Performance Analysis of Solar Air Heater by Modified Absorber Plate

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Abstract

Introduction: In the realm of sustainable energy, solar air heating systems have emerged as crucial contributors, utilizing solar radiation to generate heat for diverse applications. This research focuses on augmenting system efficiency by integrating a blower and a double-pass air flow mechanism, aiming to optimize heat transfer and enhance overall performance. The innovation seeks to address challenges in conventional solar air heating, promising improved sustainability and energy utilization. Through meticulous experiments and the utilization of advanced instrumentation, the study explores system behavior in varying environmental conditions. The outcomes showcase substantial efficiency enhancements, reaching an instantaneous efficiency of 95.39%, providing essential insights for the advancement of solar air heating technology across industries.

Materials and Methods: This study introduces an innovative solar air collector system designed to optimize functionality. The system comprises alloy steel inlet and outlet ducts with carefully designed dimensions to control air velocity and enhance heat transfer efficiency. The collector box, constructed from robust stainless steel, incorporates a transparent glass insulator and a high-performance aluminum absorber plate with double-sided V-shaped pins. Precision instruments, including temperature sensors, a solar power meter, an angle finder, a digital anemometer, and an air quality meter, were strategically employed for data acquisition. The experiment, conducted in an outdoor laboratory, involved maintaining a constant airflow of 3.21 m/s - 4.10 m/s using a blower. Data collection included solar radiation, air velocities, temperatures, and humidity. The comprehensive data analysis aimed to assess heat transfer efficiency, air circulation dynamics, and system performance under varying environmental conditions.

Results: The solar air heating system demonstrated impressive performance over three days. Inlet temperatures ranged from 35.3°C to 45.7°C, with outlet temperatures varying between 44.7°C and 59.5°C. The system exhibited efficient heat transfer, reflected in a steady rise of heat absorption from 23,771 J to 47,479 J. Inlet velocity increased from 3.21 m/s to 4.07 m/s, while outlet velocity reached 2.4 m/s. The overall efficiency rose from 54.36% to an impressive 94.09%.

Conclusions: The examined solar air heating system (SAH) demonstrates a noteworthy efficiency boost of 95.39%, notably during peak hours (12:00 PM to 3:00 PM) due to a Blower and double-pass air flow mechanism. This efficiency surge leads to consistent temperature rise reductions (9.9°C to 14.9°C), positioning SAH as a promising sustainable energy solution, with implications for diverse industries. The study's key findings, including a mass flow rate of 2.642244 Kg/s and heat absorption of 47479.53933 Joules, set crucial benchmarks for future advancements in solar air heating systems.

Keywords: Solar Air Heating System; Thermal Performance; Efficiency Metrics; Solar Radiation Influence; Sustainable Energy Systems

1. Introduction

In our modern world, the demand for vast and sustainable energy resources is escalating due to the growing energy needs of societies and the imperative to address environmental pollution [1, 2, 3]. To meet this challenge, researchers have pursued innovative methods, including Solar Air Heaters (SAHs), as a cost-effective means of harnessing solar energy for heating in residential and industrial settings [4, 5]. These SAHs offer various configurations and techniques to enhance their thermal performance, including integration with buildings and other energy systems [6, 7, 8]. Building-integrated SAHs and other advanced solutions have been extensively explored to bolster thermal efficiency while reducing energy consumption [9, 10, 11]. Additionally, researchers have delved into the integration of SAHs with phase change materials (PCMs) and photovoltaic modules to enhance overall system efficiency and mitigate emissions [12]. However, despite these commendable advancements, conventional SAHs grapple with challenges pertaining to cost-effectiveness and installation complexities. This work opens a new era in the operation of solar heating systems by introducing a method that combines two different types of materials, asphalt SAH and perforated metal SAH. By capitalizing on the inherent strengths of each collector type, this innovative paradigm aspires to augment the overall system performance of solar air heating, rendering it more accessible and effective across diverse applications. In a world where the global drive toward sustainable energy solutions is paramount, the fusion of these collector types within solar air heating represents a promising stride toward a cleaner, more sustainable energy landscape. Solar energy, renowned for its cleanliness and renewable characteristics [13], presents vast potential for a multitude of low-temperature applications, including agricultural product drying [14]. However, traditional open sun drying methods continue to persist in rural areas across China, such as Xinjiang Province for grape drying [15], Henan and Shandong Provinces for peanut drying [16, 17] and Yunnan Province for drying Panax Notoginseng, traditional herbal medicine [18, 19]. Despite its simplicity, outdoor drying has some limitations, including long drying times, good drying quality, and high product loss due to insufficient drying. [20]. To overcome these limitations, various dryers have been developed to improve drying performance and quality [21]. Solar air heating systems have gained immense significance as sustainable and energy-efficient solutions for a wide range of thermal applications. These systems capitalize on the abundant and renewable resource of solar energy to heat air, offering a clean and eco-friendly alternative to conventional heating methods. Central to the effectiveness of these solar air heating systems is the absorber plate, a critical component responsible for capturing and efficiently transferring solar energy to the surrounding air. In recent years, researchers and designers have been interested in finding new ways to improve the performance of solar heating systems by replacing their holders with heat-absorbing panels. These modifications encompass a spectrum of alterations encompassing design enhancements, novel materials utilization, and advanced coatings. The general purpose of these innovations is to improve heat absorption and the ability to transfer energy that has the potential to be effective from solar heat to new generation energy. In this comprehensive study, we delve into the intricacies of a solar air heating system that incorporates a meticulously modified absorber plate. Our primary objective is to rigorously evaluate the real-world impact of these absorber plate modifications, scrutinizing parameters such as thermal efficiency, heat transfer rates, and precise temperature control. Beyond the technical aspects, we also delve into the economic feasibility of implementing this advanced solar air heating system, thus bridging the gap between theoretical innovation and practical applications. In an era where sustainable energy solutions are paramount, harnessing the full potential of solar power through advancements in solar air heating technology holds the key to a greener, more sustainable future. This study serves as a critical step in this trajectory, shedding light on the tangible benefits and potential practical implications of innovative absorber plate designs within solar air heating systems.

