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Solar Lens Concentration for Water Heating: Analyzing Useful Energy and Outlet Temperature Profiles

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Abstract. The objective of this study was to demonstrate the potential of convex lenses as an alternate approach in solar water heating. The Convex Lens Solar Water Heating System (CSP) consists of convex lenses, and a copper thermally insulated receiver tube. The convex lenses are mounted on the top of the collector, where sunlight is collected and directed on the rising tube, maximizing the effectiveness of solar radiation capture and rapidly heating the water inside the tube. In this study, a series of experiments were carried out at different flow rates of 4,6 and 10g/s. The results showed that the useful heat obtained increases from 46.3 to 238.6 watts, while the highest output temperature is 41.5 °C with a flow rate of 4 g/S, and it decreases with the increase in mass flow rate and the decrease in solar intensity.

Keywords: Convex lens, Concentrating Solar Power (CSP), Flow rate, Solar Water Heating، Useful Energy.

1. Introduction

In the quest for sustainable and environmentally friendly energy sources, solar power has emerged as a promising solution to address the ever-increasing global energy demands and environmental issues. Among the various solar technologies, solar collectors stand out as pioneering and widely adopted systems for harnessing solar energy. These innovative devices efficiently capture and convert sunlight into thermal energy, which is then transferred to a coolant (such as water, air, or oil) flowing through the collector. This process offers an effective and versatile method for generating heat and power in residential, commercial, and industrial settings. Solar collectors can be categorized into two types: non-concentrating and concentrating collectors [1].

The flat plate solar collector (FPSCs) falls under the non-concentrating collector category and is commonly used for domestic and industrial applications due to its mechanical simplicity. These collectors typically consist of a blackened absorber, a transparent cover made of low-iron content glass to minimize convection and enhance transmittance while reducing radiation losses to the atmosphere, and back and side insulation to minimize conduction losses. Various geometries have been proposed for FPSCs, ranging from the widely used fin-and-tube collector to sandwich-like collectors with a direct fluid-absorbing surface that comes into contact with the absorbing surface [2].

Indeed, the performance of flat plate solar collectors (FPSCs) is influenced by numerous parameters. These parameters include the design of the absorber and absorber tube, the thermophysical properties of the working fluid, its inlet conditions, the effectiveness of insulation, and ambient conditions like temperature and solar irradiation.

Among these factors, the volume flow rate of the working fluid is a critical parameter that significantly impacts the efficiency of the collector. Proper control and optimization of the flow rate are crucial for achieving the best possible heat transfer and energy conversion from solar radiation to thermal energy in the FPSC system [3].

To improve the performance of Flat Plate Solar Collectors (FPSCs), diverse strategies have been utilized, encompassing augmenting the absorptivity of the absorber, optimizing heat transfer between the absorber plate and tubes, reducing the boundary layer in receiver tubes to enhance convective heat transfer, and other relevant approaches [4.5].

Numerous researchers have carried out experimental and theoretical investigations on solar collectors to address the challenge of heat loss during periods of inactivity or cold nights. Although proper insulation and glazing materials can help mitigate this issue, complete elimination of heat loss is not achievable. A promising approach to reduce heat loss involves the integration of convex lenses onto the cover of the solar collector.

In the context of convex lenses utilized in solar collectors, each light ray passing through the lens and intersecting its optical center experiences no deviation. When a light beam approaches the lens parallel to its optical axis, it undergoes refraction in a manner that either converges towards or appears to originate from a specific point termed the image focus (F) on the optical axis of the lens.

Convex lenses are economical and lightweight optical components. In the design of a convex lens, efforts are made to remove as much non-optical interface material as possible since the lens's power is concentrated in the optical interface.

The distinctive feature of a convex lens is its ability to converge incident rays. When an infinite set of parallel rays, aligned with the principal axis of the lens, impinges on the lens surface, the lens concentrates them at a single point. The principal axis refers to the axis that is perpendicular to the plane of the lens. The point where all incident rays converge after passing through the lens is termed the focal point, and the distance between this focal point and the lens plane is known as the focal length [6].

2. Literature Review

In 2023 Abdul Samim, Narjis, and Abdul Rafay Khatri investigated the use of convex lenses to analyze the performance and heat transfer of solar-powered water heating systems. Convex lenses concentrate solar radiation on water layers in a single place, making them suitable for diffusible radiation. The water absorbs high heat from the lens arrays, allowing for effective heating. The research intends to produce a water heating system entirely dependent on solar radiation, conserving electricity, gas, and reactive energy required by geysers and other living needs. Convex lenses are preferred for diffusible radiation [7].

