Hindawi
Advances in Materials Science and Engineering
Volume 2023, Article ID 5657609, 10 pages
https://doi.org/10.1155/2023/5657609

Research Article

Experimental Investigation on Incorporation of Zinc-Ferrite Nanocoated Baffles for Improving the Performance of Field Power Electrical Transformer Integrated with a Solar Air Heater

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Received 16 May 2022; Revised 27 July 2022; Accepted 2 August 2022; Published 17 April 2023

Academic Editor: Ravi Samikannu

Solar energy is the most accessible, eco-friendly, and renewable energy source available to meet the world's expanding energy needs. Solar collectors are commonly utilized to convert solar energy directly into heat for purposes ranging from house heating to timber seasoning and crop drying. The purpose of this research is to design a modified solar air heater (SAH) with a baffle plate and to examine the performance due to the provision of zinc-ferrite nanocoated baffles. The entire system is mounted over a transformer for effective cooling and also produces hot air for industrial requirements. A flat plate collector and a centrifugal blower were used in the experiment. Maximum output air temperatures of 55°C, 62°C, and 72°C were measured for collectors without baffles, baffled collectors, and inverted baffled collectors, respectively. It was also found that the thermal efficiency of flat plate collectors without baffles was 36%, with baffles, it was 44%, and with inverted baffles it was 54%. This study shows that inverted SAH with zinc-ferrite nanocoated baffle plates works better than SAH without baffle plates or with baffle plates in the normal position.

1. Introduction

Solar radiation contains a significant amount of thermal energy in both direct and indirect forms, making it one of the most abundant renewable sources of energy available on the planet. The sun releases approximately 3.8×10^{23} kW of energy; but due to the 150 million kilometers between the sun and the Earth, 1.8×10^{23} kW of energy is lost [1]. The Earth's surface receives around 3.4×10^{6}exa Joules of solar energy per year. This thermal energy is not equivalent to the thermal energy generated by nontraditional energy sources such as fossil fuels or nuclear energy [2]. Currently, fossil fuels account for 80% of global energy consumption. Global demand for fossil fuels will almost certainly exceed annual output within the next two decades. Oil or gas shortages have the potential to spark global financial and political crises and confrontations [3].

In his research study, Karsli [4] compared four distinct types of solar flat plate air heaters. These included a collector with a finned collector at 75 degrees, a collector with a finned collector at 70 degrees, a collector with tubes, and a base-collector. The determination of the efficiency of the air heater is dependent on solar radiation and the surface shape of the solar collectors, as well as the fact that the overall loss is lower at a greater decreased temperature parameter. Otham et al. [5] came up with and tried out four new solar-aided forced convection air heaters: the V-groove air heater, the multipass collector with an energy storage arrangement, the dehumidifier for herbs, and a photovoltaic collector system. It was suggested that the likelihood of the construction of a self-sufficient solar flat plate collector, which will not require any external electrical energy to operate, would be high. The solar air heaters operated at single pass and counterflow operating conditions, Nowzari–Aldabbagh [6] and found that a solar collector with a quarter ($1/4^{th}$)-perforated sheet did better than one with a half (1/2th) -perforated sheet. The average efficiency of the multipass solar energy extractors with 10D and 20D quarter-perforated glass sheets was 51.23% and 54.61%, respectively, while the average efficiency of the collector with half-perforated covers was 48.21% and 51.17%, respectively. It was 50.92% efficient at the same mass flow rate when the double-pass air heater with a regular cover had the same amount of air coming through it. Abuskha–Şevik [7] investigated thermal efficiency values that ranged from 44.8% to 66%, depending on the rate at which the water was being circulated. The mean performance of SAH in terms of thermal efficiency of a v-groove SAC is about 6% higher than the average thermal efficiency of a flat plate SAC. According to the results of the 0.1 kg/s test, a 13–15% gain in thermal efficiency over the 0.04 kg/s test may be attained using this strategy when compared to the previous test. The practicality of placing an aluminum can formulated absorbing plate into the multipass channel of conventional solar energy extractors in order for it to absorb the sun's heat is being investigated by Esen [8]. In order to carry out the experiment, three distinct absorber plates were produced and put through their paces under a variety of circumstances. Because Type I users put the cans on the absorber plate in the wrong place at the wrong time, the order of the cans on the plate became a jumbled mess. These objects were placed in an orderly fashion by people who employed Type II technology. It is a form of a plate that appears to be flat on the surface (without cans). It was determined that the investigations were carried out for working fluid flow rates ranging from 0.03 kg/s to 0.05 kg/s, respectively, and that the results were in favor of the hypothesis is supported. Type I was the most efficient of the three when moving at a rate of 0.05 kg per second.