In Bangalore, India, the examination of solar air collectors (SACs) revealed that incorporating sand coatings of varied grain sizes significantly improved energy efficiency and raised outlet temperatures, showcasing a promising sustainable approach for solar heating [22]. Solar thermal heating (SAH) and solar water heating (SWH) offer environmentally friendly and cost-effective solutions to the energy needs of regions such as Gaza, using renewable solar energy to produce heat and water beneficial to the region and the economy sectors [23]. Combining perforated metallic and asphalt solar air heaters achieves an 80% afternoon efficiency, utilizing the asphalt heater's space-efficient energy storage and the perforated heater's early morning high-temperature output for a sustainable heating system [24]. Recent research emphasizes the potential of solar air heaters, particularly the use of twisted rib turbulators to enhance heat transfer efficiency and optimize exergetic efficiency for maximizing energetic performance[25]. This study explores the performance enhancement of solar air heaters through the integration of staggered/longitudinal finned absorber plates with aluminum sponge porous material, demonstrating significant improvements in energetic and exergetic performance, air temperature ratios, daily exergy efficiencies, and convective heat transfer coefficients, making it a promising approach for applications such as solar drying[26]. Evaluation of solar heat exchanger with modified absorber plates with square barrier and threaded pin fins shows superior performance by solving the problem of lack of heat transfer in plain air. Environment. and economics demonstrate the potential to increase the efficiency and sustainability of solar heating [27]. By examining the thermal and hydraulic performance of a solar water heater with a grooved absorber surface, this study shows that optimized designs with specific angles, features, and Reynolds number can improve convective heat transfer when energy efficiency is taken into account [28]. This study proposes that the voltage is greater than the temperature to improve the cost and output value and provide 24-hour temperature backup above ambient. emphasizing the importance of temperature and air circulation and providing negative feedback to improve performance [29]. This study uses CFD modeling to evaluate the performance of an indirect solar generator with V-shaped slotted absorber panels and multi-hole panels, trying to evaluate the model and improve the efficiency of drying different products. [30]. This study investigates enhanced solar collector thermal efficiency through V-shaped corrugations on the absorber plate, optimizing incidence angles and introducing new convection correlations, emphasizing the positive impact of V-groove corrugations, selective absorption layers, surface selectivity, internal vacuum, and directional selectivity [31]. A novel solar air collector design employing parallel corrugated aluminum plates demonstrated substantial pear drying with a noteworthy mass reduction from 997.3g to 135.13g over 24 hours, achieving a thermal efficiency of 11.11%, emphasizing its applicability for crop preservation and the potential of solar energy in developing countries [32]. This study investigates the effectiveness of solar panels in drying flowers using galvanized steel panels, black clear glass and closed pipes, and demonstrates the potential of using solar energy to dry produce, particularly when potassium metabisulfite is used as the dryer[33]. This literature review explores flat plate solar collectors, focusing on their applications in solar drying, encompassing fundamental mechanisms, collector types, energy and exergy analyses, experimental results, integration with heat pumps and biomass furnaces, and their efficacy in drying marine and agricultural products, urging additional research on economic aspects and hybrid photovoltaic solar collectors [34]. This study presents a solar greenhouse hybrid dryer combined with photovoltaic systems and solar collectors for the processing of small tomatoes, utilizing mathematical models to study the effect of pre-treatment and compare the good final product with open air dry and measure the energy consumption to ensure good health [35]. This literature review examines the performance of four solar panels incorporating materials such as design and solar radiation, showing that the collector with 75° angled fins exhibits the best performance from the collector and temperature rise studied [36]. An experimental investigation of a solar air heating system with a V-corrugation absorber plate, surface-modified using shot-blasting technology, reveals improved thermal efficiency and CO2 mitigation potential for preserving agricultural produce by reducing moisture content [37]. This study uses random forest, linear regression, and K nearest neighbor machine learning model to evaluate the thermal performance of solar heating with C-shaped finned absorber panels, friction factors and overall efficiency [38]. The experimental research demonstrates that the modified v-corrugated absorber plate in Model-1 Solar Air Heater outperforms the normal Model-2, showing 11.5% to 14.5% higher thermal efficiency across various airflow rates, with improved heat exchange efficiency attributed to the perforation jet configuration, minimal environmental impact, slightly higher pressure drop in Model-1, but overall cost-effective for room heating compared to a Split unit, suggesting future research avenues in theoretical modeling, optimizing duct locations, and exploring enhancements like mirrors, porous materials, and solar cells [39]. The study revealed that ribbed surface roughness, utilizing black paint infused with graphene nanoparticles in solar air heaters, led to lower thermal efficiency compared to smooth plates, with a notable 4.56-5.34%

improvement observed for roughened absorber plates under specific solar intensities[40]. In particular, tubular cyclonic solar heating with radial fins using five fins and 0.050 kg/s air flow showed good thermal and hydrothermal efficiencies in an experimental setup in Egypt; here this was realized by factors such as solar radiation and temperature and disappointingly, financial analysis reveals that the cost of obtaining thermal energy is decreasing [41].

