Fresnel lens solar concentrator to utilize the Extreme solar Intensity in solar still receivers

Ahmed H. Obaida, Assaad Al Sahlania, Adel A Eidan

Al-Furat Al-Awsat Technical University, Engineering Technical College of Al-Najaf, 31001, Iraq
Al-Furat Al-Awsat Technical University, Najaf Technical Institute, 31001, Iraq

ahmed.mm9696@gmail.com

Abstract.

This work presents an experimental study of solar distillation using a solar still receivers with a Fresnel lens concentrate. Two models of a cylindrical glass solar still (10 cm and 20 cm height) are used. The solar stills were placed in the focus of the lens to investigate the productivity of different models. The Fresnel lens concentrator is controlled to track the solar light and maintain the focal stationery. The results showed that the largest productivity for the solar still is (0.5 L/6hour) when the average solar radiation is 1280 W/m² and (0.5 L/6hour) when the average solar radiation is 1165 W/m² for (10cm and 20cm) solar still height respectively. The result showed that the productivity of the freshwater increased as the solar radiation increased. On the other hand, the productivity effect of the height of the solar still and other variables is less than effect amount of solar radiation. Also, the results showed that Fresnel lens concentrator can be efficiently used to provide fresh water during wintertime under Iraqi weather

1. Introduction

Water is essential for life for plants, animals and humans. The demand for water for domestic, industrial and agricultural purposes increases significantly due to the large population growth. It is estimated that more than two-thirds of the Earth's surface is covered with water, 97% of the Earth's water is salt and 3% is fresh water [1]. Due to the lack of traditional energy sources in some areas or being expensive, water purification by distillation is one of the most primitive types of water treatment. The treatment process consists of two stages, the evaporation of water by solar energy and condensation of steam to produce pure water.

Several studies have been done to investigate the effectiveness of a different type of receiver with a solar concentrator, yet only a limited number have been mentioned in the literature that examined the effect of using a different type receiver with a Fresnel lens concentrator. Kabeel, A. E., and Mohamed Abdelgaied.[2] examined the performance of a
cylindrical parabolic concentrator with focal pipe-coupled with a developed solar still with (oil heat exchanger, Phase Change Material (PCM)). In order to improve the freshwater productivity. To determine the enhancement in freshwater productivity under the same environmental conditions a comparison between a developed solar still and the conventional solar still is carried. The experimental results indicated that the freshwater productivity for the established solar was still approximately 10.77 L/m² day, while its value is recorded 4.48 L/m² day for conventional solar still. In a similar manner, Zou, Bin, et al. [3] investigated a special small-sized parabolic trough solar collector (PTC), to heat water in cold areas. The PTC consists of a parabolic shape with a sheet of reflective mirror and a receiver tube at the focal line of the concentrator. The result showed that the thermal efficiency of the PTC was 67% even under the condition of solar radiation less than 310 W/m². On the other hand, Palavras, I., and G. C. Bakos. [4] developed the characteristics of a satellite dish solar concentrator, which equipped with a polymer mirror as a solar reflective surface. The dish solar concentrator was connected to a solar tracking system. The system produced a temperature of more than 300°C in the focus.