According to Yeh and Lin [9], a flat plate solar air heater's double-pass channel might use an aluminum absorption plate to absorb the sun's heat (SAH). For the purpose of research, three alternative absorber plates were created and tested. Type I users messed up the order of the cans on the absorber plate by putting them out of order. They were placed in a straight line by those who utilized Type II. It is a type of plate that is flat in appearance (without cans). The studies showed that the air induction capacity of SAH ranges between 0.03 kg/s and 0.05 kg/s, and that the results were positive. Type I was most efficient while moving at a rate of 0.05 kg/s. Bansal et al. [10] conducted an experiment to compare SAHs with and without longitudinal fins in order to better understand SAHs. They discovered that SAHs with fins have greater performance at lower mass flow rates. Omojaro–Aldabbagh [11] conducted a test using a single and double-finned plate SAH with a steel wire mesh to determine their effectiveness. They demonstrated that the energy efficiency of the collector with many passes is superior to that of the collector with a single pass. During the course of their investigation, Alta et al. [12] constructed three distinct variants of the SAH: one without expanded surfaces, one with larger surfaces, and one that combined enlarged surfaces with a double-glass cover. According to the results of this investigation, the dual glass finned plate SAH is the most efficient of the three designs tested. According to the study, it was also discovered that the length of time that air circulates in the SAH has an impact on the temperature of the air that comes out of the SAH, according to the study. Lin et al. [13] investigated the thermal efficiency of two distinct types of SAH integrated with corrugated designed absorber plates and identified that they were both effective and efficient. The researchers noticed that when they used a cross-corrugated surface instead of a flat plate, the thermal efficiency of the heater increased dramatically when compared to the former. Karim–Hawlader [14] analysed the energy conversion characteristics of a SAH integrated with conventional, v-corrugated, and finned absorber plates. One of the investigations conducted by the researchers was the fact that an air heater with V corrugation profiles can be converted into a flat plate air heater. Furthermore, it was discovered that second-pass air flow improves heater efficiency [15]. Furthermore, the flat plate was heated with respect to roughness profiles, geometrical aspects of which were defined in previous research [16].

Roughness geometry and performance factors were studied in an experiment done by Saini–Verma [17] on experimental mixed convection roughened duct. A variety of factors, including Reynolds number, roughness pitch, and height, were found to have an impact, as well as the effects of nuzzling number and friction factor, among others [18]. They were able to demonstrate that when the absorption plate's roughness geometry was in the shape of a dimple, the Nusselt number and friction factor were both increased as a result. The roughness parameter, they said, should be set in accordance with the intended energy gain for fan operations, in more detail [19]. In order to evaluate the thermohydraulic performance of a SAH with a 60-degree v-shaped rib roughness on the absorption plate on the absorption plate [20]. Mahmood et al. [21] carried out an experiment on the absorption plate. After doing their research, they came to the conclusion that increasing the roughness of the absorption plate boosted heat efficiency while decreasing heat loss. Additionally, they discovered that when the mass flow rate was low, the thermal and effective thermal efficiency of the heater were typically similar. However, as the mass flow rate increased, the effective thermal efficiency decreased as a result of the friction factor and the additional pump effort that was required to operate the heater. El-Sebaii et al. [19] conducted an experiment on the absorption plate of a SAH using ribs of various roughness's, including continuous ribs, transverse continuous, an *d* cracked continuous rib v-shaped ribs and determined that all ribs should be used [22]. Luan–Phu [23] attained the maximum effective efficiency of 63% at an optimum baffle angle position of 60∘ with a flow Reynolds number of 24000. Khanlari et al. [24] and Venkateshwar et al. [25] used Cuo nanocoated baffles for solar air heaters and obtained a maximum efficiency of 76.22% [24, 25]. Venkateshwar et al. [26] integrate the SAH with a thermoelectric generator and improve its performance by a reduction in process heat generation of 1 to 6.25%. Sivakumar et al. [27] coated a solar absorber sheet with CuO nanoparticles and black paint to increase heat transmission. The nanoembedded modification reduced the drying time by 6%. Abd-Elhady et al. [28] examined solar cookers utilizing metallic wires and nanographene. According to their findings, nanoadditives raised the oil temperature by 8%. Shanmugan et al. [29] evaluated the influence of SiO_2/TiO_2 nano-coating on a stepped solar box cooker's thermal performance. Nanocoating enhanced thermal performance by 31%. This study's objectives are to build a modified SAH with a baffle plate and investigate the performance of the SAH as a result of providing zinc-ferrite nanocoated baffles. The complete system is built on top of a transformer for efficient cooling, and it also generates hot air to fulfill the requirements of various industries. After reviewing the available research in the published works, it was determined that improving the overall performance of SAHs might be accomplished by employing strategies that are both straightforward and efficient. Within the scope of the current investigation, a baffled SAH has been conceived, and its functionality has been enhanced by making use of baffles and an absorber with zinc nanocoating. In this regard, experimental analysis has been applied to the task of specifying a suitable baffle design for SAH. After that, SAHs with and without nanocoating have been produced, and the experimental investigation of their performance has been carried out. The primary objectives of this research are to (1) develop solar air heating systems for industrial applications that are both environmentally friendly and highly effective, and (2) to investigate the effect that integrating nanoembedded absorber coating has on the efficiency of solar air heaters. Figure 1 depicts the primary design configurations that were taken into consideration for this work.