The problem at hand revolves around the optimization of solar air heaters to enhance their efficiency while addressing sustainability and energy conservation concerns. Traditional solar air heaters often struggle with low thermal efficiency due to limitations in their absorber plate design. Many existing designs rely on electricity, leading to higher energy consumption and potential environmental impacts. Moreover, there is a lack of research on solar air heaters with modified absorber plates, which could potentially offer more efficient and pollution-free operation. Additionally, there is a growing need for sustainable solutions in agricultural waste management, where solar air heaters could play a role. To solve these problems, the solar heating system with modified heat sink panels must be evaluated by taking into account factors such as collector efficiency, slope angle, and air flow rate. This project addresses these challenges by analyzing the performance of a solar thermal system equipped with modified absorber panels. New design includes two-sided V-pins on the heat sink to improve heat dissipation. Additionally, this project aims to achieve the following:

1. Assess the thermal efficiency and heat transfer characteristics of the modified solar air heater.
2. Investigate the influence of varying angles of inclination and air flow rates on collector performance.
3. Develop a pollution-free, human-powered solar air heater capable of converting vegetable waste into high-quality composite fertilizer.
4. Provide recommendations for improving the modified solar air heater's design and potential applications in sustainable agricultural waste management.

By addressing these challenges and objectives, this project aims to contribute to the development of energy-efficient, eco-friendly solar air heater technology and sustainable agricultural practices.

The existing body of research highlights limitations in the efficiency and practicality of traditional solar air heaters, prompting the need for innovative enhancements. This study introduces a novel approach by modifying the absorber plate with double-sided V-shaped pins, with a focus on evaluating the resulting improvements in efficiency and heat transfer capabilities. Moreover, the research introduces an inventive, pollution-free, human-powered solar air heater capable of converting vegetable waste into valuable composite fertilizer, addressing critical challenges in agricultural waste management. The primary objective of this project is to tackle existing issues in solar air heating technology, striving to enhance efficiency, investigate various angle and airflow rate configurations, and develop an eco-friendly and practical heating solution. By accomplishing these goals, this project seeks to advance energy-efficient solar air heaters while promoting sustainable agricultural practices, ultimately benefiting both the environment and the economy.

2. Methods and Methodology

2.1 Experimental Set-up

The experimental setup incorporates a solar air collector system, carefully designed with specific features to optimize its functionality. This setup includes duct for both the inlet and outlet air which is made up of alloy steel material, crafted from durable alloy steel material. The inlet duct, initially 20 cm wide and later diverging to 57 cm, is designed to reduce the velocity of the incoming air, while the outlet duct, also made of alloy steel, is engineered to increase it velocity. Circular gaps integrated into both ducts ensure a smooth and uninterrupted airflow during the experiment. The solar air collector itself is constructed as a rectangular box using robust stainless steel material, with precise dimensions of 95 cm in length, 57 cm in width, and 20 cm in height. It features a 4 mm thick transparent glass plate on the upper part, acting as insulator. Inside the collector, an aluminum absorber plate is strategically positioned, measuring 45 cm in length and 90 cm in width. This absorber plate boasts double-sided V-

shaped pins, maximizing heat absorption and promoting optimal heat transfer efficiency.
Figure 1 & Figure 2 depicts a schematic diagram of solar air collector experimental setup (Front view and Side view).

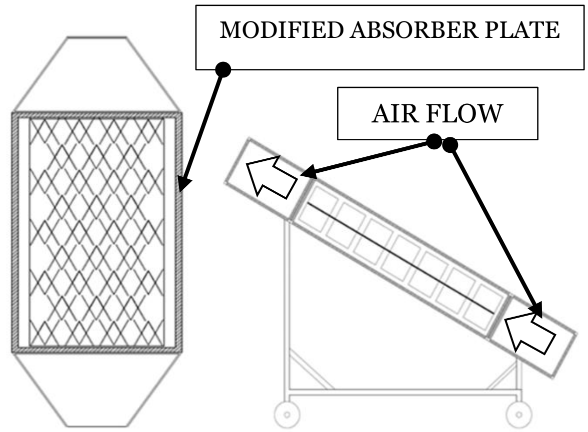

Figure no 1: Shows Front View

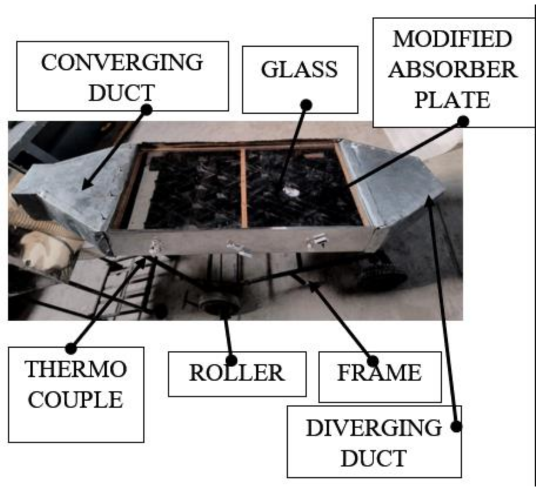

Figure no 2: Shows Side View

Figure 3 depicts a Fabrication Model of solar air collector experimental setup

2.2 Instrumentation and Data Acquisition

The experimental setup employs a broad variety of high-precision sensors to gather data, ensuring accurate and comprehensive measurements. Precise monitoring of temperature variations is made possible by these devices, which have high-precision temperature sensors placed strategically on the collector's surface as well as inside the inlet and outflow ducts.

Table no 1: Shows Measuring Equipment used in the Experiments.

