Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

Improving Performance of Solar Still by External Solar Panels and Cylindrical Parabolic Collector for Seawater Desalination

A. Bagheri[a], N. Esfandiari[a,*], B. Honarvar[a]

*[a]Department of Chemical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran; * Email: esfandiari_n@miau.ac.ir*

ARTICLE INFO

Received: 20 May 2019
Received in revised form: 15 Jun 2019
Accepted: 31 Jul 2019
Available online: 01 Aug 2019

Keywords:
solar energy; water desalination; solar panel; cylindrical parabolic collector

ABSTRACT

This study has examined the use of a cylindrical parabolic collector (CPC) and solar panels in the solar still unit for more heating. The results of two different setups were then compared so that the first setup was a simple solar still unit and the second setup was a solar still unit with solar panels and the CPC device. The depth of saline water in the basin was 30 mm. Based on the results, the use of solar panels, thermal elements and the CPC device had a major impact on the amount of water sweetening during the experiments. In this paper, the experiments presented a new method for increasing the amount of water. With regards to the newly presented method, there has been a significant increase in the amount of solar energy absorbed in the whole process of water sweetening. Experiments were performed at 300-watt and 400-watt solar panels and CPC devices with lengths of 1 m and 2 m. The cooling of solar panels was also investigated and compared with the process without cooling.

1. Introduction

Water is one of the most important materials on earth for the survival of beings. Drinking water is one of the essential requirements for human life [1]. Freshwater is an important source for the survival of all beings [2]. Since many of the water on Earth's surface are saline water, so over the years, many researchers have proposed water-sweetening methods. One of the methods of sweetening the water can be sweetened by the solar method. Small-scale solar distillation has had a significant share in the supply of drinking water in small and rural communities [3]. This is a sustainable method for producing fresh water [4]. In order to optimize the seawater sweetening, many researchers have made innovations. Different types of adsorbent materials and their effects on the performance of solar water desalination have been investigated [5].

In an experimental work, the effect of a condenser on the performance of the solar still was investigated [6]. The effect of the storage reservoir and black absorber on the solar still and the efficiency of this system have been investigated [7]. The positive effect of insulation as well as the use of a dual slope has been investigated [8]. The system efficiency increased by installing partitions on the solar still [9]. The proper insulation on solar still can increase solar still performance by reducing heat losses [10]. The solar still's productivity increased with increasing sunlight, as well as increasing the temperature of the test environment [11]. Maximum solar still solar energy efficiency is related to ambient temperature and solar radiation [12]. Solar dish concentrator (SDC) was used to increase productivity on solar still [13]. Wind speed has had a major effect on the efficiency of the solar distillation system [14]. The process of sweetening seawater can be done in different seasons. This solar still has the highest yield in the summer season [15].

One of the factors that influence the sweetening of water in the solar still is the water depth [16-17]. The occurrence of solar radiation greatly increases the basin temperature and improves system performance [18]. Making changes to the shape of the solar still unit is one of the things that has been used over the years to improve the process efficiency. Extensive surfaces and fins connected to energy absorber plates have been used to distribute the heat in different layers of water in the basin and thus increase the efficiency of the system [1]. Adsorbents can be used to increase the range of the system. Absorbent materials in the basin have increased the absorption of solar energy [19].

The parameters affecting freshwater production have been investigated by the use of an artificial neural network [20]. As well, investigation of the effective parameters on the efficiency has been conducted for the hybrid solar still system [21]. The efficiency of water sweetening has been enhanced through structural reforms on the solar still [22]. Another effective parameter on water sweetening that has been investigated was energy storage [23]. Researches reviewed the optimization of the solar still system [24]. The water sweetening has been examined by analyzing various methods [25].

Internal solar collector has also studied due to an effect on the efficiency of the solar system [26]. Solar sweeteners that work when using solar energy are suitable for remote areas [27]. The mathematical modeling of the seawater sweetening process is presented after analysis of equations for this process [28]. An investigation was performed on the parameters affecting the energy system for the production of fresh water and electrical energy to analyze them economically [29].