Kale et al. conducted an investigation to evaluate the efficiency of a convex lens Concentrated Solar Power (CSP) system for generating hot water and steam. The study employed six convex lenses, each with an area of 0.0471m2, in conjunction with a copper receiver having an internal diameter of 5mm and an outer diameter of 10mm. The experimental results indicated that the system achieved a peak temperature of 810°C at a mass flow rate of 1kg/hr. with an observed efficiency of approximately 63-64%. The researchers concluded that the inclusion of convex lenses significantly contributed to achieving optimal results in the CSP system [8].

Vinod Kumar Verma et al. conducted an experimental investigation aimed at analyzing the heat transfer performance of convex lenses for solar applications. The study involved the utilization of six convex lenses along with a copper receiver tube. A two-axis manual tracking system was employed to continuously track the sun's movement. The findings of the study demonstrated that employing convex lenses for Concentrated Solar Power (CSP) is particularly well-suited for solar water heating applications, as it enables achieving superior heat transfer capabilities [9].

Li et al. investigated the enhancement of heat transfer using a triangular perforated fin through a combination of computational fluid dynamics (CFD) simulation and experimental analysis. The results obtained from both the CFD software and the experiments were found to be in agreement. The study concluded that the use of a triangular perforated fin significantly improves heat transfer performance [10].

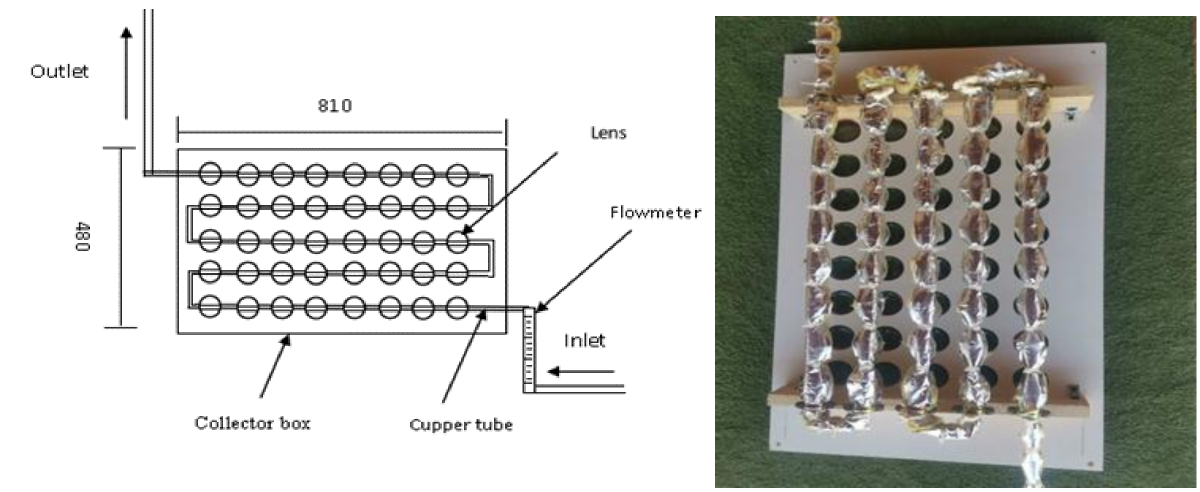
Ammaralifarhan et al. conducted an experimental study involving three types of solar collectors. The first solar collector featured an absorber plate with perforations, while the other two had absorber plates with perforations containing holes of 3mm and 6mm, respectively. The findings revealed that the solar collector with a 3mm hole perforation in the absorber plate exhibited higher energy gain compared to the one with a 6mm hole perforation. Furthermore, it was observed that a higher number of holes with a smaller diameter in the absorber plate resulted in increased efficiency when compared to a lower number of holes with a larger diameter in the absorber plate [11].

S. Thulasi et al. conducted experiments involving plain, CTPT (Concentric Twisted Tape) and CSPT (Concentric Solid Plate) collectors. The findings indicated that the integration of convex lenses along with the insertion of CTPT and CSPT significantly enhanced the heat transfer performance. Specifically, CTPT with a minimum twist ratio of 3 exhibited 1.9 times higher efficiency compared to CSPT twist inserts.

Overall, the implementation of convex lenses and CTPT with a minimum twist ratio of 3 resulted in an enhancement of up to 9% in the collector's overall efficiency, outperforming the conventional configuration [12].

However, based on previous studies as well as the scientific journey, this study aimed to further investigate a Convex Lens Solar Water Heating System by reducing heat loss during periods of activity and inactivity by reducing the area of open contact with the environment.