NAME	**ACCURACY And MEASURING RANGE**	**FUNCTION**
Extech EA80-EasyView indoor Air Quality and CO2 Meter/ Datalogger	±3% of reading or ±50 ppm & 0 to 6000 ppm	Real-time monitoring of humidity or CO2 levels in solar air collector environments
Tenmars TM-207 Solar Power Meter	± 10 W/m2 [± 3 BTU / (ft2xh)] or ± 5% & 2000 W/m2, 634BTU / (ft2xh)	Measures solar radiation to assess the efficiency of solar collectors
BTMETER BT-846A PRO HVAC Anemometer	± 3% or ± 0.2 reading & Higher Range Speed range: 0.001-100 mph Air Temperature range 32.0 º – 113.0 º F (0-45ºC	Measures air velocity to optimize airflow through the collector
ClC Tools Angle Finder (4 Inch) magnetic Base	Accuracy within ½ of 1 degree & 0-90 Degrees	Helps in adjusting the angle of the solar collector for optimal sunlight exposure
TPM-10 LED Digital Thermometer Sensor Meter	Temperature measuring accuracy: 1ºC & Temperature range: 50 - 110ºC	Monitors temperature in the solar air collector

The solar radiation intensity is measured and recorded using a solar power metre (Tenmars TM-207), which provides vital information for comprehending the energy intake. To help choose the best location for the solar air collector to absorb solar energy, an angle finder (4-1/8" angle finder with a magnetic base) is also used to measure the orientation and angle of the collector precisely. Air velocities at the inlet and exit ducts are measured and recorded using a digital anemometer (Btmeter BT-846A Pro HVAC Anemometer) to evaluate the effectiveness of air circulation. Additionally, an indoor Air Quality metre (Extech EA80- EasyView) is used to measure and track the humidity levels at the collector's input and output in order to keep an eye on how humidity affects the system's operation. The measuring tools used in the studies are displayed in Table 1. With the help of this extensive instrument suite, it is possible to gather the vital information required to assess the solar air collector system's performance in a range of environmental circumstances.

2.3 Experimental procedure

The experimental procedure was conducted at the outdoor lathe laboratory of Kongu Engineering College, India, during bright and sunny days from 9 AM to 3 PM. The solar air collector, featuring alloy steel inlet and outlet ducts, was positioned to receive maximum solar radiation throughout the experimental duration. A blower attached to the inlet duct maintained a constant airflow of 3.21 m/s - 4.10 m/s within the system, ensuring consistent air circulation. Throughout the experiment, precise measurements of solar radiation, air velocities, temperatures, and humidity were recorded at regular intervals to monitor the dynamic changes within the collector and ducts. Special attention was given to the temperature variations facilitated by the transparent glass plate, which effectively intensified solar radiation on the absorber plate within the collector. Data collected from the various instruments, including temperature sensors, a solar power meter, an angle finder, a digital anemometer, and a hygrometer, provided valuable insights into the system's performance under varying environmental conditions. The systematic data collection approach aimed to comprehensively analyze the system's heat transfer efficiency, air circulation dynamics, and the influence of solar radiation on temperature changes and overall system performance.

2.4 Mathematical Equation

The heat absorbed by the solar air collector (Q_s) is calculated using the equation 1:

$$\mathrm{Q_S} = \mathrm{MC_P}(\mathrm{T_{OUT}} - \mathrm{T_{IN}}) \quad (1)$$

The efficiency of the solar air collector system (η_{EE}) is determined by the equation 2:

$$\eta_{EE} = \frac{Q_S}{Q_{ab}} = \frac{MC_P(T_{OUT}-T_{IN})}{I_S A_C} \quad (2)$$

The overall efficiency of the system (η_{eff}), accounting for the energy used by the fan (P_{fan}), is calculated by the equation 3:

$$\eta_{eff} = \frac{Q_s - P_{fan}}{Q_{ab}} \quad (3)$$

This set of mathematical formulations provides the framework for analyzing the heat absorption, efficiency, and Overall Efficiency aspects within the solar air collector system

2.4 Uncertainty analysis

Experiments were run three times to guarantee data consistency in the face of fluctuating sun radiation. Prior to computation, the test data were subjected to weighted average statistical analysis. Uncertainties regarding mass flow rate, air temperature, air velocity, solar radiation, heat absorbed by the solar air collector, efficiency of the solar air collector, and overall efficiency of the solar air collector are computed and listed in Table 2 using the propagation of error method[42]. Equation 4 was utilized to evaluate the bias error and determine the uncertainty values.

$$B = \pm\left[\left(\frac{1}{2}Resolution\right)^2 + (Accuracy)^2\right]^2 \quad (4)$$

Table no 2: Shows Uncertainly Details.

Parameter	Uncertainties
Solar Radiation	±5 W/m2
Temperature Rise	±0.1 ºC
Inlet Velocity	±0.05m/s
Mass Flow Rate	±0.02 Kg/s
Heat Absorbed	±50 Joule
Efficiency	±0.5%
Overall Efficiency	±0.5%

3. Results and Discussion

3.1 Intel and Outlet Temperature with Day Time

The graph figure 4 depicts the performance of a solar air heater (SAH) over three days, showcasing a consistent increase in both inlet and outlet air temperatures from 9:00 AM to 3:00

PM. Inlet temperatures ranged from 35.3°C to 45.7°C, while outlet temperatures varied between 44.7°C and 59.5°C. This indicates the SAH's efficient heating capability, particularly during peak solar intensity at 3:00 PM.

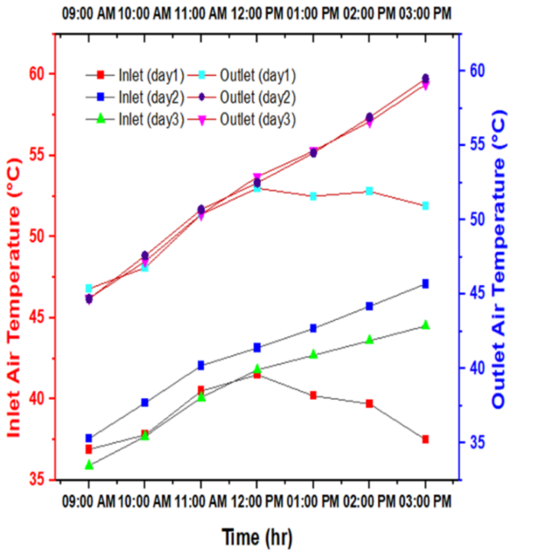

Figure no 4: Shows Variation of Inlet & outlet temperature with time

The morning hours witnessed a gradual rise in temperatures (9:00 AM - 10:00 AM), signaling the SAH's initiation of solar energy absorption. Late morning and early afternoon (11:00 AM - 12:00 PM) exhibited a significant temperature increase, highlighting improved heat transfer efficiency. Afternoon (1:00 PM - 3:00 PM) showcased peak performance with stable inlet temperatures and rising outlet temperatures, peaking at 59.5°C. The consistent temperature differential implies sustained and effective heat transfer within the collector. These results underscore the SAH's potential for applications requiring elevated temperatures, making it promising for sustainable and energy-efficient solutions in diverse settings, including space heating and industrial processes.