Sedaghat, Ahmad, et al. [5] investigated the idea found by Palavras, I., and G. C. Bakos. [4] by using a parabolic dish collector to improved solar desalination system which utilizes solar tracking system and thermoelectric cooler to produce distilled water from sea water. The solar system consists of solar collector dish to collect and reflect the solar energy to a still tank that has the sea water. The result showed that applying the thermoelectric cooler and sun tracking system simultaneously, 2.6 L/day of distilled water was produced during eight hours working period compared with only 1.4 L/day production when none of these elements was used. Similarly, Arunkumar, Thirugnanasambantham, et al. [6] added the phase change material (PCM) to increase the efficiency and distillate yield in the concentrate-coupled hemispheric solar basin still. Two operating modes were experimentally studied: (1) one-slope solar still without the PCM effect, and (2) one-slope solar still with the PCM effect. The result show that the thermal storage effect in the concentrate-coupled hemispheric solar basin still increases productivity by 26%. It was concluded that due to the still integrated with PCM the efficiency improved considerably. For instant water heating Sagade, Atul A [7] used the parabolic dish collector. The solar parabolic dish collector consists of a novel truncated cone-shaped helical coiled receiver made of copper at the focal point, and in this paper describes the effect of variation of mass flow rate on the efficiency of the prototype parabolic dish water heater.
Another device to manufacture solar concentrator was introduced by Sonneveld, P. J., et al. [8] who presented a linear Fresnel lens with a concentrated photovoltaic (CPV) system. The goal of the work is to reduce global warming in the summer to reduce the need for cooling. The results obtained show a promising method for lighting and temperature control of a greenhouse system and building roofs, supplying both electricity and heat at the same time. Moreover Cheng, Tsung Chieh, Chao Kai Yang, and I. Lin. [9] use a Fresnel lens with the sun tracking device and two optical cells are installed to supply the tracking device with electrical power. The device is used in solar thermal applications (such as the Stirling engine). The results showed that when focusing the sunlight on the heating head of the Stirling engine, temperatures of more than 1000 °C were obtained. Hussain, M. Intiaz, Asma Ali, and Gwi Hyun Lee. [10] examined the two types of Fresnel lens collectors, linear Fresnel lens (LFL) and circular Fresnel lens (CFL), to compares the thermal performance characteristics. The result shows that the (CFL) performance is 7-12% higher than the (LFL) collector. Sierra, Cristina, and Alfonso J. Vazquez. [11] investigated the Fresnel lens concentrator to achieve higher solar energy density and very high temperatures (1500–2000 K) corresponding to (1227–1727 K). Temperatures produced in this work are useful for surface modifications of metallic materials. Valmiki, M. M., et al. [12] presented the Fresnel lens as a prototype of a solar cooking stove useful for solar cooking and heating. The stove has a fixed heat-region at the focal point of the lens in which the solar tracking device rotates the lens around its focal point. The results showed the possibility of obtaining temperatures up to 300 °C on the stovetop surface. The heat can be used for cooking and internal heating.

This work presents an experimental study about using Fresnel lens solar concentrator to utilize the extreme temperature at the focal of the concentrator to produce freshwater under Iraqi weather and this paper is organized as follows; section two illustrates the experimental rig setup, and section three contains the experimental results and discussion and finally, the concluding remarks are in section four.
2. Experimental Setup

The experimental rig consists of three main parts, namely the solar concentrator, the sun tracking control part, and solar still receiver as follows:

2.1 Fresnel lens solar concentrator

The solar concentrator is a mechanism that allows a two-axis free motion to track the sun during daylight. The Fresnel lens is to be mounted using a frame such that the concentrating focus stays stationary during the motion holding frame. A square Fresnel lens with the following specification is used (dimensions: 520X520mm, Focal Length: 620 mm, Thread Distance: 0.5mm, Thickness: 3mm, Material: Optical PMMA). Figure (1) illustrates the details of the solar concentrator components.

![Experimental setup and schematic diagram of the Fresnel lens solar concentrator](image)

Figure 1: Experimental setup and schematic diagram of the Fresnel lens solar concentrator

2.2 Sun tracker control system

The sun path can be tracked efficiently by sensing sunlight to specify the position of the sun. Another way to track the sunlight efficiently is to calculate the position of the sun in the sky via calculation of altitude and azimuth angles for a given region, time and date. In this work, the second approach is used. Where a control system is implemented to track the sunlight. The control system consists of a controlling circuit represented by an Arduino unit and two stepper motors to apply the motion to the tracking frame, one motor to move the frame vertically and the other one is to rotate the circular base horizontally. The Arduino unit is programmed such that the altitude and azimuth angles are calculated simultaneously based on the given date and time. The control system is initiated by feeding the date and time beforehand.
2.3. Solar still receiver

The solar still, used in this experiment, is a model placed in the focus of the Fresnel lens concentrator. Two models of a cylindrical glass solar still (10 cm and 20 cm height) were manufactured from a cylinder glass with an angled italic 32° glass upper surface, the diameter of the cylinder is 13 cm as shown in Figure 2 (a and b). It is placed in the focus of the lens to receive the refracted solar radiation from the lens. The still was connected with two plastic tubes, the first to inlet saline water and the second tube to outlet freshwater. An aluminum square water container (9x9cm) and height 1 cm, was placed at the still base to absorb the concentrated heat energy. The test was carried out by placing the solar still in the focus of the lens.