2. Methodology

2.1. Experimental Setup. The experimental setup was planned and constructed in the Coimbatore climatic conditions of Tamil Nadu, India. The schematic layout in Figure 1 depicts the experimental setup for the SAH with zinc -ferrite nanocoated baffle plate. This analysis considers a standard flat plate collector with a surface area of 0.5 m^2. As zinc-ferrite nanocoated baffle type absorber panel, an aluminum sheet (1.4 mm thickness) is employed that has been black coated to absorb more solar radiation [30]. The spacing between baffles is maintained at 100 mm to make the flow more turbulent. A glass frame serves as a clear cover for the SAH. The glass wool insulation insulates the system from the sides and bottom, minimizing heat loss. The entire apparatus is mounted on a 10° inclined stand that corresponds to the test location's latitude. A blower with a capacity of 1.0 hp is used to supply the solar collector with the necessary air. While the zinc-ferrite nanocoated baffle type absorber plate arrangement is similar to that of a typical SAH, the airflow inside the SAH is zigzagged, as illustrated in Figure 2, which is connected to the blower. Without a baffle plate, with a baffle plate, and with an inverted baffle plate, the system is investigated in a SAH with a mass flow rate range of 0.01 kg/s. The SAH is put through its paces and graphs are created.

2.2. Instrumentation. SMIS Instruments, Bangalore, supplies a top-of-the-line pyranometer (type LP PYRA02, Delta Ohm) that is used to monitor solar radiation during the day. The sensitivity and resolution are, respectively, 12V and 25 W/m2. A pyranometer is additionally equipped with a shadow ring to monitor global radiation [31]. At the beginning of an experiment, the airflow rate is measured. The EQTM-4001 hot wire anemometer has a temperature range of about 0–50°C, an air velocity range of approximately 0–25 m/s, and a relative humidity range of approximately 20–80 percent [32]. It measures the incoming air speed with a precision of up to 2 percent. There is room for up to 99 readings. The K-type thermocouple sensor is used to measure the intake and outlet air temperatures, as well as the temperatures of the glass and absorber plate [33]. With a resolution of 0.1°C, a data logger (type Logger 02 or MEZARIT) shows and retains all temperatures. The precision and kind of the instruments are detailed in Table 1.

2.3. Thermal Performance of the SAH. The following parameters are used to determine the thermal performance of SAH without baffle, with baffle and inverted baffle are analyzed [34, 35].

(i) Mass flow rate

$$(\dot{m}) = \rho AC. \tag{1}$$

(ii) Reynolds number

$$(\mathrm{Re}) = \frac{\rho AV}{\mu}. \tag{2}$$

(iii) Hydraulic diameter

$$(d_e)\frac{4A}{P}. \tag{3}$$

Useful heat gain [32]