3.2 Intel and Outlet Velocity with Day Time

The Inlet Velocity and Outlet Velocity of the solar air heating system in figure 5, measured in meters per second (m/s), exhibit interesting patterns throughout the day, reflecting the performance dynamics of the system. The Inlet Velocity starts at 3.21 m/s at 9:00 AM and experiences a gradual increase, peaking at 4.07 m/s by 3:00 PM. This rising trend indicates an efficient utilization of solar energy, leading to improved airflow into the system. The morning hours witness a steady rise, suggesting enhanced air circulation as the system initiates solar energy absorption.

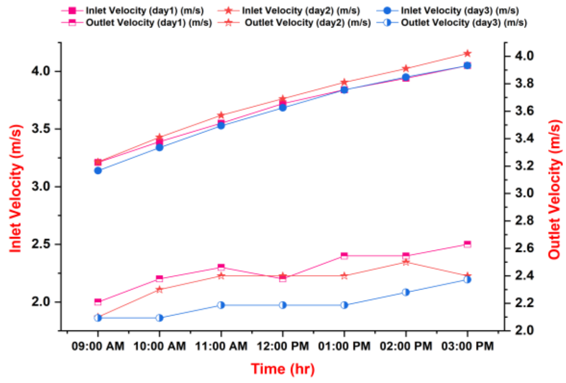

Figure no 5: shows Variation of Inlet & outlet velocity with time

Concurrently, the Outlet Velocity shows a similar pattern, starting at 2 m/s at 9:00 AM and reaching 2.4 m/s by 3:00 PM. The consistent increase in outlet velocity throughout the day signifies effective heat transfer and energy conversion within the solar air heating system. The afternoon period (1:00 PM - 3:00 PM) particularly demonstrates the system's peak performance, indicating optimal heat exchange and efficient utilization of solar radiation.

3.3 Heat Absorption with Day Time

Figure 6 displays the performance of a solar air heater (SAH) over three days. The experiment measured the heat absorption (Qs) of a solar air heating system from 9:00 a.m. to 3 p.m. The results show a continuous and progressive increase in heat absorption, demonstrating the system's ability to collect solar energy throughout the day.

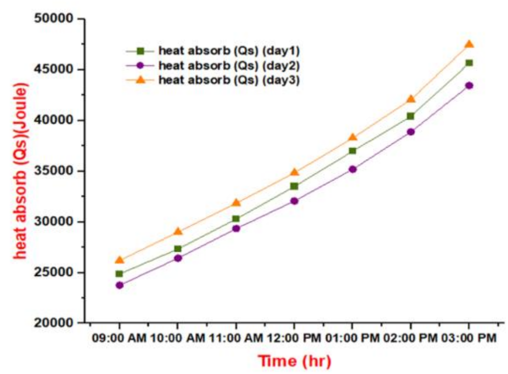

Figure no 6: Shows Variation of heat absorb with time

In the morning hours (9:00 AM - 10:00 AM), heat absorption ranged from 23,771 J to 26,431 J, signifying the system's initial solar energy absorption. As the morning progressed into late morning and early afternoon (11:00 AM - 12:00 PM), a substantial rise in heat absorption occurred, with values ranging from 29,348 J to 35,199 J, highlighting improved heat transfer efficiency. The afternoon period (1:00 PM - 3:00 PM) showcased the system's peak performance, reaching the highest heat absorption values between 38,878 J and 47,479 J, aligning with maximum solar intensity. The consistent upward trend in heat absorption over the three days affirms the solar air heating system's capability to accumulate significant solar energy efficiently. These findings underscore the practical viability of the modified absorber plate, demonstrating its effectiveness in enhancing heat transfer within the collector and promoting sustainable, energy-efficient heating solutions.

3.4 Solar Radiation with day time

The Figure 7 depicts the solar radiation levels measured at different times of the day over a three-day span. At 9:00 AM, the solar radiation starts at 824 W/m² and progressively increases, reaching its peak at noon with a value of 950 W/m². Subsequently, the radiation begins to decrease, reaching 840 W/m² by 3:00 PM. These fluctuations correspond to the natural variations in sunlight intensity throughout the day.

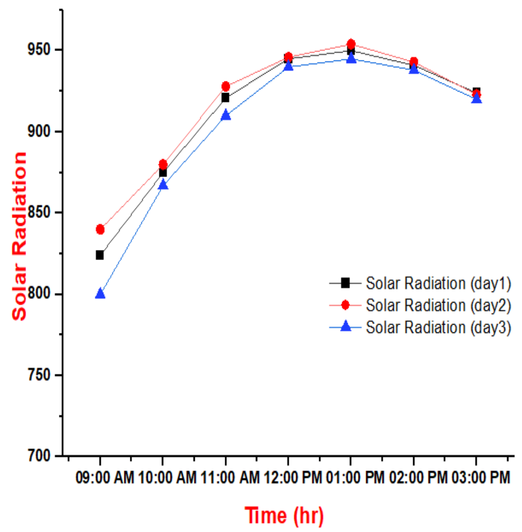

Figure no 7: Shows Variation of Solar Radiation with time

In the morning, the rising solar radiation aligns with the increasing angle of the sun in the sky, reaching its highest point at noon. The subsequent decline is influenced by changing solar positions and atmospheric conditions, forming a typical daily radiation pattern. The recorded solar radiation values are crucial as they directly impact the heat absorption capability of the solar air heating system. Specifically, the system demonstrates optimal heat absorption during the peak radiation period around noon, highlighting its efficiency in utilizing solar energy for heat generation.

