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Testing The Performance of a Solar Heater Using Convex Lenses as a Means of Concentrating Solar Radiation

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Abstract: Enhancing the efficiency of solar water heaters remains a priority in renewable energy research, particularly in increasing thermal gain and water temperature. Despite advancements in solar heater design, a knowledge gap exists in optimizing heat absorption using passive optical components. This experimental study investigates the impact of integrating convex lenses into flat-plate solar heaters to concentrate solar radiation. Two identical solar heaters were constructed—one with convex lenses fixed between double glass plates and one without lenses. Both units were tested under identical conditions over three days in December 2024 in Shatrah, Iraq. The results revealed that the lens-equipped heater showed a slight increase in heat gain, particularly during early sunlight hours. However, at midday, performance equalized due to lens-induced shading effects. The findings suggest that while convex lenses can modestly improve early-day heating efficiency, design modifications are needed to mitigate their shading drawback for optimal all-day performance.

Keywords: Solar Heater, Convex Lens, Solar Radiation, Heat Gain, Renewable Energy, Passive Solar Concentration

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1. Introduction

The whole world is moving towards investing in renewable energy and reducing dependence on fossil fuels. The Solar heater is one of the important applications for investing in solar energy, which is the most important source of renewable energy. The aforementioned heater is a means of heating water by investing in solar radiation and has many advantages, including its ability to absorb and store heat [1]. It does not emit carbon monoxide as it does in gas heaters [2]. Solar heaters are also not subject to corrosion as is the case with gas heaters, as burners and chimneys are subject to corrosion and mechanical damage [3]. The solar heater is also characterized by ease and speed of installation, in addition to ease of maintenance, which avoids the risks of fire and suffocation. It is also characterized by the highest levels of safety compared to gas and electric heaters, and does not emit sound or noise [4]. As is known, there are many types of solar heaters, including the heater that contains a flat plate collector, which consists of a solar collector, heat exchangers, and a storage tank [5]. The efficiency of the solar heater increases with the increase in its ability to absorb radiation. Therefore, through the current study, we aim to increase the concentration of solar radiation reaching the components of the flat-plate solar heater using convex lenses that collect and concentrate the rays [7].

Literature Review

Lenses have been used since ancient times for the purposes of magnification and focusing radiation in cameras and glasses. They have also been used in observation devices such as telescopes, and we must not forget in the manufacture of microscopes for the purpose of magnifying the image by two hundred times. The lens used in the above is the convex lens, which focuses on collecting rays. A lens is a transparent body that works to focus or disperse light rays due to the property of refraction of light [8]. A simple lens consists of a single transparent piece, while a compound lens consists of several simple lenses usually arranged on a common longitudinal axis known as the optical axis. Lenses are made of different materials such as glass or plastics, and are formed by the casting process to the desired shape [9]. A lens can focus light to form an image. In our current research, We used a set of lenses arranged on the glass plate [10].

We avoided using any adhesive material that might block the radiation. The lenses were fixed by placing another glass plate on top of the first plate so that the lenses were between them [11]. Convex lenses are optical devices made of transparent isotropic materials such as glass, and they have spherical surfaces where the two surfaces of the lens are either equal in curvature or different in curvature, depending on the purpose for which the lens is used [12]. If a convex lens is placed in the path of a beam of parallel light rays, they all meet at a single point approximately on the other side of the lens, which is the focus of the lens [13]. Conversely, if a light source is placed at the focal point of a converging lens, the rays exit the lens as a parallel beam of light rays.

The first case describes an object that is very far away, to the extent that the rays that reach the lens from it are parallel, and its image is formed at the focal point. In the second case, an object standing at a focal length from a lens, its image is formed at infinity [14]. We tried to employ the first case by receiving the solar rays coming from infinity and projecting them onto a group of converging lenses that were glued to the glass plate of the collector in order to receive them and focus them at the focal point inside the collector. Thus, the concentrated radiation reaches the parts of the collector and thus the water inside the pipes in order to heat it [15]. A convex or converging lens is shaped so that all light rays impinging on it parallel to their optical axes intersect (or focus) at a single point on an optical axis on the other side of the lens, as shown in the Figure 1 and Figure 2.

2. Materials and Methods

In this experimental study, the methodology was designed to evaluate the performance enhancement of a flat-plate solar water heater through the integration of convex lenses as a passive solar radiation concentrator. Two identical solar heaters were fabricated with equal dimensions, materials, and structural configurations to ensure consistent baseline conditions. One unit served as the control model, while the second incorporated small convex lenses with a 5 cm diameter placed between two transparent glass plates positioned directly above the water pipes. The lenses were arranged to concentrate incoming solar radiation toward the absorber area without using adhesives, preventing obstruction of light. Both heaters were installed side by side at an identical tilt angle of 45 degrees in Shatrah, a city in southern Iraq, where environmental conditions remained constant for both setups. Data collection was conducted over three consecutive days in December 2024. Each day, water temperature was recorded hourly from 8:00 a.m. to 2:00 p.m. for both the cold water entering and the hot water exiting the heaters. The difference in temperature, or heat gain, was then calculated to assess thermal performance. This approach enabled a direct comparison between the two models under real-time solar exposure. The methodology aimed to isolate the impact of convex lens concentration on heat absorption, emphasizing the early morning period when solar intensity is lower. Careful attention was paid to consistency in positioning, measurement intervals, and environmental exposure to ensure the reliability and validity of the comparative results.