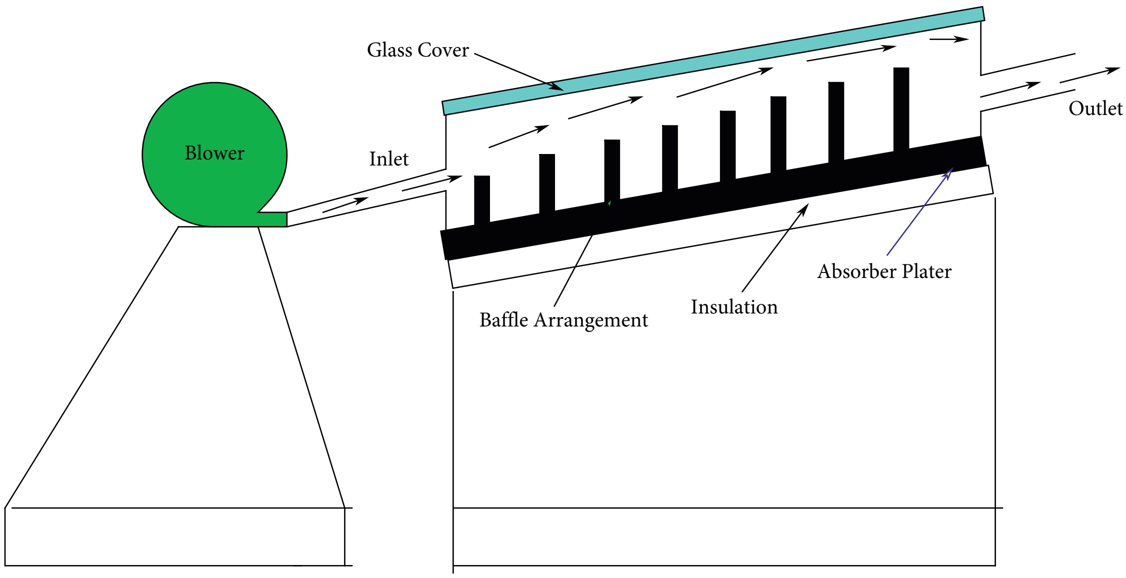

FIGURE 1: Schematic view of the solar air heating system.

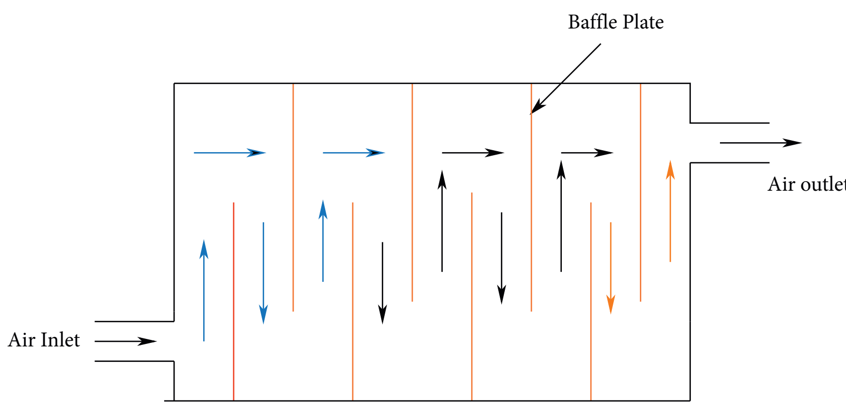

FIGURE 2: Flow of air inside the solar air heater.

TABLE 1: Accuracy and range of measuring instruments.

S.N	Instrument	Accuracy	Range
1	Pyranometer	±1.89%	0 to 1700 W/m^2
2	Thermocouple	1°C	0 to 175°C
2	Anemometer	2%	0 to 25 m/s

$$(Q_u) = \dot{m}\, c_p\, \Delta T. \quad (4)$$

(iv) Energy efficiency

$$\eta = \frac{Q_u}{AI}. \quad (5)$$

(v) Nusselt number =

$$0.023 Re_d^{0.8} \times \mathrm{Pr}^n. \quad (6)$$

3. Results and Discussion

The performance of the flat plate SAH is carried out in three different conditions; they are SAH without a baffle plate, with zinc-ferrite nanocoated baffle plate, and inverted baffle plate. The readings were observed in the climatic conditions of Coimbatore, Tamil Nadu, India.

Figure 3 depicts the outlet temperature of a SAH in relation to solar insolation during the daytime, with and without a baffle, and with and without an inverted baffle. The graph showed that the output temperature of the SAH