3.5 Change in Temperature with Day Time

The Figure 8 represents the temperature rise within a solar air heating system across three days, showcasing a consistent and progressive increase in temperature from 9:00 AM to 3:00 PM. The morning hours exhibit an initial rise of 9.9°C at 9:00 AM, followed by a steady ascent, peaking at 14.9°C by 3:00 PM. This pattern aligns with the solar radiation's heightened intensity during midday.

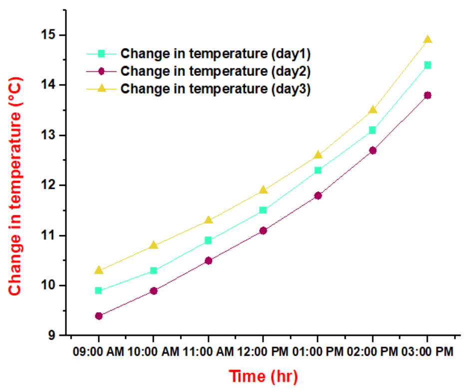

Figure no 8: Shows Variation of Temperature Rise with time

The temperature rise readings, ranging from 9.9°C to 14.9°C, highlight the system's efficiency in capturing and retaining solar heat. The morning increments suggest effective solar energy absorption, while the peak at 3:00 PM indicates optimal heat retention. Such consistent and substantial temperature rise signifies the system's reliability and its potential for various applications requiring sustained high temperatures.

3.6 Efficiency with Day Time

The efficiency graph figure 9 illustrates the performance of a solar air heating system over three days, showcasing an upward trend in efficiency percentages from 9:00 AM to 3:00 PM. The morning hours begin with an efficiency of 55.81%, gradually increasing and peaking at an impressive 95.39% by 3:00 PM. This observed pattern is in direct correlation with the rise in solar radiation intensity during midday.

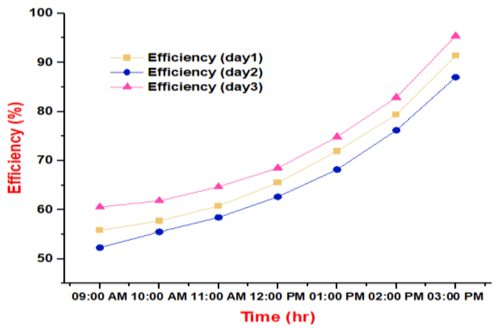

Figure no 9: Shows Variation of Efficiency with time

The efficiency readings, ranging from 55.81% to 95.39%, signify the system's ability to effectively convert solar radiation into usable heat energy. The morning efficiency values suggest the system's initialization of solar energy absorption, while the peak efficiency at 3:00 PM demonstrates optimal utilization and retention of solar heat.

3.7 Overall Efficiency with Day time

The overall efficiency figure 10 of the solar air heating system, accounting for the energy consumption of the fan (P_{fan}), exhibits a noteworthy increase from 9:00 AM to 3:00 PM over three days. The fan power consumption remains constant at 650 Watts throughout the day.

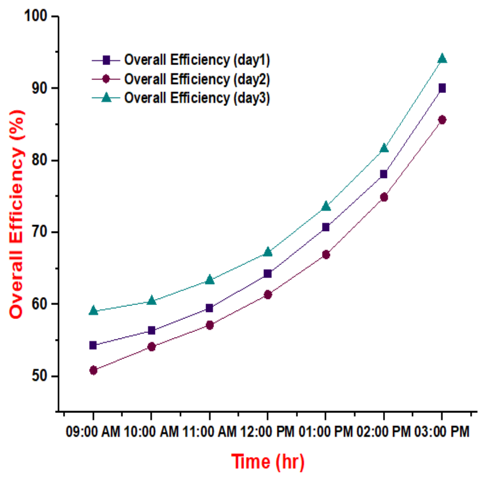

Figure no 10: Shows Variation of Overall Efficiency with time

Starting at 54.36% at 9:00 AM, the overall efficiency gradually rises, reaching 94.09% by 3:00 PM. This indicates the system's ability to effectively utilize solar radiation for heating, even when accounting for the energy required to operate the fan. The morning hours witness a steady climb in efficiency, reflecting the initiation of solar energy absorption and heat transfer within the collector. The peak overall efficiency of 94.09% at 3:00 PM signifies optimal performance during the period of maximum solar intensity. This result is particularly promising, considering the inclusion of the fan's energy consumption in the calculation. The overall trend underscores the system's potential for providing efficient and sustainable thermal solutions.

3.8 Mass Flow Rate with Day Time

The Mass Flow Rate, measured in kilograms per second (Kg/s) in figure 11, exhibits notable variations throughout the day, providing insights into the efficiency of the solar air heating system. The Mass Flow Rate starts at 2.083932 Kg/s at 9:00 AM and undergoes a consistent increase, peaking at 2.642244 Kg/s by 3:00 PM. This upward trend indicates a gradual enhancement in the rate at which air passes through the system, suggesting effective heat transfer and energy conversion.