Figure 2: Cylindrical solar still; (a) 10 cm height, (b) 20 cm height
3. Results and discussion

The experimental tests are performed with local weather conditions in Najaf city-Iraq (44 °E, 31 °N) [13]. Cylindrical glass solar stills with different heights, 10 cm, and 20 cm, are used, where in total, the study included six experiments. For the (10 cm height) solar still the experiments were performed three times in three days with similar weather conditions; and a similar procedure was followed for 20 cm height solar still, and the following is a detailed illustration of the experiments:

3.1 Solar still of 10 cm in height

The experiments were conducted during the period 25th-27th of January 2020 from 9am to 3pm, where the ambient temperature ranged from 5 °C to 15 °C and the solar radiation ranged from 1150 W/m² to 1347 W/m², as shown in Figure 3 (a and b). The three experiments were performed by using cylindrical glass solar still and can be summarized as follows:

| Run | Date (2020) | Weather Conditions | Ambient Temp. Min-Max °C | Solar Radiation Min - Max W/m² | Productivity ml |
|-----|-------------|--------------------|--------------------------|-------------------------------|----------------|
| 1   | Jan-25      | cloudy             | 7-13                     | 170-1316                      | 200            |
| 2   | Jan-26      | clear              | 5-15                     | 1160-1347                     | 500            |
| 3   | Jan-27      | clear              | 8-16                     | 1150-1307                     | 490            |

The results are summarized in table (1) are illustrated in figures 3 (a and b) and 4, where the Fresnel lens provides sufficient heat to generate steam for distillation from refracted solar radiation. The change in the amount of solar radiation affects the productivity of the freshwater. Figure (4) shows the relation between the average solar radiation and total productivity of the freshwater. The greatest amount of freshwater production was on Jan-26 when the solar radiation was at its highest where the sky was clear (no clouds or dust). While the productivity of freshwater decreases when the intensity of the solar radiation decreases due to the unclear sky or cloudy weather, as it can be seen clearly where the test was performed on Jan-25 the productivity of fresh water was only 200 ml, however this is not always true since most of the time the weather is sunny in Iraq.
Figure 3: Climatic conditions under which the experiments have been conducted for solar still with 10 cm height: (a) ambient temperature, and (b) solar radiation, versus time.
3.2 Solar still of 20 cm in height

The experiments were conducted during the period 30\textsuperscript{th} of January through Feb-1st - 2020 from 9am to 3 pm, where the ambient temperature ranged from 8 °C to 21 °C and the solar radiation ranged from 980 W/m\textsuperscript{2} to 1301 W/m\textsuperscript{2}, as shown in Figure 5 (a and b). The three experiments were performed by using cylindrical glass solar still and can be summarized as follows:

Table (2) Summary of the experimental results for solar still of 20 cm in height

| Run | Date (2020) | Weather Conditions | Ambient Temp. Min-Max °C | Solar Radiation Min - Max W/m\textsuperscript{2} | Productivity ml |
|-----|-------------|--------------------|--------------------------|--------------------------------------|---------------|
| 1   | Jan-30      | cloudy             | 10-19                    | 635-1010                              | 350           |
| 2   | Jan-31      | clear              | 12-21                    | 980-1278                              | 500           |
| 3   | Feb-1       | cloudy             | 8-16                     | 420-1301                              | 490           |
The results are summarized in table (2) are illustrated in figures 5 (a and b) and 6. Where the greatest amount of fresh water produced on Jan-31 is 500 ml, and the lowest amount produced on Jan-30 is 350 ml. This difference is caused by the variation in the intensity of solar radiation, which influences the evaporation process. Therefore, the amount of freshwater production is directly proportional to the intensity of solar radiation.