In this paper, solar still unit examines and compares the two processes of water desalination. In water sweetening systems, gaining more sweetened water has always been one of the most important goals for water sweeteners. The basic energy used in solar still devices is solar energy. This new method has used two other auxiliary devices (solar panels and CPCs) in addition to energizing the solar still device. The solar panels absorb the solar energy in the form of heat transfer by the help of a thermal element within saline water outside the solar still device to increase its temperature for the process of distillation in the solar still device. The CPC also raises the temperature of the saline water before entering the solar still. New devices introduced in this process were used in different modes to increase the absorption of solar energy. The results indicated that the use of new devices has increased the amount of sweetened water in the sweetening process.

2. Materials and Methods

The experimental equipment is located at Yasuj, Iran, at an altitude of 1850 meters above sea level with geographical coordinates of 30°40'6 " N and 51°35'17" E.

2.1. Experimental Setup 1

In the first design of the experimental system, the solar still unit was used with a double-slope. The basin was aluminum and the depth of water in this basin was 30 mm. The seawater was used for sweetening the water in this device. Dimensions of basin floor were 0.5 m * 1 m and the basin's height was 22 cm. For preventing the thermal leakage, 5 cm thick glass fiber insulation was used. The floor of the device was painted black in order to better absorption of energy. The thickness of the glass of the basin roof was 6 mm and was placed at a 30 ° angle from the horizons on the basin. An inlet pipeline has been installed to enter saline water from the saline water reservoir to the basin, and an outlet pipe was installed for the discharge of fresh water from the distilled fresh water preserved in the tank. The height of the solar still unit was 0.5 m from the ground. The representation of this process has been shown in Fig 1.

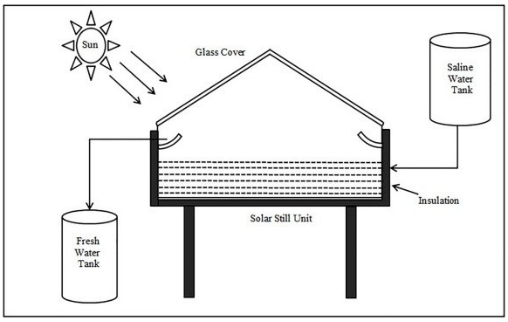

Figure 1. Schematic diagram of experimental setup 1.

2.2. Experimental Setup 2

The solar still unit, solar panels, and the cylindrical parabolic collector (CPC) were used in the second design. Design of this process can be observed in Fig 2. The processor used 300 W and 400 W solar panels. The charge-controller (CC) was also used to standardize the output power of solar panels which has used 10 A and 20 A charge controller in this process. The 250 W and 300 W heat elements have been used for heating the water. The batteries used in the process were two 12 v, 150 Ah batteries in the system. Two DC pumps with constant flow rates of 1 l/min and 10 l/min were also required for water pumping in the process. The insulation tank was completely insulated with glass wool. Due to the need for the system, three valves were used to open and close the flow. The desalinating system included a brine and insulated glass basin and a glass cover like the solar still unit available in the first experimental setup. The cylindrical parabolic collector was also made of stainless steel, in lengths of 1 m and 2 m, with a width of 1 m. The pipe was located at the focal length of this device with a diameter of 1 cm. The fresh water was stored in a separate reservoir. In order to complete this process, 30 liters of saline water was used to circulate the process. The amount of 15 liters of saline water, equivalent to 30 mm in the basin, was used in the process of sweetening. During the 1 hour, 15 liters of saline water was heated by the thermal element and the CPC device in the water heater. The saline water in the basin was evacuated every 1 hour from the basin and moved to the water heater for heating up with a constant flow of 10 l/min. The solar panels heated up the water in the water heater for 45 min, and then the water passed through a pump with a constant flow rate of 1 l/min from the center of the CPC device in 15 minutes. After heating in these devices, it was stored in the insulation tank at the end of 1 hour, again, this warm water entered the basin. The water flow was performed every hour. As a result, 15 liters of saline water were still heated and 15 liters of saline water were being sweetened in the solar still unit. As solar panels were expected to have the highest efficiency at 25 °C, they were used in some experiments using cold water to cool solar panels. At noon, when the temperature of these solar panels rises, direct solar water was sprayed directly onto these solar panels to maintain a temperature of 25 °C in these solar panels. In each experimental setup, several different scenarios have been used for testing. Table 1 demonstrates the specification of each of the experimental cases pertaining to each setup.