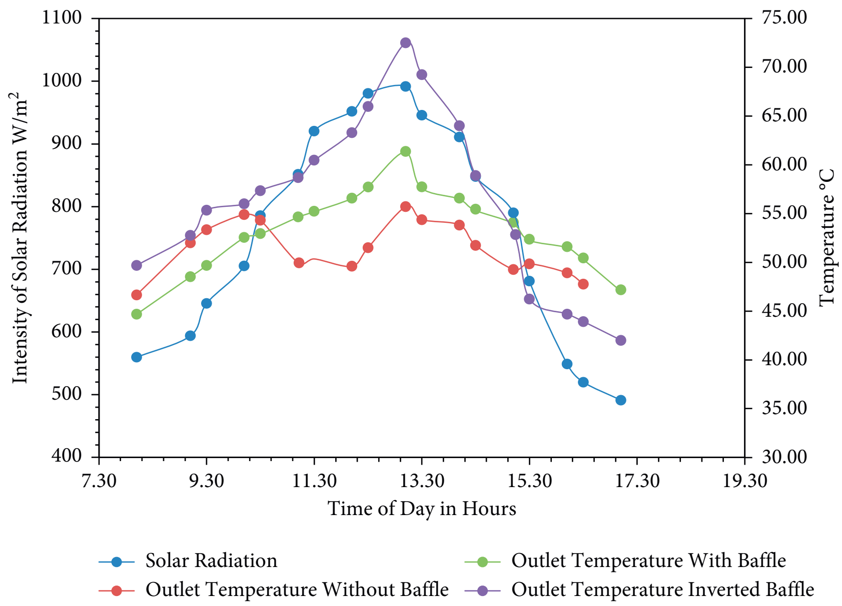

Figure 3: Outlet temperatures with respect to solar radiation of SAH.

gradually increases with solar radiation and that it gradually decreases with solar radiation, as seen in the graph. The highest outlet temperature for all of the above scenarios is 55°C at 980 W/m^2 for SAH without baffle plate, 62°C at 992 W/m^2 for SAH with a baffle plates, and 72°C at 1045 W/m^2 for SAH with inverted baffle plate when exposed to maximum solar radiation.

Figure 4 depicts the beneficial heat gain in W for SAH with, without, and inverted baffle plate in relation to the time of day in hours for SAH with, without, and inverted baffle plate. From 8.00 to 14.00 hours, the useable heat gain increases with the passage of time; after 14.00 hours, the useful heat gain decreases with the passage of time and is also related to the amount of solar insolation received. The highest usable heat gains for SAH without a baffle plate are 178.8 W, for SAH with a zinc-ferrite nanocoated baffle plate is 220 W, and for SAH with an inverted baffle plate is 340 W. The time it takes for air to circulate within the SAH may enhance the useful heat gain.

Experiments were performed both with and without baffle plates, and studies were carried out both with and without an inverted baffle plate. All of these tests were carried out in the SAH with a flow condition of air ranges of approximately 0.01 kg/s and under the climatic conditions of Coimbatore. Among these tests were experiments with and without an inverted baffle plate. As a function of the passage of time during the day, the fluctuations in solar radiation, as well as the temperatures of the air, the glass, and the absorber plate for the SAH with an inverted baffle plate are depicted in Figure 5. When the solar insolation reaches its maximum value of 950 W/m^2, the temperature of the air leaving the building ranges from 60 to 72°C.

The thermal efficiency of the SAH with inverted zinc-ferrite nanocoated baffle plate is depicted in Figure 6 (right). The efficiency of the SAH will rise as the amount of usable heat gain increases. As solar radiation increases, the amount of useful heat gain will increase as well, increasing the efficiency of the SAH. The long air circulation time in the inverted baffle plate results in a large increase in air temperature.

The heat transfer coefficient varies depending on the temperature of the air exiting the system, the Reynolds number, and the Nusslet number. The baffle configurations generate a turbulent flow within the SAH's internal chamber. The heat transmission coefficient is high during the first 12–14 hours of operation because of the increased heat accumulation by the air within the SAH. After that, the amount would gradually decrease. Figure 7 displays the evolution of the SAH's heat transfer coefficient over time.

With respect to the pressure drop, Figure 8 displays the link between the effective thermal efficiency and the effective useful heat gain. When compared to the mass flow rate of 0.010819 kg/s the pressure drop measures around 1.8 bars. The effective thermal efficiency has grown significantly, going from 9 hours to 14 hours when compared to their effective usable heat gain, which is a major increase. When something like this takes place, the value of the effective efficiency drops until it is equal to the value of the effective useful heat gain. Any further increase in the airflow rate will result in a decline in thermal performance as a direct consequence of the increased fan power required to offset the frictional losses brought on by the increased airflow rate.

An energy study was performed on the inverted a baffle plate SAH with a mass flow rate of 0.010819 kg/s, and the results are displayed in Figure 9. The maximum energy gain is about 74.69 W with a solar intensity of 1045 W/m^2 at 1pm; the corresponding energy efficiency is 14%.