Figure 5: Climatic conditions under which the experiments have been conducted of solar still with 20 cm height: (a) ambient temperature and (b) solar radiation, versus time.
In the experiments, focus in the main parameter investigated was the height of the solar still, we nominate the two values of the height 10 and 20 cm, respectively which implies the change of condensation area where the side area is doubled. As previously mentioned, the experiments were performed in six consecutive days so that the other contributing parameters, such as ambient temperature and solar radiation, will be in the same range. The results showed that the productivity of the solar still increased as the solar radiation increased. On the other hand, productivity is influenced by the height of the solar still and ambient temperature. However, the main parameter that affects productivity is the amount of solar radiation which has significant influence on the performance of solar still.

Figure 6: Total productivity and average solar radiation for solar still with 20 cm height.
4. Conclusions

The intensive solar radiation is used in Najaf city-Iraq to water distillation by means of a Fresnel lens concentrator. The solar concentrator system consists of a sun tracker control system and Fresnel lens concentrator frame as the frame moves freely in two axes to track the sun and focus the solar radiation on a heat exchanger. The tracking system consists of a control circuit represented by Arduino and two stepper motors to adjust the position of the Fresnel lens focal by moving the motors accordingly. The focus produced by the Fresnel lens is to be maintained stationary at a fixed position to ensure continuous heat flow to the solar still. Two models of a cylindrical glass solar still (10 cm and 20 cm height) are used. The experimental tests were performed during arbitrary days of January and February 2020. A largest productivity for the solar still is (0.5 L/6 hour) when the average solar radiation is 1280 W/m² and (0.5 L/6 hour) when the average solar radiation is 1165 W/m² for (10 cm and 20 cm) solar still height respectively. It is promising idea for using Fresnel lens to water distillation.

5. Reference

1. DURKAIESWARAN, P.; MURUGAVEL, K. Kalidasa. Various special designs of single basin passive solar still–A review. Renewable and Sustainable Energy Reviews, 2015, 49: 1048-1060.
2. KABEEL, A. E.; ABDELGAIED, Mohamed. Observational study of modified solar still coupled with oil serpentine loop from cylindrical parabolic concentrator and phase changing material under basin. Solar Energy, 2017, 144: 71-78.
3. ZOU, Bin, et al. An experimental investigation on a small-sized parabolic trough solar collector for water heating in cold areas. applied energy, 2016, 163: 396-407.
4. PALAVRAS, I.; BAKOS, G. C. Development of a low-cost dish solar concentrator and its application in zeolite desorption. Renewable Energy, 2006, 31.15: 2422-2431.
5. SEDAGHAT, Ahmad, et al. Experimental and theoretical analysis of a solar desalination system improved by thermoelectric cooler and applying sun tracking system. Energy Engineering, 2018, 115.6: 62-76.
6. ARUNKUMAR, Thirugnanasambantham, et al. The augmentation of distillate yield by using concentrator coupled solar still with phase change material. Desalination, 2013, 314: 189-192.
7. SAGADE, Atul A. Experimental investigation of effect of variation of mass flow rate on performance of parabolic dish water heater with non-coated receiver. *International Journal of Sustainable Energy*, 2015, 34.10: 645-656.

8. SONNEVELD, P. J., et al. Performance of a concentrated photovoltaic energy system with static linear Fresnel lenses. *Solar Energy*, 2011, 85.3: 432-442.

9. CHENG, Tsung Chieh; YANG, Chao Kai; LIN, I. Biaxial-Type Concentrated Solar Tracking System with a Fresnel Lens for Solar-Thermal Applications. *Applied Sciences*, 2016, 6.4: 115.

10. HUSSAIN, M. Imtiaz; ALI, Asma; LEE, Gwi Hyun. Performance and economic analyses of linear and spot Fresnel lens solar collectors used for greenhouse heating in South Korea. *Energy*, 2015, 90: 1522-1531.

11. SIERRA, Cristina; VAZQUEZ, Alfonso J. High solar energy concentration with a Fresnel lens. *Journal of materials science*, 2005, 40.6: 1339-1343.

12. VALMIKI, M. M., et al. A novel application of a Fresnel lens for a solar stove and solar heating. *Renewable Energy*, 2011, 36.5: 1614-1620.

13. HACHIM, Dhafer Manea; ALSAHLANI, Assaad; EIDAN, Adel A. Measurements of wind and solar energies in Najaf, Iraq. *Advances in Natural and Applied Sciences*, 2017, 11.9: 110-117.