Experimental Evaluation of Fresnel’s lens solar concentrator in Iraq

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Abstract. This work presents an experimental study to utilize extreme sun rays temperature via Fresnel's lens concentrate using a solar tracking system. The experimental rig consists of a freely rotating two-axis frame that is controlled by an electronic circuit that implements Arduino and stepper motors as a control system to adjust the position of the Fresnel's lens focal by moving the motors accordingly. The focal of the sunray is to be maintained stationary at a fixed position to ensure continuity of heat flow on the absorption plate. The experimental results showed that the focal temperature reached as high as 422° C when the ambient temperature was 17° C. Observing the results, gives an idea of promising ability to use the Fresnel's lens in a wide range of renewable energy applications such as heating and heat storage.

1. Introduction
Solar energy is sustainable and so will never run out energy. Fossil fuels used in many energy sources are limited and decreased; in addition, it pollutes the environment as a result of the emissions of the combustion. Solar energy is one of the alternative solutions with its great potentials. Solar Energy can be utilities in many different forms. One of the forms is the solar concentrator where solar concentrators are devices that focus the sunlight from a large area, by reflection or refraction using parabolic or lens, respectively, on a small receiver. Such action increases the intensity of solar radiation on surface of the small receiver. As the sun change its relative location, the solar concentrators have to track the sun to be the solar radiation is directed on the absorption surface. Many studies have been accomplished to investigate the effectiveness of solar tracking system with solar concentrator, yet only a limited number were mentioned in the literature that examined the effect of using solar tracking system with Fresnel lens concentrator. Zhai, H., et. al.(2010) [1] used linear Fresnel lens solar concentrator with evacuated tube absorber employing one-axis solar tracking system. The results showed that the thermal efficiency of this solar collector is higher than the commonly used flat-plate or evacuated tube solar collectors. Hussain,M.I., et. al.(2015) [2] examined two types of Fresnel lens collectors: linear Fresnel lens (LFL) and spot Fresnel lens (SFL), both types had the same surface area. the collectors were equipped with a dual-axis solar tracking system. They found that the (SFL) performance is 7-12% higher than the (LFL) collector. Sierra,C., et. al.(2005) [3] investigated the Fresnel lens concentrator of solar energy to achieve higher solar energy density and very high temperatures (1500–2000 K), such temperatures are useful for surface modifications of metallic materials. Hussain M.I,&Lee,G.H. (2015). [4] used Fresnel lenses and U-shaped solar energy receiver with concentrated photovoltaic thermal (CPV/T), the system was equipped with a two-axis solar tracking system. The results showed that the energy released depends on the ambient temperature and the intensity of the solar radiation. Xie,W.T., et. al.(2011) [5] used a Fresnel lens solar collector
with different configurations of cavity receiver (conical, cylindrical, and spherical). The study showed that, among the three types of the receivers, the best shape was the cone, which has the highest thermal efficiency and the lowest heat loss. Palavras, I., & Bakos, G.C., (2006) [6] 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 obtained a temperature of more than 300°C in the focus. Badran, A.A., et. al. (2010). [7] used a parabolic dish solar collector, the dish was covered by aluminum foil as a solar reflective material. The device was worked in two ways: the first by using a bare bowl, and the second by using a bowl inside a glass container. The results show that using the bowl inside the glass container is reduces the boiling time from 60 to 40 minutes per 7 kg of water and increases cooking energy by 275%. Abu-Malouh, R., et. al. (2011) [8] used a parabolic dish thermal collector to construct a solar cooker. The collector was equipped with a dual-axis solar tracking system. When temperature of the ambient was 32°C, the pan developed temperatures of more than 93°C. Bakos, G.C., et. al. (2001) [9] used a parabolic trough solar collector (PTC) for steam generation. The system had the ability to track the sun's daily path. The results showed that the efficiency of the PTC is a function of the pipe length, the diameter of the pipe, the intensity of the solar radiation, and the heat transfer fluid flux. In this work, a Fresnel’s lens is implemented to study the thermal characteristic of concentrated sunlight focus during winter days in Najaf city- Iraq on steel and aluminum plate. By knowing the amount of energy and level of temperatures range provided by focal of Fresnel’s lens, the work can be extended to address many different solar energy applications.

2. Theory

The solar tracking system is a device that tracks the sun wherever it goes in the sky with the payload on it. This payload may be a solar cell or solar concentrator. The Solar tracking system can be categorized, dependent on their type of signal operation, as either closed-loop or open-loop type.