3.1. Comparison Analysis. The comparison between the present results with earlier published results is shown in Table 2. The zinc nanocoated solar air heater enhances the thermal efficiency by 21.78%, 59.4%, and 66.23% compared

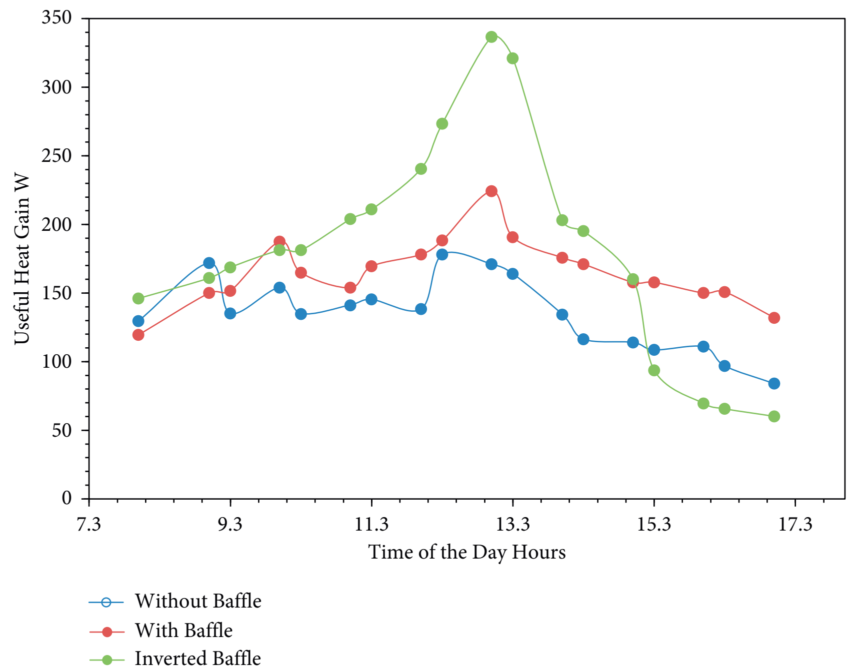

Figure 4: Useful heat gain for SAH without, with zinc -ferrite nanocoated baffle, and inverted baffle plate.

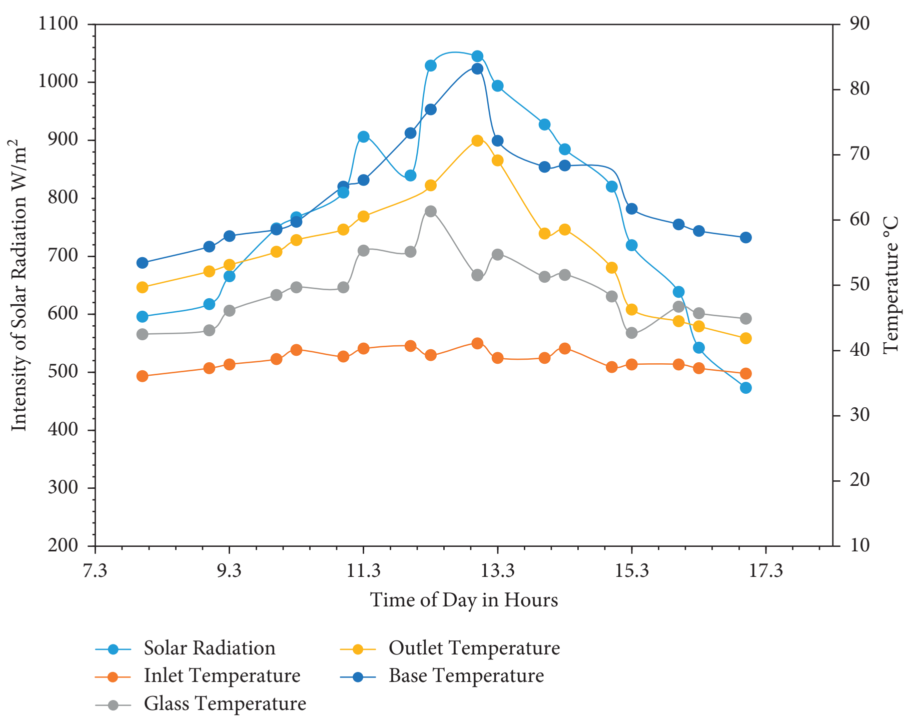

Figure 5: Hourly variations of solar radiation and temperature of air, glass, and absorber plate on day time in hours.

with conventional baffle, sequential array, and staggered array baffled SAH. The zinc-ferrite coating improves the absorptivity of the absorber plate and enhances the temperature differences between the baffled absorber and flowing fluid, which improves the energy efficiency by 70.3%, 26.03, and 7.3%, respectively.

