Design Of All-Purpose Solar Air Dryers for Rural Areas

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Abstract — This work presents a numerical analysis of a solar air heater system designed to operate in Vijayawada, a city in India known for its high solar radiation levels. The study utilizes maximum heat flux data specific to the Vijayawada location as the input heat source for the system. The analysis explores the effects of varying Reynolds numbers on the system's performance, specifically focusing on the output temperature, heat transfer coefficient, Nusselt number, and pressure drop. These parameters provide insights into the efficiency and performance of the solar air heater under different operating conditions. In this system, the pipes are constructed using Coca-Cola 350 ml pop tins, which offer a cost-effective and innovative material for the heat exchanger. The solar collector area is designed to be 1 m², with six pipes of 52 mm diameter arranged to maximize heat transfer.

Keywords: Solar Panel, Solar Energy, Solar Dryer

I. Introduction

A solar air heater is a device that uses solar energy to heat air for various applications, such as space heating, drying processes, and ventilation. The system typically consists of a collector, a heat exchanger, and a storage or distribution mechanism. The primary function of a solar air heater is to convert solar radiation into thermal energy, which is then transferred to the air passing through the collector. This process involves the use of materials that absorb solar radiation and convert it into heat, which is then transferred to the circulating air. Solar air heaters are considered an environmentally friendly and sustainable alternative to traditional heating methods, as they reduce reliance on fossil fuels and contribute to reducing greenhouse

Hikmet Esen, et. al. [1] Solar air heaters have been a reliable solution for various applications that require low to moderate temperatures. Imagine being able to dry crops, season timber, and heat spaces efficiently and sustainably. That's exactly what solar air heaters offer. In our research, we sought to push the boundaries of solar air heater technology. We aimed to enhance the heat transfer rate and improve the efficiency of a simple, fabricated solar air heater. To achieve this, we introduced granular carbon as a long-term heat-absorbing medium inside the heater. We evaluated the thermal performance of our solar air heater design under four different configurations. We operated the system under natural and forced convection conditions to simulate real-world scenarios.

Anil Singh Yadav et. al. [2] In this study, we set out to compare three innovative flat-plate solar air heater designs, two with fins (Type II and Type III) and one without (Type I), with varying glass cover configurations, including single and double glass covers, and evaluated their energy and exergy output rates under various conditions, such as air flow rates of 25, 50, and 100 m3/m2h, tilt angles of 0, 15, and 30 degrees, and temperature conditions over time, and found that the heater with double glass covers and fins (Type II) outperformed the others, with a higher temperature difference between input and output air, and interestingly, discovered that the circulation time of air inside the heater played a more crucial role than the number of transparent sheets, leading to the conclusion that lower air flow rates are preferred in applications where temperature differences are critical.

M.A. Wazed et. al. [3] In many rural areas of developing countries, reliable and affordable energy sources for drying agricultural products are scarce, making solar energy an attractive alternative. Solar energy allows for independent, simple, and adapted systems perfect for rural regions. To explore this potential, we designed, built, and tested six natural circulation air heating solar collectors, each with unique features such as single or double plastic glazing, black painted absorbers, and front or back-pass configurations. Our solar air heaters consisted of a hardboard frame, insulation, absorber surface, and clear plastic glazing, all mounted on a stand facing south.

R.K. Nayak et. al. [4] As the world shifts towards renewable energy, solar power is being harnessed for various applications, including cooking, heating, cooling, and power generation. Solar air heaters (SAHs) are one such innovation, specifically designed for drying, timber seasoning, and space heating. In this study, we created an SAH that can produce a consistent exhaust temperature for extended periods, even in poor ambient conditions or during off sunshine hours. To achieve this, we used a mixture of desert sand and granular carbon (in a 4:6 ratio) as thermal heat storage inside the SAH. We also employed two 300W halogen lights to boost the exhaust temperature by placing them in the inlet and outlet ducts. Our experiments were conducted on natural and forced convection to evaluate the performance of two identical SAH designs, one with and one without heat storage.

Aymen EL Khadraoui et. al. [5] When designing a solar collector, it's short-sighted to focus solely on the upfront cost. What's often overlooked is the long-term service cost, which can significantly add to the total cost over the collector's lifespan. The key to maximizing energy savings lies in boosting the collector's efficiency through a higher heat transfer coefficient. In our study, we experimented with five solar collectors, each measuring 0.9 x 0.4 meters, featuring a unique geometric design with narrowed and expanded flow lines. We set up four different cases with dimensions of 1.2 meters, ensuring that the heating fluids traveled at least 4.5 meters before exiting the collector. This clever design induced turbulence in the fluid flow, thereby increasing heat transfer. By evaluating the results on days with identical radiation, we compared the efficiencies of our collectors to conventional flat-plate collectors.