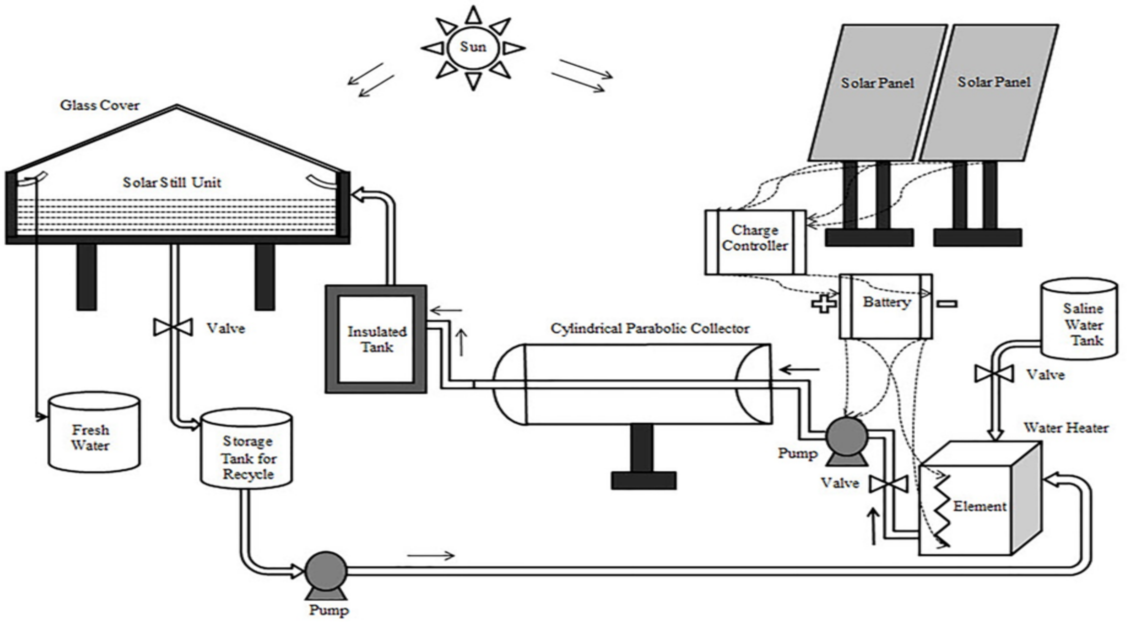

Figure 2. Schematic diagram of experimental setup 2.

Table 1. Details of Case studies in setup 1 and setup 2.

experimental Case	Solar Panel	CPC	Cooling Panel	Thermal Element	Battery	Charge Controller
Case 1	-	-	-	-	-	-
Case 2	300 W	1 m	-	250 W	2*12v*150Ah	10 A
Case 3	300 W	2 m	-	250 W	2*12v*150Ah	10 A
Case 4	300 W	2 m	✓	250 W	2*12v*150Ah	10 A
Case 5	400 W	1 m	-	300 W	2*12v*150Ah	20 A
Case 6	400 W	2 m	-	300 W	2*12v*150Ah	20 A
Case 7	400 W	2 m	✓	300 W	2*12v*150Ah	20 A

2.3. Experimental measurements

All experimental data were collected from 9 AM to 5 PM, in May 2018. The data about the weight of water, the glass cover temperature, the water temperature, the ambient temperature, the solar radiation on the ground and wind speed were measured during these experiments. Some instruments were also used to measure experimental data including a digital thermometer to measure temperature data, a solarmeter to measure the solar intensity, a digital anemometer to measure wind speed, and the calibrated cylinder to measure the amount of fresh water. The depth of water in the basin was 30 mm, and experimental measurements were performed every hour.

The movement and flow of water in the second experimental setup was occurred every hour. so that, 15 liters of saline water has been warmed and 15 liters of saline water was distilled into a solar still unit for one hour. Table 2 presents the accuracy of the measuring devices.

Table 2. accuracy for measuring device.