2.1 Closed-loop tracking:

This type tracks the sun using sensors that produces signals relative to the intensity of the sunlight. In general, this type consists of a column with a specific shape mounted with four individual solar sensors. The sensors is placed parallel to the central axis of the solar collector. In addition, the closed-loop type includes a control circuit that collects the signals from the four individual sensors and sends them to the controller. The controller makes a differential between the amounts of solar radiation. The controller then sends a signal to the motors to monitor the position of the solar collector until the individual sensors reaches the balance situation. Beshears, D. L. et. al. (2003) [10]

2.2 Open-loop tracking

Rather than using sensors, the sun position in the sky is determined by computing the values of the altitude and the azimuth coordination of the sun position. The position of the sun is calculated with respect to the earth, where the collector is to be installed, by using the local time, date, longitude, latitude and time zone (explained in details in the following section), Then, the values of the coordination are entered into controller which sends the required instruction signal to the motors to track the sun. Beshears, D. L. et. al. (2003) [10]

2.3 Solar angles

The position of the sun is calculated at any time for a specific location on the earth through the angles of solar altitude angle (α) and solar azimuth angle (Z). The solar altitude angle (α) is calculated mathematically for each month, day and hour of the year using Eq. (1) [11]:

\[
\sin(\alpha) = \sin(L) \sin(\delta) + \cos(L) \cos(\delta) \cos(h) \quad (1)
\]

Where (α) is the solar altitude angle,

L is the local latitude,

δ is the solar declination angle,

h is the hour angle.
Solar azimuth angle (Z)
The solar azimuth angle (Z) is calculated mathematically for each month, day and hour of the year using Eq. (2): [10]

\[ \sin(Z) = \frac{\cos(\delta) \sin(h)}{\cos(\alpha)} \]  

3. Experimental Setup

The experimental setup consists of two main parts, namely the solar concentrator and the sun tracking control part as follows:

3.1 Fresnel’s lens solar concentrator

The solar concentrator is a mechanism that allows a two-axis free motion to track the sun during daylight. The Fresnel's lens are to be mounted using a frame such that the concentrating focus stays stationary during the motion holding frame. The size of Fresnel’s lens plays crucial role in the amount of heat produced at the focal spot. Large Fresnel’s lens (1000 x 1000 mm) can produce 1000°C which is extremely high temperature, also it is manufactured in some specific dimensions, namely (1000 x 1000 mm) and (520X520mm). In this work, the smaller available Fresnel’s lens is chosen, where a square Fresnel’s lens with the following specification is used (dimensions: 520X520mm, Focal Length: 620 mm, Thread Distance: 0.5mm, Thickness: 3mm, Material: Optical PMMA). The focal temperature is rather suitable to moderated solar applications in Iraq. Figure (1) illustrates the details of the solar concentrator components.

![Figure 1. Experimental setup and schematic diagram of the Fresnel’s lens solar concentrator](image)

3.2 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 an open-loop 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.

4. Results and discussion

The experimental tests are performed with local weather conditions in Najaf city- Iraq. Where square plates (10 X 10 cm) made of different metals are used to study the thermal characteristics of the heat focal provided by Fresnel's lens. Two different plates are used, namely steel and aluminum. To study the temperature distribution on the plate, five thermocouples type-K are installed on the plate surface as shown in Fig. (2) the temperature measurement is recorded by means of a digital data logger. The experiment test is performed in Dec-9-2019. The results are illustrated in Figures (3), where the
The highest recorded temperature is 422 °C at the center of the plate and 134 °C at the edge when the intensity of the solar radiation is 1140 W/m² and the ambient temperature is 17 °C.

![Absorbing plate with the focal of the Fresnel's lens and the thermocouples](image)

