layer, the instantaneous efficiency can give erroneous values. The over day efficiency was calculated and illustrated in table 3.

Table 3. System's efficiency variation according to the condenser's inclination angle

Angle	Efficiency [%]
80°	30.4
62°	32.8
45°	37.6

4 CONCLUSION

An experimental investigation for an ETC-condenser desalination unit was performed. The experiments were performed in outside weather conditions with measuring the ambient temperature, wind speed, and global inclined solar radiation. The present study investigated the effect of three different parameters on the performance of the system considering the daily desalinate yield and the system's efficiency. These parameters are the water film thickness inside the ETC, the condenser's diameter and the condenser's inclination angle. It was found that the less water film thickness achieves the highest desalinate quantity over the day. This is due to the less heat capacity included in the smaller WFT values. Considering the condenser's diameter, it was found that the large diameter condenser achieves the highest condensate over the day giving over day efficiency of 51% . However, it was found also that the smaller diameter gives fast desalination. Although increasing the inclination angle of the condenser helps in collecting the condensate rapidly, it was found to act negatively on the over day desalinate. The near horizontal condenser achieves the best condensate over the day with over day efficiency of 37.6%.

REFERENCES

Abbaspour, Mohammad Javad, Meysam Faegh, and Mohammad Behshad Shafii. 2019. "Experimental Examination of a Natural Vacuum Desalination System Integrated with Evacuated Tube Collectors." *Desalination* 467 (June): 79–85. https://doi.org/10.1016/j.desal.2019.06.004.

Agrawal, Mehul, and Lt Piyush Nema. 2016. "Experimental Works on Solar Distil Combined to EGT (Evacuated Glass Tube) By Means of an Air as Unimportant Fluid." *International Journal of Engineering Development and Research* 4 (4): 2321–9939.

Ali, A, Mohammad Deyab, Alrayan Ahmad, Abdallah Saeed, and Ahmed Muhanna. n.d. "SOLAR DESALINATION AUGMENTED WITH EVACUATED-TUBE COLLECTOR," 1–10.

Durkaieswaran, P, and K Kalidasa Murugavel. 2015. "Various Special Designs of Single Basin Passive Solar Still – A Review." *Renewable and Sustainable Energy Reviews* 49: 1048–60. https://doi.org/10.1016/j.rser.2015.04.111.

El-Nashar, Ali M. 2009. "Seasonal Effect of Dust Deposition on a Field of Evacuated Tube Collectors on the Performance of a Solar Desalination Plant." *Desalination* 239 (1–3): 66–81. https://doi.org/10.1016/J.DESAL.2008.03.007.

El-Sebaii, A A. 2004. "Effect of Wind Speed on Active and Passive Solar Stills." *Energy Conversion and Management* 45 (7): 1187–1204. https://doi.org/https://doi.org/10.1016/j.enconman.2003.09.036.

El-Sebaii, A A, and E El-Bialy. 2015. “Advanced Designs of Solar Desalination Systems: A Review.” *Renewable and Sustainable Energy Reviews* 49: 1198–1212. https://doi.org/https://doi.org/10.1016/j.rser.2015.04.161.

Elsheniti, Mahmoud B., Amr Kotb, and Osama Elsamni. 2019. “Thermal Performance of a Heat-Pipe Evacuated-Tube Solar Collector at High Inlet Temperatures.” *Applied Thermal Engineering* 154 (October 2018): 315–25. https://doi.org/10.1016/j.applthermaleng.2019.03.106.

Essa, M.A., and N.H. Mostafa. 2017. “Theoretical and Experimental Study for Temperature Distribution and Flow Profile in All Water Evacuated Tube Solar Collector Considering Solar Radiation Boundary Condition.” *Solar Energy* 142. https://doi.org/10.1016/j.solener.2016.12.035.

Essa, Mohamed A, Nabil H Mostafa, and Mostafa M Ibrahim. 2018. “An Experimental Investigation of the Phase Change Process e Ff Ects on the System Performance for the Evacuated Tube Solar Collectors Integrated with PCMs.” *Energy Conversion and Management* 177 (June): 1–10. https://doi.org/10.1016/j.enconman.2018.09.045.

K. Sampathkumar, T.V. Arjunan, P. Senthilkumar. 2011. “Single Basin Solar Still Coupled with Evacuated Tubes - Thermal Modeling and Experimental Validation.” *International Energy Journal* 12 (1): 53–66. http://www.rericjournal.ait.ac.th/index.php/reric/article/view/652/387.