Device	accuracy
Anemometer	±0.1 m/s
Digital thermometer	±0.1 °C
Calibrated cylinder	±1 ml
Solar meter	±1 W/m^2

3. Results & Discussion

Experimental results were measured for 2 different setups. The saline water depth in the solar still was 30 mm which was equal to 15 liters of saline water. The first setup was the simple solar still unit and the second setup consisted of the solar panels, the CPC system and the circulation of saline water in the system for every one hour. Test data were measured in May 2018. The results of freshwater discharge have shown that the use of solar panel for supplying the energy of the thermal elements and the use of the CPC system led to an increase in obtaining the freshwater. Fig 3 indicates the amount of sunlight and wind speed on May 24th, 2018. As can be seen, the maximum radiation was 1062 W/m^2 at 12 PM. Table 3 represents meteorological data related to the days of the test in May 2018.

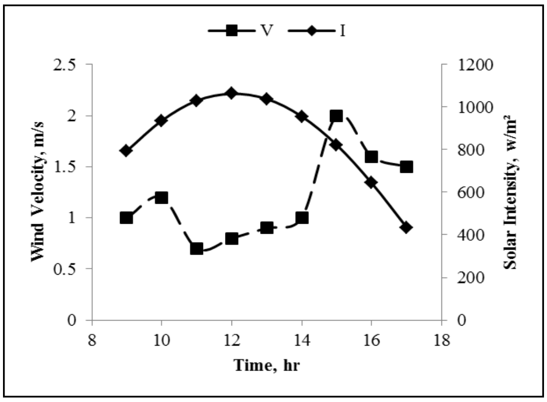

Figure 3. Hourly solar intensity and wind velocity on 24 May 2018.

3.1. Solar still temperature

The temperature was measured during different test hours at solar still unit. These experiments were performed to illuminate the different temperatures such as the water temperature in the basin, the glass cover temperature, and ambient temperature. The measurement of this study was carried out between 9 AM and 5 PM. Fig 4 and Fig 5 show the graphs and diagrams of received solar intensity data, water temperature, ambient temperature, and glass cover temperature over 2 days. Fig 4 shows the first setup and Fig 5 shows the Case 7 of the second setup. As shown in each graph, the amount of solar energy that has been received since 9 AM has started to rise and reached its peak at 12 PM, afterwards, the amount of solar radiation was gradually decreasing. The ambient temperature and water and glass cover temperatures began to rise from 9 AM and reached the peak at 1 PM for both setups shown in Fig 4 and 5. As the temperature pattern reveals, the temperature of the water, the ambient temperature, and the glass cover temperature gradually decreased after 1 PM. The main reason for rising the temperatures was the solar power absorption of the solar still unit, as well as using the CPC device.

As shown in both charts, the maximum difference of water temperature was in ambient temperature which was equal to 24.2 °C in Fig 4 and 37.5 °C in Fig 5 at 1 PM. A comparison of the two graphs has shown that the temperature of water at the second setup at 1 PM was higher than the first setup, which indicates the effectiveness of the solar panel system and the use of the CPC device.

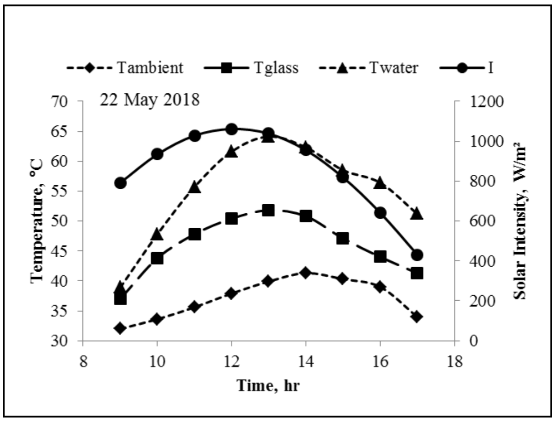

Figure 4. Hourly solar intensity, water temperature, ambient temperature and glass cover temperature on 22 May 2018.