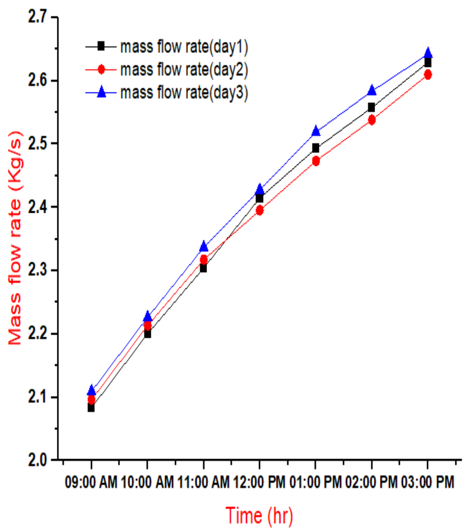

Figure no 11: Shows Variation of Mass Flow Rate with time

During the morning hours (9:00 AM - 10:00 AM), the Mass Flow Rate experiences a steady rise, reflecting the system's initiation of solar energy absorption. As the day progresses into late morning and early afternoon (11:00 AM - 12:00 PM), a more significant increase in the Mass Flow Rate is observed, suggesting improved heat transfer within the collector and increased overall system efficiency. The afternoon period (1:00 PM - 3:00 PM) showcases the system's peak performance, with a relatively stable Mass Flow Rate and a continuous rise, peaking at 2.642244 Kg/s by 3:00 PM. The sustained high Mass Flow Rate during this time indicates effective and continuous heat transfer within the solar air heating system.

3.9 Intel and Outlet Temperature with Mass Flow Rate

The solar air heating system displays a pronounced positive correlation between Mass Flow Rate and Inlet/Outlet Temperatures in figure 12, underscoring its efficient heat transfer capabilities. Throughout the day, as Mass Flow Rate steadily increases from 2.083932 kg/s to 2.642244 kg/s, both Inlet and Outlet Temperatures exhibit a consistent upward trend.

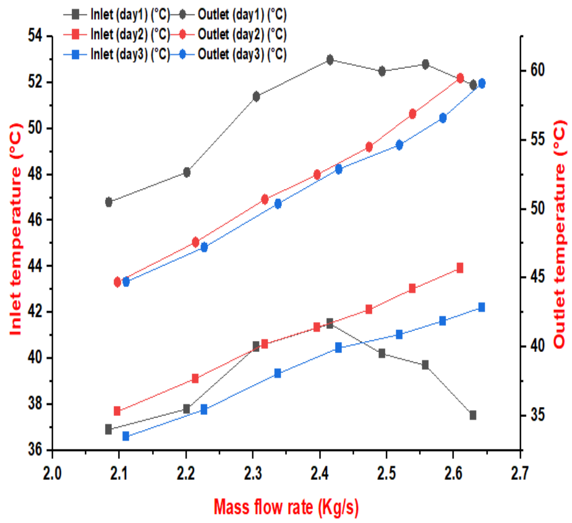

Figure no 12: Shows Variation of inlet & outlet Temperature with Mass Flow Rate

In the morning hours, a gradual temperature rise from 36.9°C to 44.7°C signifies the initiation of solar energy absorption. The period between 11:00 AM and 12:00 PM witnesses a substantial temperature surge, indicating improved heat transfer within the collector. At 3:00 PM, the peak Mass Flow Rate aligns with the highest Outlet Temperature of 59.5°C, emphasizing the system's effectiveness in harnessing solar energy. The synchronous elevation of Mass Flow Rate and temperatures highlights the system's proficiency in facilitating efficient heat exchange.

3.10 Heat Absorption with Mass Flow Rate

The Figure 13 illustrates the correlation between Heat Absorption (Qs) and Mass Flow Rate in a solar air heating system, spanning various time intervals during the day. At 9:00 AM, the system exhibits a Mass Flow Rate of 2.083932 kg/s, resulting in a Heat Absorption of 24880.89772 Joules. As the day progresses, both variables consistently increase, indicating a positive relationship.

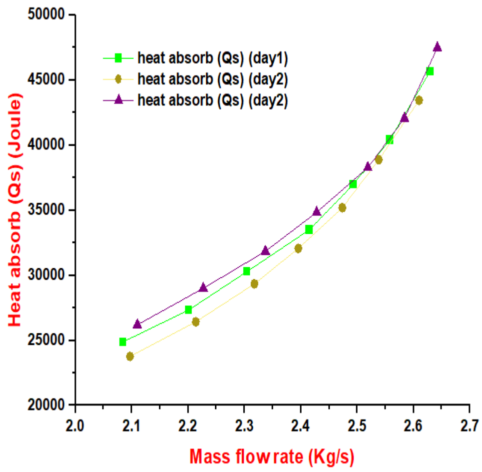

Figure no 13: Shows Variation of Heat Absorb with Mass Flow Rate

By 1:00 PM and 2:00 PM, the Mass Flow Rate peaks at 2.557848 kg/s and 2.62926 kg/s, correspondingly yielding elevated Heat Absorption values of 40410.41741 J and 45660.78086 J. This signifies the system's efficiency in harnessing solar energy during peak sunlight hours. The trend continues into the afternoon, with Heat Absorption reaching its zenith at 3:00 PM (47479.53933 J) when the Mass Flow Rate attains its highest value of 2.642244 kg/s.

3.11 Solar Radiation with Mass Flow Rate

The Figure 14 depicts the interdependence of Solar Radiation and Mass Flow Rate in a solar air heating system throughout the day. At 9:00 AM, Solar Radiation is 824 W/m², coupled with a Mass Flow Rate of 2.083932 kg/s. As the day progresses, Solar Radiation fluctuates, impacting the corresponding Mass Flow Rate, which peaks at 2.473452 kg/s around 12:00 PM.