3. Results and Discussion

The hot water temperature was measured and recorded as a function of daylight hours starting from 8:00 am until 2:00 pm, where the temperature of the cold water (entering the heater) and the temperature of the hot water (water exiting the heater) were recorded for the two models every hour for three days in December 2024, then the difference between the temperature of the cold water and the hot water, i.e. the heat gain of the two heaters, was calculated every hour. Where T1 is the water temperature of the tank of the first model, the red line. T2 We noticed as shown in Figures (2) and (3). We will refer to the heater without lenses as the first heater, while the heater containing lenses is the second heater. We noticed through the measurements that the second heater was more efficient in heating during the first hours of the day, but the difference is small, ranging between one degree of heat and sometimes two degrees or between them, but at noon the two models are equal in efficiency. It was found that the lenses in the second heater create a shadow area that blocks the radiation reaching the heater tubes and thus reduces its efficiency.

If a ray of parallel light rays falls on a convex lens, they converge at approximately one point, which is the focus of the convex lens. The distance between the center of the lens and the focus is called the focal length, which is positive in a convex lens. As shown in the Figure1 and Figure 2.

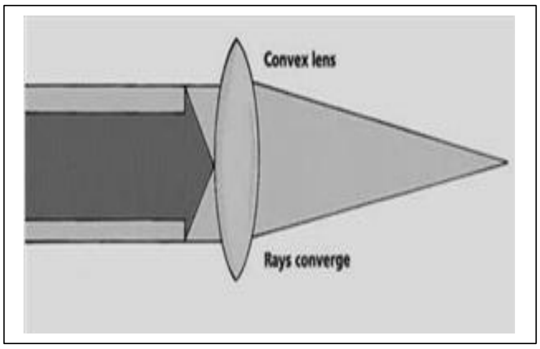

Figure 1. Illustration of Light Rays Converging Through a Convex Lens.

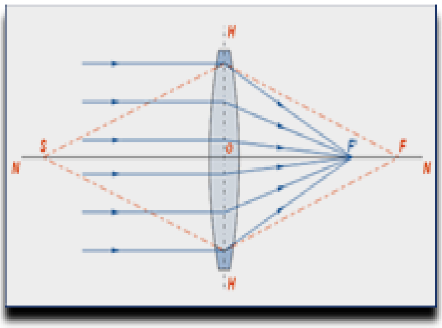

Figure 2. Ray Diagram of a Convex Lens Showing Convergence at the Focal Point.

One of the properties of lenses is that the wider the lens, the less clear the image becomes due to the imbalance that occurs to the light rays falling in the circles far from the center of the lens. The camera lens is characterized by having lens numbers, for example, the number 2 means that the lens aperture is large. The clarity of the image suffers from this expansion due to the imbalance of the rays on the edges of the large area of the lens. If we choose lens number 5 when photographing, this means a small lens aperture, and increased image clarity. The art of photography depends on reconciling a small lens aperture in order to obtain a clear image and the intensity of lighting. If the lighting is weak, we are forced to increase the lens aperture, and thus the clarity of the image decreases.

For this reason, we used small lenses instead of using a large lens. The small lenses were placed on the glass plate and another glass plate was placed on top of it to avoid using an adhesive material, i.e. forming a double glass plate between the lenses. After the sunlight passes through the double glass plate after being focused, it falls into the focus of the lens, which we placed on the heater tubes, as shown in Figure 3 and Figure 4.

Figure 3. Photograph of the Solar Heater Equipped with Convex Lenses.

Figure 4. Photograph of the Standard Solar Heater Without Convex Lenses.

The first step in the work was to manufacture two identical solar heaters in terms of dimensions, components, raw materials and engineering design. The second step was to stick small 5 cm diameter lenses on the glass plate facing the radiation of only one of the heaters and leave the other without lenses as shown in the figure. The third step was to place the two heaters side by side at the same angle of inclination of (45) in the city of Shatrah located in southern Iraq. The fourth step was to test the performance efficiency and compare the results and measurements and record the data over three days in December 2024.

4. Conclusion

The findings of this study demonstrate that integrating convex lenses into flat-plate solar heaters can modestly enhance heat gain, particularly during the early hours of sunlight, with recorded temperature differences ranging between one to two degrees Celsius compared to the conventional heater. However, the advantage diminished by midday due to shading effects caused by the lenses, which impeded uniform radiation distribution. This outcome suggests that while convex lenses show potential as a passive method to improve solar energy utilization, particularly in low-radiation periods, their design and placement require optimization to avoid efficiency trade-offs during peak sunlight hours. The implications of this research are significant for the advancement of cost-effective, energy-efficient solar heating systems, especially in regions with fluctuating solar intensities. Future studies should focus on refining lens configurations, exploring adaptive or dynamic lens systems, and conducting long-term testing across different seasons and geographic locations to enhance the consistency and scalability of this approach in practical renewable energy applications.

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