Table 3. Meteorological data

					Time				
		9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
	Solar Intensity (W/m^2)	792	934	1028	1061	1038	955	819	642	432
22nd may	Wind (m/s)	0.7	0.7	1.1	1.7	0.9	1.8	0.9	1	1
	Ambient temperature (^{0}C)	32	33.6	35.6	37.9	39.9	41.3	40.3	39	34
	Solar Intensity (W/m^2)	792	936	1029	1062	1038	955	820	643	434
23rd may	Wind (m/s)	2	1.8	0.7	1.4	0.8	0.9	1	1.7	1
	Ambient temperature (^{0}C)	32.1	33.8	35.6	38	40.1	41.4	40.5	39.3	34.1
	Solar Intensity (W/m^2)	794	936	1030	1062	1038	956	822	643	435
24th may	Wind (m/s)	1	1.2	0.7	0.8	0.9	1	2	1.6	1.5
	Ambient temperature (^{0}C)	32.3	34	35.6	38.1	40.5	41.4	40.5	39.4	34.3
	Solar Intensity (W/m^2)	794	936	1031	1062	1038	956	821	643	435
25th may	Wind (m/s)	1.3	1.4	1.2	1.1	0.9	2	1.4	0.8	1.5
	Ambient temperature (^{0}C)	32.6	34	35.6	38.4	40.6	41.5	40.6	39.8	34.4
	Solar Intensity (W/m^2)	795	937	1033	1064	1039	957	820	644	436
26th may	Wind (m/s)	1.5	2	1.6	0.9	1.9	1.1	0.8	1	1.3
	Ambient temperature (^{0}C)	33	34.1	35.7	38.5	40.7	41.9	41	40.2	34.6
	Solar Intensity (W/m^2)	795	937	1034	1065	1039	955	821	645	436
27th may	Wind (m/s)	1.6	1.2	1	0.9	1.5	1.9	2	2	1.2
	Ambient temperature (^{0}C)	33.1	34.5	36.1	38.9	40.8	42	41.3	40.2	34.7
	Solar Intensity (W/m^2)	796	937	1035	1065	1039	956	821	644	437
28th may	Wind (m/s)	0.7	0.7	0.7	1	0.9	1.2	1.3	0.7	1
	Ambient temperature (^{0}C)	33.3	34.7	36.4	39	40.9	42.2	41.6	40.4	35

Fig 6 and Fig 7 show the water temperature and glass cover at different hours, respectively, between 9 AM and 5 PM. The temperatures in these two charts were measured in 7 different modes. In Fig 6, the water temperature in the first and second setups was measured in different states. The Case 2 to Case 7 were related to the second setup and the Case 1 was for the first setup. As shown in Fig 6, Case 7 had the highest water temperature compared to other cases which involved the stronger solar panels, a 2 m long CPC device, and the solar panel cooling system. In Fig 7, the Case 7 had the highest glass cover temperature as well as other cases. The temperature differences between the various cases indicated the effect of different solar panels, the effects of the CPC device, and the solar panel cooling system. The lowest temperature was related to Case 1 pertaining to the first setup. As can be seen, the maximum temperatures of both Fig 6 and Fig 7 were at 1 PM.

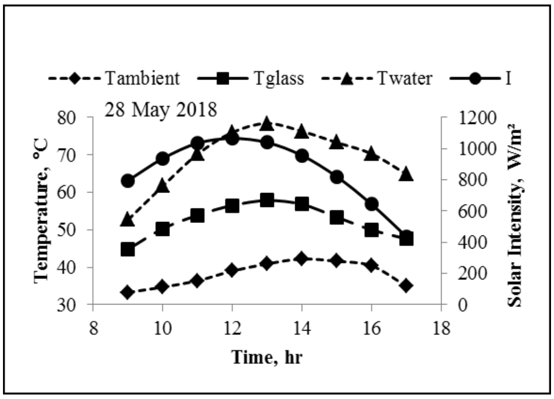

Figure 5. Hourly solar intensity, water temperature, ambient temperature and glass cover temperature on 28 May 2018.