M, Chandrashekara, and Avadhesh Yadav. 2017. “Water Desalination System Using Solar Heat: A Review.” *Renewable and Sustainable Energy Reviews* 67: 1308–30. https://doi.org/https://doi.org/10.1016/j.rser.2016.08.058.

Mamouri, S Jahangiri, H Gholami Derami, M Ghiasi, M B Shafii, and Z Shiee. 2014. “Experimental Investigation of the Effect of Using Thermosyphon Heat Pipes and Vacuum Glass on the Performance of Solar Still.” *Energy* 75: 501–7. https://doi.org/https://doi.org/10.1016/j.energy.2014.08.005.

Manokar, A Muthu, K Kalidasa Murugavel, and G Esakkimuthu. 2014. “Different Parameters Affecting the Rate of Evaporation and Condensation on Passive Solar Still – A Review.” *Renewable and Sustainable Energy Reviews* 38: 309–22. https://doi.org/https://doi.org/10.1016/j.rser.2014.05.092.

Omara, Z M, Mohamed A Eltawil, and ElSayed A ElNashar. 2013. “A New Hybrid Desalination System Using Wicks/Solar Still and Evacuated Solar Water Heater.” *Desalination* 325: 56–64. https://doi.org/https://doi.org/10.1016/j.desal.2013.06.024.

Panchal, Hitesh N. 2015. “Enhancement of Distillate Output of Double Basin Solar Still with Vacuum Tubes.” *Journal of King Saud University - Engineering Sciences* 27 (2): 170–75. https://doi.org/https://doi.org/10.1016/j.jksues.2013.06.007.

Praveen T Hunashikatti, KR Suresh, B Prathima, Gulshan Sachdeva. 2014. “Development of Desalination Unit Using Solar Still Coupled with Evacuated Tubes for Domestic Use in Rural Areas.” *Current Science* 107 (10).

Sampathkumar, K., T. V. Arjunan, and P. Senthilkumar. 2013. “The Experimental Investigation of a Solar Still Coupled with an Evacuated Tube Collector.” *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* 35 (3): 261–70. https://doi.org/10.1080/15567036.2010.511426.

Shafii, M B, S Jahangiri Mamouri, M M Lotfi, and H Jafari Mosleh. 2016. “A Modified Solar Desalination System Using Evacuated Tube Collector.” *Desalination* 396: 30–38. https://doi.org/https://doi.org/10.1016/j.desal.2016.05.030.

Shafii, Mohammad Behshad, Mojtaba Shahmohamadi, Meysam Faegh, and Hani Sadrhosseini. 2016. "Examination of a Novel Solar Still Equipped with Evacuated Tube Collectors and Thermoelectric Modules." *Desalination* 382: 21–27. https://doi.org/10.1016/j.desal.2015.12.019.

Shahmohamadi M., Shafii, M.B. and Sadrhosseini H. 2015. "SOLAR WATER DISTILLATION BY USING WATER IN THE INNER GLASS EVACUATED TUBES." *Third Southern African Solar Energy Conference*, 11–13.

Sharshir, Swellam W., A. W. Kandeal, M. Ismail, Gamal B. Abdelaziz, A. E. Kabeel, and Nuo Yang. 2019. "Augmentation of a Pyramid Solar Still Performance Using Evacuated Tubes and Nanofluid: Experimental Approach." *Applied Thermal Engineering* 160 (April). https://doi.org/10.1016/j.applthermaleng.2019.113997.

Singh, Ragh Vendra, Shiv Kumar, M M Hasan, M Emran Khan, and G N Tiwari. 2013. "Performance of a Solar Still Integrated with Evacuated Tube Collector in Natural Mode." *Desalination* 318: 25–33. https://doi.org/https://doi.org/10.1016/j.desal.2013.03.012.

Xiao, Gang, Xihui Wang, Mingjiang Ni, Fei Wang, Weijun Zhu, Zhongyang Luo, and Kefa Cen. 2013. "A Review on Solar Stills for Brine Desalination." *Applied Energy* 103: 642–52. https://doi.org/https://doi.org/10.1016/j.apenergy.2012.10.029.

Yadav, Suraj, Himanshu Manchanda, Mahesh Kumar, Rakesh Kumar, and Research Scholar. 2017. "Stepped and Evacuated Tube Collector Coupled Solar Stills: A Comprehensive Review," no. 4: 2394–0697.