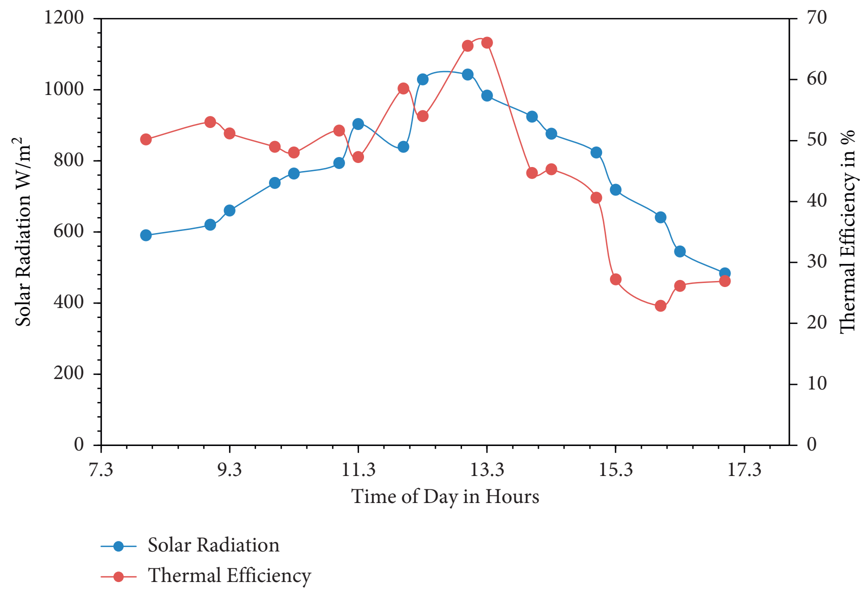

Figure 6: Thermal efficiency of the SAH with inverted baffle plate.

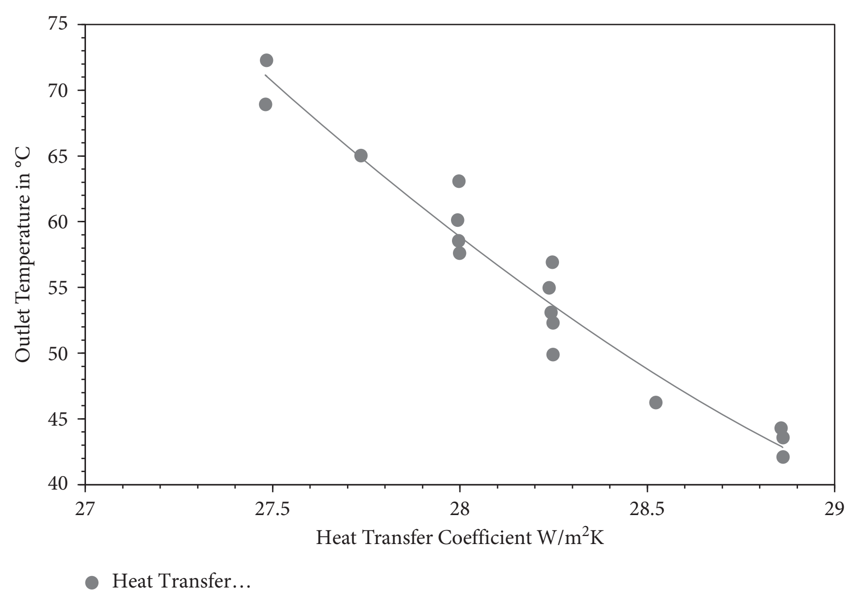

Figure 7: Heat transfer coefficient variation with outlet temperature of air.