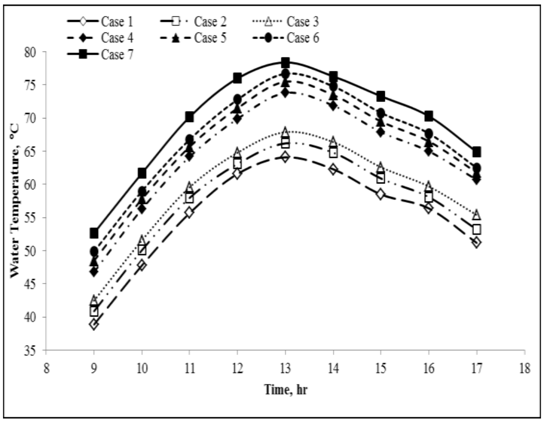

Figure 6. Hourly water temperature in different cases.

3.2. Fresh water production

Fig 8 shows the amount of fresh water in the experimental setups every hour. The measurement of experimental data began at 9 AM and continued until 5 PM. The results have shown that the amount of fresh water has risen gradually to 9 AM and peaked at 2 PM. Fig 8 shows different experimental cases. The largest amount of sweetened water was in 400 W solar panel cases, along with a 2m-long CPC device and the solar panel cooling system.

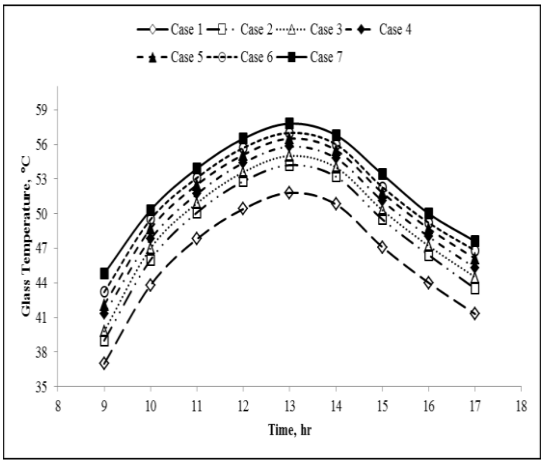

Figure 7. Hourly glass temperature in different cases.

The depth of water in the solar still unit was 30 mm. The greatest amount of desalinated water between different cases was related to the Case 7, which was measured at 2 PM and was equal to 0.669 kg. The amount of water swept was 0.378 kg at 2 PM in the first setup relating to Case 1.

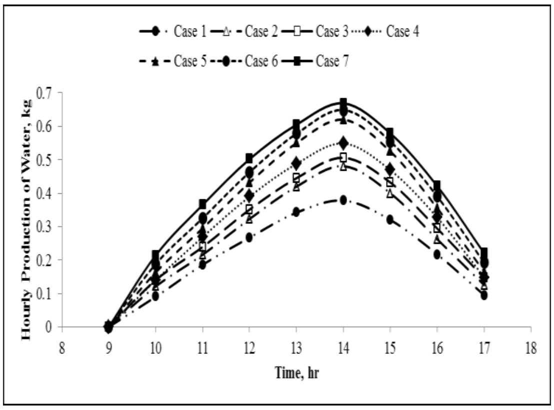

Figure 8. Hourly production of fresh water for different cases.

Fig 9 shows the rate of accumulated fresh water in both two experimental setups and the results of all cases. The largest amount of freshwater was 3.375 kg for Case 7 during all hours of the day. The lowest amount of fresh water in the second setup was 2.348 kg for Case 2. The amount of water desalinated in Case 1 of the first setup was 1.895 kg over all hours of the day.

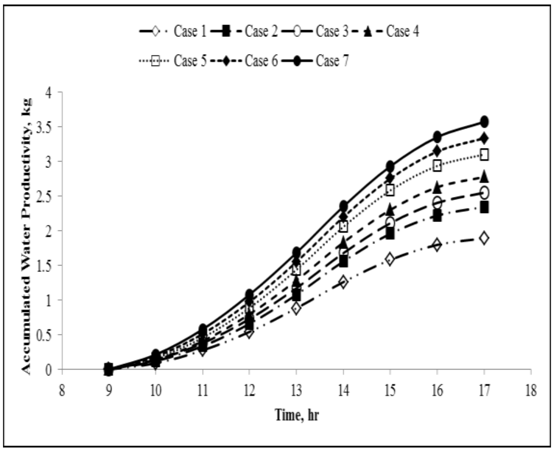

Figure 9. Accumulated production of fresh water for different cases.