Hakan et. al. [6] In this article, existing research on solar heating systems is comprehensively adopted to gather the results of various studies and capture discussion and evaluations. We address the world of solar heat generation technology and examine the diverse selection of designs, including those with innovative geometry of absorber panel surfaces that increase heat transfer speeds. We will also look at solar air heaters equipped with heat storage materials, especially phase change materials. This allows these systems to provide thermal energy even in the absence of sunlight. Interestingly, the strategic use of fins in absorber plates and clever surface geometry can greatly improve heat transfer during sunny times.

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F.K. Forson et. al. [8] A mathematical model and solution procedure have been developed to predict the thermal performance of single-pass solar air collectors. The model considers four common types of flat-plate collector designs, with varying configurations of glass covers, absorber plates, and air channels. By assuming uniform surface temperatures and linearly varying air temperatures, the model uses thermal network analysis to derive a set of simultaneous equations for mean temperatures. To solve these equations, a matrix inversion method is employed, using an iterative process to refine the temperature estimates until they converge to a stable solution. This procedure can be extended to predict the performance of collectors of any length, making it a versatile tool for designing and optimizing solar air collectors.

M. Cuzminschia et. al. [9] In a groundbreaking experiment, a solar air heater (SAH) system was tested to warm an innovative greenhouse in Baghdad, Iraq, where the harsh winter climate demands efficient heating solutions. The innovative greenhouse design integrated a traditional greenhouse with a bank of solar air heaters on the roof, cleverly harnessing solar radiation without compromising the interior's sunlight requirements. To accurately calculate the heating load, an energy balance method was employed, taking into account the crucial factor of soil heat storage, which was found to contribute a significant 13-19% of the heating load. The SAH system consisted of six units with a single glass cover and a 'V' corrugated absorber plate, connected in parallel and mounted on the greenhouse roof.

Abhishek Saxena et. al. [10] Jet impingement is a powerful technique for enhancing convective heat transfer, and it's being explored for use in solar air heaters to boost their performance. While impinging jets can achieve impressive heat transfer rates, they also come with a significant drawback: increased friction, which can lead to higher energy costs. This study delves into the thermohydraulic performance of impinging jet solar air heaters, comparing their effective efficiency to that of conventional solar air heaters. The researchers investigated how various factors, including Reynolds number, jet diameter, and streamwise and spanwise pitch, impact effective efficiency. Their findings reveal that impinging jet solar air heaters outperform conventional ones within a specific range of Reynolds numbers. By developing correlations and crunching the numbers, the team achieved a remarkable maximum effective efficiency of 70% for impinging jet solar air heaters.

Deniz Alta et. al. [11] In a bid to boost the efficiency of a simple solar air heater (SAH), researchers conducted an experimental study that explored the potential of thermal heat storage. The innovative approach involved using a rectangular cavity filled with paraffin wax as a latent storage unit. To assess the impact of this phase change material (PCM), two identical solar air collectors were tested - one with PCM and one without. The results were striking: during nighttime hours, the outlet air temperature of the SAH with PCM was significantly higher. Moreover, the daily energy efficiency of the SAH without PCM was a modest 17%, whereas the SAH with PCM achieved an impressive 33% efficiency, demonstrating the substantial benefits of integrating thermal heat storage into solar air heater design.

Turhan Koyuncu et. al. [12] This study explores the efficiency of a novel solar air heater (SAH) system using a cutting-edge modeling approach called least squares support vector machine (LS-SVM). The SAH system features an innovative design where an absorbing plate made from aluminum cans is inserted into a double-pass channel in a flat-plate SAH. Given the complex, multivariable nature of SAH systems, traditional modeling methods fall short, but the LS-SVM approach shines with its exceptional generalization capabilities, unaffected by the dimensionality of input data. To fine-tune the LS-SVM model, various mass flow rates and collector types were tested, and the optimal parameters were pinpointed through rigorous testing.

Abhishek Saxena et. al. [13] Solar air heaters are the go-to solution for harnessing solar energy for various applications, including drying agricultural products, space heating, seasoning timber, and curing industrial products. One clever way to boost the performance of these heaters is by introducing artificial roughness on the surface, which enhances heat transfer to the fluid flowing through the duct. Researchers have been exploring this concept for over three decades, and this article aims to provide a comprehensive overview of the different types of roughness geometry used to create artificial roughness in solar air heaters. By analyzing 38 experimental studies, the authors identify 20 distinct shapes and orientations of roughness elements, which are then compared to determine their relative performance.

Irfan Kurtbas et. al. [14] In a bid to address the massive energy demands of Bangladesh, researchers designed, built, and tested a solar air heater, with a focus on its performance during the country's chilly winter months. From mid-November to mid-February, Bangladesh experiences cool temperatures, clear skies, and minimal rainfall, making it an ideal time to harness solar energy. To combat the short winter days, the solar air heater was cleverly designed to minimize heat loss during long nights, maximizing light gain and heat retention. The results were impressive: the heater efficiently warmed the air, achieving a maximum room temperature of 45.5°C and a temperature difference of 12.25°C from the ambient temperature when using forced circulation, and 41.75°C and 8.5°C, respectively, with natural circulation.