3. Experimental Set Up



a b

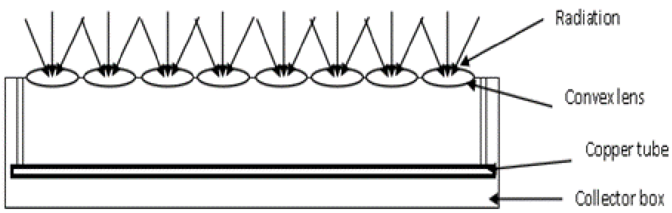
Fig. 1. Schematic diagram of the experimental setup: a - sketch of system, b - photo of the back side of the system.

The complete solar collector system is constructed using wooden materials with dimensions (**810** mm *480 mm). This wooden setup plays a crucial role in preventing heat loss from the system. Inside the collector, a copper tube with a length of 4 meters and an internal diameter of (10 mm) and an external diameter of (11 mm) is used. The entire assembly within the collector is enclosed by a wooden cover, and convex lenses are evenly spaced on this cover. The wooden cover has a thickness of (18 mm), and 40 convex lenses are placed at a distance of (**100** mm) from the top and bottom edges of the wooden cover. The lenses are spaced at (20 mm) intervals, and their focal length is (80 mm). The convex lenses are primarily responsible for concentrating the solar radiation onto a single point of the copper tube.

In order to measure temperatures at different points in the installation, a digital thermometer called thermometer MP1300 was used. In order to obtain maximum solar radiation, it is necessary to have appropriate orientation with the Earth's latitude. In Surman, a latitude of (32°) is recommended for optimal exposure to solar radiation.

The digital pyranometer type METEON CMP6 is used to measure solar intensity, and the flow rate was measured using a MPB flow meter type.

Convex lenses are conventionally employed for focusing purposes, and in this particular system, they assume a crucial and dominant role. Lenses with a focal length of (80 mm) are utilized in this setup. The lens structure allows it to receive solar rays from various angles and effectively concentrates all the radiation onto a single point on the thermally insulated copper tube. This arrangement enables the copper tube to receive the maximum amount of solar radiation. Unlike regular plain solar water heaters, which lack this feature and exhibit lower efficiency, the incorporation of convex lenses in this system greatly contributes to achieving maximum heat levels.



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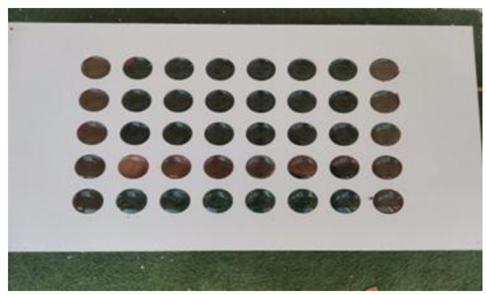

b

Fig. 2. Concentration of incident rays by convex lens: a- sketch of the system; b-photo of the front side of the system

Table 1. Specifications of Convex lenses

Diameter	50 mm
Focal distance	80 mm
Thickness at the center	9 mm
Thickness at the edges	2mm

4. Result And Discussions

Three clear sunny days are used for the panel's experimental testing. Readings are taken every hour for the entire day by manually tracking the sun. The graph depicts the fluctuation in maximum solar intensity for the several days, which ranges from 454 W/m^2 to 908 W/m^2.

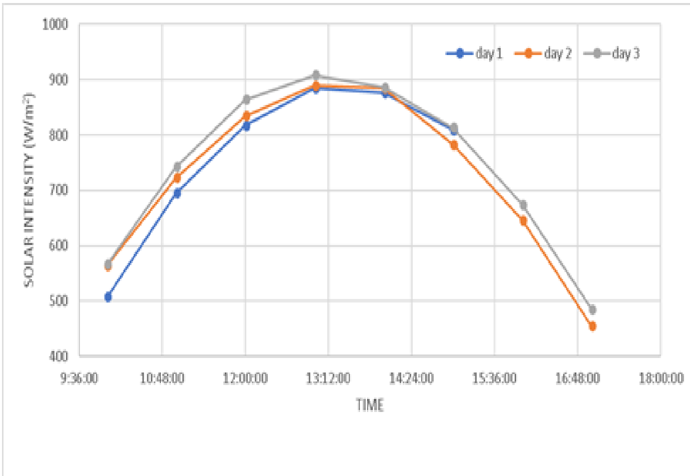

Fig. 3. Variation of Solar Intensity over days.