Fig 10 indicates the amount of water in various cases. According to the results, the lowest amount of freshwater was related to the Case 1, where due to the lack of solar panel, the CPC device, and the lack of cooling system, the amount of water was reduced to the fresh water. The effect of using a solar panel with a larger power and longer CPC device and cooling system on the amount of sweetened water have been shown in different cases. The absorption of solar energy by the solar panel and the CPC device led to a greater thermal uptake of water by the thermal element, and rising water temperatures led to an increase in evaporation and amount of fresh water.

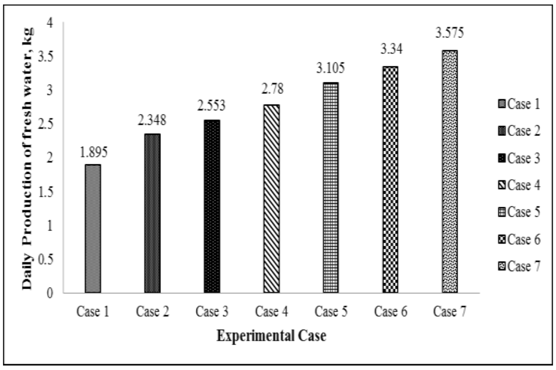

Figure 10. Daily production of fresh water in different experimental cases.

4. Conclusions

Two different experimental setup functions were investigated in solar still unit. The Case 1 was for the first setup and Case 2 to the Case 7 were for the second setup. The largest amount of water sweetened was 3.375 kg per day for the Case 7. Case 7 has used 400 W solar panel, 300 W thermal element, 2 m-long CPC device having 30 mm water depth in the basin. Case 1 had the lowest amount of water sweetened at 1.895 kg during the test. The highest temperature for the Case 7 was 78.4 °C at 1 PM. During the tests, it was found that more solar power absorbed by more powerful solar panels and a longer CPC device would increase the performance of solar still unit. Using the cooling process of solar panels also reduces the temperature of solar panels, so increasing the performance.

References

[1] Jani, H.K. and Modi, K. V. (2018). A review on numerous means of enhancing heat transfer rate in solar-thermal based desalination devices. Renewable and Sustainable Energy Reviews, 93(April), 302–317.

[2] Sathyamurthy, R., El-Agouz, S.A., Nagarajan, P.K., Subramani, J., Arunkumar, T., Mageshbabu, D., Madhu, B., Bharathwaaj, R. and Prakash, N. (2017). A Review of integrating solar collectors to solar still. Renewable and Sustainable Energy Reviews, 77(October), 1069–1097.

[3] Sellami, M.H., Belkis, T., Aliouar, M.L., Meddour, S.D., Bouguettaia, H. and Loudiyi, K. (2017). Improvement of solar still performance by covering absorber with blackened layers of sponge. Groundwater for Sustainable Development, 5, 111–117.

[4] Ayoub, G.M. and Malaeb, L. (2014). Economic feasibility of a solar still desalination system with enhanced productivity. Desalination, 335(1), 27–32.

[5] Abdallah, S., Abu-Khader, M.M. and Badran, O. (2009). Effect of various absorbing materials on the thermal performance of solar stills. Desalination, 242(1–3), 128–137.

[6] Hassan, H. and Abo-Elfadl, S. (2017). Effect of the condenser type and the medium of the saline water on the performance of the solar still in hot climate conditions. Desalination, 417(February), 60–68.

[7] El-Agouz, S.A. (2014). Experimental investigation of stepped solar still with continuous water circulation. Energy Conversion and Management, 86, 186–193.

[8] Altarawneh, I., Rawadieh, S., Batiha, M., Al-Makhadmeh, L., Alrowwad, S. and Tarawneh, M. (2017). Experimental and numerical performance analysis and optimization of single slope, double slope and pyramidal shaped solar stills. Desalination, 423(February), 124–134.

[9] Rashidi, S., Abolfazli Esfahani, J. and Rahbar, N. (2017). Partitioning of solar still for performance recovery: Experimental and numerical investigations with cost analysis. Solar Energy, 153, 41–50.