**Figure 2.** Absorbing plate with the focal of the Fresnel’s lens and the thermocouples

It is clear from Fig. (3) that the temperatures increase when the intensity of the solar radiation increase. Whereas the temperature decreases significantly when the sky is unclear or cloudy weather, as it can be seen clearly in Fig. (4) where the test was performed on Dec 5-2019. At 11:00 AM the temperature decreased due to low solar radiation. The same experiment was repeated on Dec 8, 2019, where a square aluminum plate (10 X 10 cm) is used with the exact distribution and locations of thermocouples. Figure (5) illustrates the temperature distribution for the aluminum plate where the highest temperature obtained was at the focus which is 317 °C and 130 °C at the edge when the intensity of the solar radiation is 1069 W/m² and the ambient temperature is 16.2 °C. However, it can be noticed that the steel plate recorded higher temperature than the aluminum and that is because the difference in the coefficient of thermal conductivity which causes more heat dissipation to the surrounding. It is also worthy to mention that the works on Fresnel's lens in literature are conducted in weather condition that is significantly different than the weather conditions in Iraq, hence, no thermal comparison could be performed. However, this work is continuous to implement many different solar applications where the comparison to other works can be considered since the solar applications researches tend to implement the most efficient thermal system.
Figure 3. Temperature of test on the steel plate (10X10 cm) on Dec-9-2019 (a) Center of plate (b) Edge of plate, and (c) average temperature.
Figure 4. Temperature of test on the steel plate (10X10 cm) on Dec-5-2019 (a) Center of plate (location of focus) (b) Edge of plate, and (c) average temperature.
Figure 5. Temperature of test on the aluminum plate (10X10 cm) on Dec-8-2019 (a) Center of plate (location of focus) (b) Edge of plate, and (c) Average temperature.
5. Conclusions
The intense solar radiation in Najaf city-Iraq is utilized to produce extremely high temperatures by means of Fresnel's lens concentrator. The solar concentrator system consists of a sun tracker control system and Fresnel's lens concentrator frame where the frame is freely moving in two-axis to track the sun. The tracking system consists of a controlling circuit represented by Arduino and two stepper motors to adjust the position of the Fresnel's lens focal by moving the motors accordingly. The focal produced by the Fresnel's lens is to be maintained stationary at a fixed position to ensure continuity of heat flow on the absorption plate. Two different absorption plates are used, namely steel and aluminum with dimensions of (10 X 10 cm). Five thermocouples are installed over the plate surface to read the temperature distribution. The test was performed during arbitrary days of December 2019 and the results showed that for steel plate the highest recorded temperature is 422 °C at the center of the plate and 134 °C at the edge when the intensity of the solar radiation is 1140 W/m² and the ambient temperature is 17 °C. Whereas, the results of using aluminum plate with same dimensions showed that the highest temperature obtained was at the focus which is 317 °C and 130 °C at the edge when the intensity of the solar radiation is 1069 w/m² and the ambient temperature is 16.2 °C. It is promising results since obtaining such considerably high temperature during wintertime can be utilized in many different solar applications. This work is continuous its final version will have heating, heat storage, and water desalination applications.

Reference
[1] Zhai, H., Dai, Y. J., Wu, J. Y., Wang, R. Z., & Zhang, L. Y. 2010 Experimental investigation and analysis on a concentrating solar collector using linear Fresnel lens. Energy Conversion and Management, 51(1), 48-55.
[2] HUSSAIN, M. Imtiaz; ALI, Asma; LEE, Gwi Hyun. 2015 Performance and economic analyses of linear and spot Fresnel lens solar collectors used for greenhouse heating in South Korea. Energy, 90, 1522-31.
[3] SIERRA, Cristina; VAZQUEZ, Alfonso J. 2005 High solar energy concentration with a Fresnel lens. Journal of materials science, 40(6), 1339-43.
[4] HUSSAIN, M. Imtiaz; and LEE, Gwi Hyun. 2015 Experimental and numerical studies of a U-shaped solar energy collector to track the maximum CPV/T system output by varying the flow rate. Renewable energy, 76, 735-742.
[5] XIE, W. T.; DAI, Y. J.; WANG, R. Z. 2011 Numerical and experimental analysis of a point focus solar collector using high concentration imaging PMMA Fresnel lens. Energy Conversion and Management, 52(6), 2417-26.
[6] PALAVRAS, I.; BAKOS, G. C. 2006 Development of a low-cost dish solar concentrator and its application in zeolite desorption. Renewable Energy, 31(15), 2422-31.
[7] Badran, A. A., Yousef, I. A., Joudeh, N. K., Al Hamad, R., Halawa, H., & Hassouneh, H. K. 2010 Portable solar cooker and water heater. Energy Conversion and Management, 51(8), 1605-09.
[8] ABU-MALOUH, Riyad; ABDALLAH, Salah; MUSLIH, Iyad M. 2011 Design, construction and operation of spherical solar cooker with automatic sun tracking system. Energy Conversion and Management, 52(1), 615-620.
[9] Bakos, G. C., Ioannidis, I., Tsagas, N. F., & Seftelis, I. 2001 Design, optimisation and conversion-efficiency determination of a line-focus parabolic-trough solar-collector (PTC). Applied energy, 68(1), 43-50.
[10] Beshears, D. L., Capps, G. J., Earl, D. D., Jordan, J. K., Maxey, L. C., Muhs, J. D., & Leonard, T. M. 2003 Tracking Systems Evaluation for the “Hybrid Lighting System”. In: ASME 2003 International Solar Energy Conference. American Society of Mechanical Engineers Digital Collection, p. 699-708.
[11] Kalogirou, Soteris A. "Solar Energy Engineering Processes and Systems", Oxford OX5 1GB, UK, Academic Press. 2014.