Outlet temperature for different flow rates, where for the three days are 10, 4 and 6 **respectively**. On several days, the mass flow rate is varied from 4 g/s to 10 g/s for the test. The maximum output temperature at 4 g/s is 41.5 °C, which corresponds to the maximum intensity of solar radiation, and the temperature decreases with increasing mass flow rate and decrease of solar intensity, as shown in the figure 4.

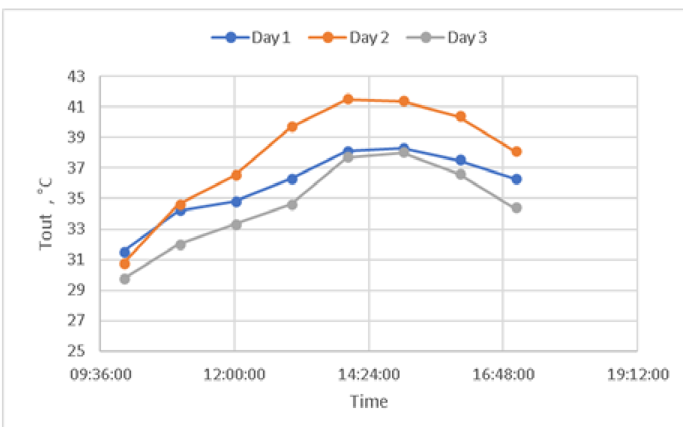

Fig. 4. Variation of outlet temperature with time for different flow rates.

During the test, the useful heat gain increased from 46.3 watts to 238.6 watts as the solar intensity increased from 722 W/m^2 to 884 W/m^2. The graph in figure (5) depicts the relationship between heat absorbed during the day and flow rate. It is directly proportional to the intensity of solar radiation and flow rate.

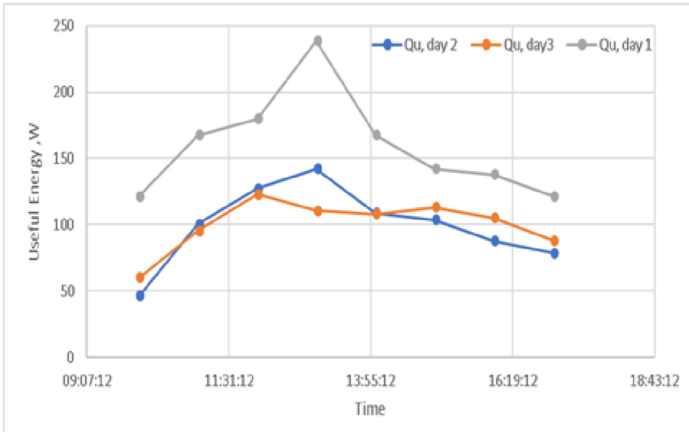

Fig. 5. Variation of useful energy with time for different flow rate

5. Comparison

In juxtaposing our study with the alternative investigations, discernible distinctions surface, elucidating the nuanced performance variations inherent in solar concentration systems. Our study employed a considerable number of lenses with a diminished diameter, yielding a distinct solar intensity range. Consequently, this design choice engendered a more expansive spectrum of useful energy production, spanning a diverse array of wattage outputs. Notably, the outlet temperature profile in our system demonstrated appreciable variability, attaining its zenith at the nadir of the flow rate. It is imperative to acknowledge that the other studies achieved higher outlet temperatures; however, contextualizing this disparity necessitates consideration of divergent system configurations and disparate climatic conditions inherent to the respective experimental setups.

The imperative for optimizing performance entails a meticulous consideration of lens characteristics, encompassing both size and quantity, as they exert a substantial impact on the overarching efficacy of solar concentration systems. Moreover, augmenting the lens diameter holds promise in amplifying the water outlet temperature. Concurrently, the adoption of automated sun tracking mechanisms stands poised to further augment outlet temperature, surpassing the efficacy of manual tracking methodologies, which introduce the potential for human-induced errors in experimental outcomes. These recommendations serve as strategic avenues for advancing the efficiency and performance of solar concentration systems.