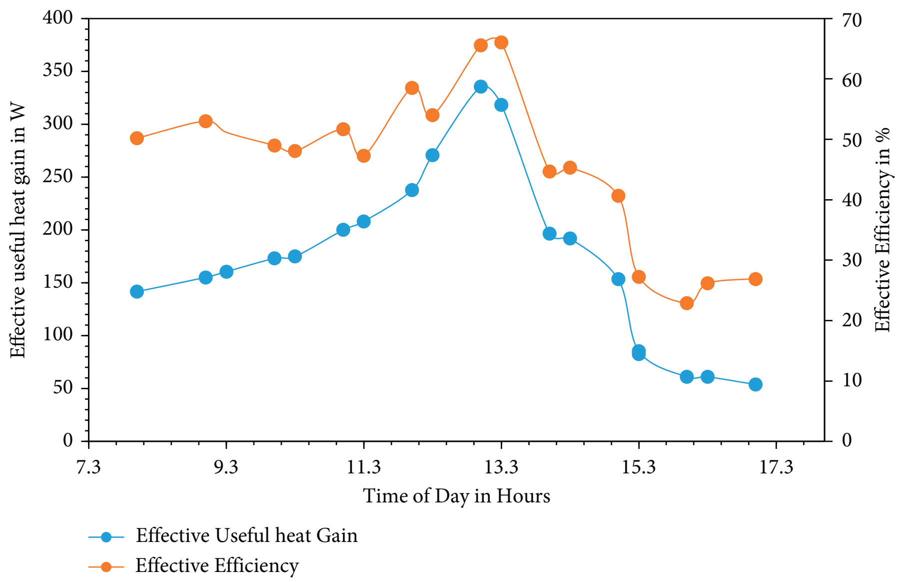

Figure 8: Hourly variations of effective useful heat gain and effective efficiency of the SAH with inverted baffle plate.

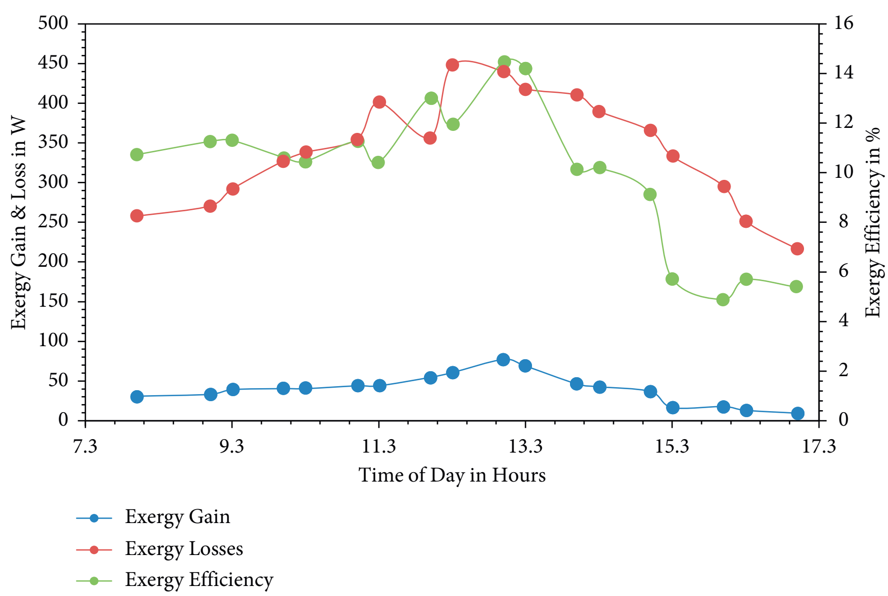

Figure 9: Hourly variations of energy gain, energy loss, and energy efficiency of the SAH with inverted baffle plate.

Table 2: Performance comparison with other configurations of SAH.

Configuration	Thermal efficiency (%)	Thermo hydraulic efficiency	Exergy efficiency (%)	Author
Finned baffle solar air heater	51.64	50.25%	4.3	Mohammadi and Sabzpooshani [36]
Baffled solar air heater-sequential array	26.78	—	10.71	Ghiami and Ghiami [37]
Baffled solar air heater-staggered array	22.29	—	13.41	Ghiami and Ghiami [37]
Zinc-ferrite nanocoated baffles in SAH	66.02	64.49%	14.48	Present work

4. Conclusion

In an experiment, a flat plate SAH was put through its paces using a baffle plate absorber. After careful thought, it can be said that the performance of the flat plate SAH was good. The highest temperature of the air coming out of the collector without baffles was 55°C, while the highest temperature of the air coming out of the collector with baffles was 62°C and the highest temperature of the air coming out of the collector with inverted baffles was 72°C. In this study, it was also found that the thermal efficiency of flat plate collectors without baffles, with baffles, and with inverted baffles was 36%, 44%, and 54%, respectively. It was found that the output of the traditional SAH with an upside-down baffle plate was better than in the other two cases. It maintains the electric transformer at 50°C, improves its operating performance, and also produces hot air for industrial applications. In subsequent research, a wide variety of nanoparticle kinds and concentrations may be utilized in order to examine the thermal behavior of this change.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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