[10] Selvaraj, K. and Natarajan, A. (2018). Factors influencing the performance and productivity of solar stills - A review. Desalination, 435(January), 181–187.

[11] Abujazar, M.S.S., Fatihah, S. and Kabeel, A.E. (2017). Seawater desalination using inclined stepped solar still with copper trays in a wet tropical climate. Desalination, 423(March), 141–148.

[12] Morad, M.M., El-Maghawry, H.A.M. and Wasfy, K.I. (2017). A developed solar-powered desalination system for enhancing fresh water productivity. Solar Energy, 146, 20–29.

[13] Omara, Z.M. and Eltawil, M.A. (2013). Hybrid of solar dish concentrator, new boiler and simple solar collector for brackish water desalination. Desalination, 326, 62–68.

[14] Hamadou, O.A. and Abdellatif, K. (2014). Modeling an active solar still for sea water desalination process optimization. Desalination, 354, 1–8.

[15] Ibrahim, A.G.M., Rashad, A.M. and Dincer, I. (2017). Exergoeconomic analysis for cost optimization of a solar distillation system. Solar Energy, 151, 22–32.

[16] Singh, H.N. and Tiwari, G.N. (2004). Monthly performance of passive and active solar stills for different Indian climatic conditions. Desalination, 168(1–3), 145–150.

[17] Sathyamurthy, R., Kennady, H.J., Nagarajan, P.K. and Ahsan, A. (2014). Factors affecting the performance of triangular pyramid solar still. Desalination, 344, 383–390.

[18] Omara, Z.M., Eltawil, M.A. and ElNashar, E.A. (2013). A new hybrid desalination system using wicks/solar still and evacuated solar water heater. Desalination, 325, 56–64.

[19] Ouar, M.L.A., Sellami, M.H., Meddour, S.E., Touahir, R., Guemari, S. and Loudiyi, K. (2017). Experimental yield analysis of groundwater solar desalination system using absorbent materials. Groundwater for Sustainable Development, 5, 261–267.

[20] Zarei, T. and Behyad, R. (2019). Predicting the water production of a solar seawater greenhouse desalination unit using multi-layer perceptron model. Solar Energy, 177(July 2018), 595–603.

[21] Shukla, D. L. and Modi, K. V. (2019). Hybrid solar still – Liquid desiccant regenerator and water distillation system. Solar Energy, 182(February), 117–133.

[22] Refat, A., Elbar, A. and Hassan, H. (2019). Experimental investigation on the impact of thermal energy storage on the solar still performance coupled with PV module via new integration. Solar Energy, 184(March), 584–593.

[23] Mahmoud, A., Fath, H., Ookwara, S. and Ahmed, M. (2019). Influence of partial solar energy storage and solar concentration ratio on the productivity of integrated solar still / humidification-dehumidification desalination systems. Desalination, 467(April), 29–42.

[24] Rehman, N. (2019). Optical-irradiance ray-tracing model for the performance analysis and optimization of a single slope solar still. Desalination, 457(October 2018), 22–31.

[25] Mehrabian-Nejada, H., Farhangi, B. and Farhangi, S. H. (2017). Application of PV and Solar Energy in Water Desalination System. Journal of Solar Energy Research (JSER), 22, 13–18.

[26] Abene, A., Rahmani, A. and Zahzouh, Z. (2017). Improving the Basin Type Solar Still Performances Using an Internal Solar Collector. Journal of Solar Energy Research (JSER), 23, 13–19.

[27] Kazemi, H., Fallah, K. and Hosseini, M. J. (2017). A Review of Solar Energy Driven HDH and Solar Still Desalination Technologies. Journal of Solar Energy Research (JSER), 23, 79–87.

[28] Fazeli, A. and Naseri, A. (2018). Mathematical modeling of solar still for desalination of seawater. Journal of Solar Energy Research (JSER), 3(1), 49–55.

[29] Samadzadeh Baghani, S., Raoufpanah, A. R. and Gholamian, E. (2018). Thermodynamic and exergoeconomic analyses of a solar based energy system for the provision of heating, electricity and fresh water. Journal of Solar Energy Research (JSER), 3(2), 83–90.