Table 2. comparison

Author	Name	Specification, data	Solar intensity w/m²	Useful energy W	Outlet temperature C°	Mass flow rate Kg/s	Max outlet temperature
Ankit S. Gujrathi [1], Prof. Dilip Gehlot[2] India	Testing and Performance of the Convex Lens Concentrating Solar Power Panel Prototype	6 lenses Dia 10 cm Focal length 18.5 cm	1061-1124	34.24-36.22	45-67	0.24-1	67° at 0.24kg/s
Abdul Samim, Narjis, Abdul Rafay Khatri Pakistan	Automatic Solar Based Water Heating System Through Convex Lenses	4 lenses Dia 9 cm Focal length 24 cm	-	-	28-58	-	58
Er. Vinod kumar verma, Vipin Tripathi, Vivek Kumar Verma, Mohd Nuzaif India	Development of CSP using convex lenses for domestic water heating	6 lenses Dia 10 cm	981-1008	-	41-55		55

6. Conclusion

The objective of this experiment was to demonstrate the potential of convex lenses as an alternate approach in solar water heating. The convex lenses mounted on the top of the solar collector, where sunlight is collected and directed on the thermally insulated rising tube, maximize the effectiveness of solar radiation capture and rapidly heating the water inside the tube. The Solar water heater with convex lenses was created at a low cost.

Experimental results from the Convex Lens solar water heating system were analyzed and compared at different flow rates of 4,6 and 10g/s and solar intensity from 507 w/m^2 to 889 w/m^2.

With the increase in flow rate and solar intensity, the useful heat obtained increases from 46.3 watts to 238.6 watts, while the highest output temperature is 41.5 °C with a flow rate of 4 g/s, and it decreases with the increase in mass flow rate and the decrease in solar intensity.

References

1- Mekhilef, S., Saidur, R. and Safari, A., 2011. A review on solar energy use in industries. Renewable and sustainable energy reviews, 15(4), pp.1777-1790.

2- Slaman, M., Griessen, R., 2009. Solar collector overheating protection. Solar Energy 83, 982–987.

3- Rommel M, Moock W.1997. Collector efficiency factor F0 for absorbers with rectangular fluid ducts contacting the entire surface. Solar Energy 60:199e207.

4- Z. Chen, S. Furbo, B. Perers, J. Fan, E. Andersen.,2012. Efficiencies of flat plate solar collectors at different flow rates, Energy Procedia, volume30, pp. 65–72, (2012).

5- K. M. Pandey, R. Chaurasiya.,2017. Review on analysis and development of solar flat plate collector, Renewable and Sustainable Energy Reviews, volume 67, pp. 641–650.

6- G. Colangelo, E. Favale, P. Miglietta, A. Risi.,2016. Innovation in flat solar thermal collectors: A review of the last ten years experimental results, Renewable and Sustainable Energy Reviews, volume57, pp. 1141–1159.

7- Samim, A. and Khatri, A.R., 2023, March. Automatic Solar Based Water Heating System Through Convex Lenses. In 2023 4th International Conference on Computing, Mathematics and Engineering Technologies (iCoMET) (pp. 1-6). IEEE.

8- Kale, S.S. and Shinde, N.N., 2012. Design and Development of CSP Using Convex Lenses for Domestic Water Heating and Steam Generation. International Journal of Mechanical Engineering and Research, 1, pp.74-78.

9- Kumar, V.E.V., Vipin, T., Kumar, V.V. and Muhaid, H., Development of CSP using convex lenses for domestic water heating. according to the International Journal of Research in Engineering and Technology, pp.2319-1163.

10- Juan li, Xiang ling and Hao peng, 2013. Field synergy analysis on convective heat transfer and Fluid flow of a novel triangular perforated fin; International Journal of Heat and Mass Transfer, 64, 526-535.

11- Suvanjan Bhattacharya, Subhankar Saha, Sujoy Saha, 2013. Laminar flow heat transfer enhancement in a circular tube having integral transverse rib roughness and fitted with Center-cleared twisted tape; Experimental Thermal and Fluid Science, 44, 727–735.

12- Thulasi, S Sivasubramaniam, V Thirumaran, 2020. Performance and heat transfer evaluation of convex lens solar water heater with serrated, triangular cut and perforated twist inserts; Materials Science and Engineering, 10.1088/1757-899X/923/1/012073.

13- Ankit S. Gujrathi, Prof. Dilip Gehlot, 2014. Testing and Performance of the Convex Lens Concentrating Solar Power Panel Prototype International Journal of Emerging Technology and Advanced Engineering ISSN 2250-2459, ISO 9001.

14- Abdul Samim, Narjis, Abdul Rafay Khatri,2023. Automatic Solar Based Water Heating System Through Convex Lenses; International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)

15- Er. Vinod kumar verma, Vipin Tripathi2014., Vivek Kumar Verma, Mohd Nuzaif,20 DEVELOPMENT OF CSP USING CONVEX LENSES FOR DOMESTIC WATER HEATING: International Journal of Research in Engineering and Technology