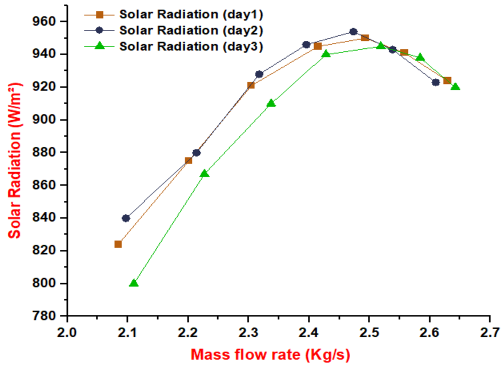

Figure no 14: Shows Variation of Solar Radiation with Mass Flow Rate

The system's responsiveness to changing solar conditions, efficiently adjusting Mass Flow Rate to maximize heat absorption. In the afternoon, as Solar Radiation declines, Mass Flow Rate also decreases, exemplifying the system's adaptive nature. At 3:00 PM, the lowest recorded Solar Radiation (920 W/m²) correlates with a Mass Flow Rate of 2.642244 kg/s, illustrating the system's ability to optimize performance under varying solar intensities.

3.12 Change in Temperature with Mass Flow Rate

The Temperature Rise with Mass Flow Rate graph reveals a crucial relationship in the solar air heating system's performance in figure 15. Across the observed Mass Flow Rates ranging from 2.083932 kg/s to 2.642244 kg/s, there is a consistent upward trend in Temperature Rise, indicating a direct influence of Mass Flow Rate on the system's thermal efficiency.

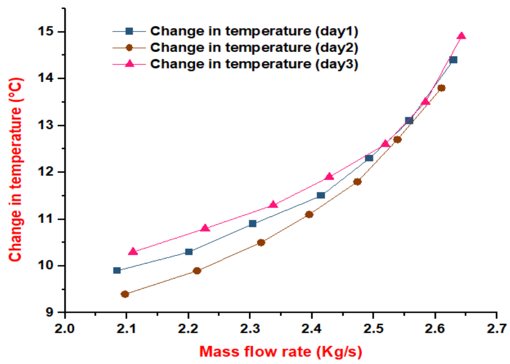

Figure no 15: Shows Variation of Temperature Rise with Mass Flow Rate

As Mass Flow Rate increases, Temperature Rise also climbs, demonstrating the system's ability to absorb and transfer heat more efficiently with a larger volume of air passing through the collector. The system achieves a Temperature Rise of 9.9°C at the lowest Mass Flow Rate and peaks at 14.9°C with the highest Mass Flow Rate, showcasing the system's adaptability to varying flow conditions.

3.13 Efficiency with Mass Flow Rate

The Figure 16 depicts the interplay between Efficiency and Mass Flow Rate in a solar air heating system. With a range of Mass Flow Rates from 2.083932 kg/s to 2.642244 kg/s, the Efficiency follows an increasing trend.

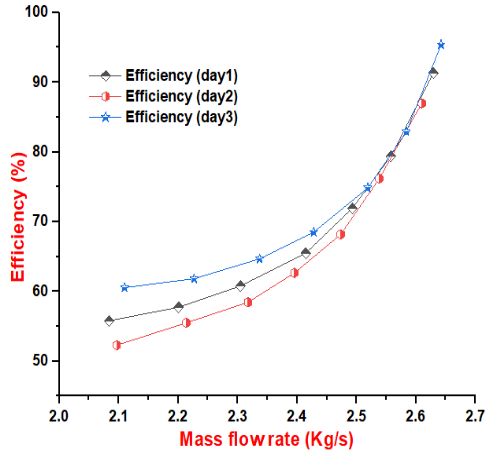

Figure no 16: Shows Variation of Efficiency with Mass Flow Rate

Starting at 55.81379709% for the lowest Mass Flow Rate, the system exhibits a progressive rise in efficiency, reaching its peak at 95.39407565% with the highest Mass Flow Rate.

3.14 Overall Efficiency with Mass Flow Rate

The Overall Efficiency with Mass Flow Rate graph illustrates the impact of varying mass flow rates on the solar air heating system's overall efficiency in figure 17. The data, spanning from 2.083932 kg/s to 2.642244 kg/s, reveals a consistent and positive correlation between mass flow rate and overall efficiency.

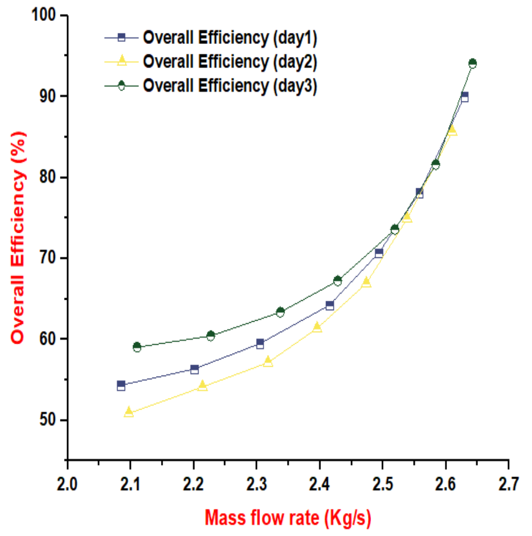

Figure no 17: Shows Variation of Overall Efficiency with Mass Flow Rate

The system begins with an efficiency of 54.36% at the lowest flow rate and exhibits a steady increase, peaking at 94.09% with the highest flow rate.

4. Conclusion

The solar air heating system (SAH) examined in this study exhibits notable efficiency improvements, substantiated by experimental findings. The inclusion of Blower and a double-pass air flow mechanism enhances the system's instantaneous efficiency to approximately 95.39%, particularly during peak hours from 12:00 PM to 3:00 PM. This heightened efficiency contributes to the consistent reduction of temperature rise times, ranging from 9.9°C to a remarkable peak of 14.9°C. The observed reduction in drying time and consistent temperature rise positions the SAH as a promising technology for sustainable energy solutions. The study's significant findings, including a mass flow rate of 2.642244 Kg/s and heat absorption of 47479.53933 Joules, provide crucial benchmarks for future solar air heating system advancements. These results contribute to the ongoing evolution of solar-driven technologies, showcasing the potential for widespread application in various industries.

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