Ravish Kumar et. al. [15] The researchers conducted experimental studies to investigate the effects of flow and sewer sections on the solar heat performance of lock jet plates shifted and drooped by cross-flow. The study, conducted in ISM Danbad, India between November and December 2013, included various mass flow rates, Reynolds numbers, depth conditions, and other parameters assessing the impact of heating on performance. The results showed that increasing the distance between the beam and the absorber plate significantly increased the outlet temperature, collector efficiency, and uncentered number, and mass flow rates had a disadvantageous effect on external temperature. Interestingly, non-traditional jet disc solar heat generation in all respects exceeded the conventional parallel plating sunlight heating. The researchers also developed a correlation between nusentilen numbers and friction factors based on experimental data, providing valuable findings for optimizing the design of such solar air heaters.

Ahmad et. al. [16] Solar air heating, a renewable heating technology, is gaining traction as fuel costs rise and environmental concerns grow. Solar air heaters, or SAHs, harness solar energy to provide heat, and their performance is influenced by a multitude of factors. This comprehensive study reviews existing research and applications, covering design, performance assessment, heat transfer enhancement techniques, experimental and numerical works, thermal heat storage, effectiveness, and recent advances. The analysis reveals that energy analysis methods have been widely used, while exergy analysis methods have been applied to a relatively smaller number of systems. Interestingly, the energy efficiencies of solar air collectors reviewed ranged from 47% to 89%.

Hasan et. al. [17] In India, various types of solar air heaters have been developed and their performance studied in detail, but their applications have been limited to just a few demonstration projects for food dehydration and space heating. This paper takes a closer look at some of these case studies, highlighting the potential of solar air heaters for drying certain cash crops. The authors also explore the use of solar air heaters for space heating and natural ventilation, presenting the results of a theoretical study that makes a strong case for more in-depth research into the applications of solar air heaters in India, with the goal of harnessing this renewable energy source to benefit the country's communities and industries.

Enibe SO et. al. [18] To boost the performance of conventional solar air heaters, researchers have been experimenting with adding obstacles to the heated wall, specifically the absorber plate. In this study, delta-shaped obstacles were mounted on the absorber surface, and the team collected data on heat transfer and flow friction in the air heater duct. The experiment covered a wide range of conditions, including Reynolds numbers from 2,100 to 30,000, various obstacle heights, longitudinal and transverse pitches, and angles of incidence from 30° to 90°. By comparing their findings with previous research, the team identified the optimal range of geometries for superior thermo-hydraulic performance, paving the way for better-designed solar air heaters that outperform existing models.

Tyagi VV et. al. [19] A mathematical model has been developed for a single pass, double duct solar air heater, providing a powerful design tool that can predict various crucial factors, including incident solar radiation, heat transfer coefficients, air flow rates, temperature, and humidity at the exit. The model's accuracy was tested by comparing its simulations with experimental data from both a full-scale air heater and a smaller laboratory version, revealing a reasonable agreement between predicted and measured values. A parametric study was also conducted, demonstrating that careful selection of collector parameters and channel depth ratios can significantly enhance the heater's performance. Notably, the air mass flow rate emerged as the dominant factor influencing the overall efficiency of the heater, highlighting its importance in optimizing solar air heater design.

Morrison DJ et. al. [20] In this groundbreaking study, we unveil an innovative design for a solar air heater, which we rigorously tested and validated through a combination of computational fluid dynamics (CFD) simulations, prototyping, and experimental testing. Our vision is to harness this cutting-edge technology to maintain consistent ambient conditions, ensuring thermal comfort while minimizing energy consumption in various settings, including indoor environments, greenhouses, passive houses, and even protecting buildings from temperature fluctuations. To put our design to the test, we conducted a comprehensive 50week trial, and the results were astounding - our numerical simulations, powered by Open FOAM, an open-source CFD software, aligned remarkably well with the experimental data, confirming the efficacy and potential of our innovative solar air heater design.

Ramin Moradi et. al. [21] This study explores the potential of combining solar air heaters (SAHs) with phase change materials (PCMs) to create a more efficient and sustainable energy storage system. By placing paraffin underneath the absorber plate, the researchers aimed to optimize the performance of the SAH. Using advanced simulation software, Ansys Fluent 17, they developed a transient two-dimensional laminar model to investigate the impact of various parameters, such as air mass flow rate, paraffin amount, and thermal conductivity, on the SAH's performance. The goal was to achieve a delicate balance between thermal energy efficiency and maximum nocturnal temperature difference. To validate their numerical model, the researchers built and tested a SAH with a 2-cm paraffin layer, and the results showed a promising agreement between simulation and experimentation, paving the way for further innovation in sustainable energy solutions.

Nidal.H et. al. [22] This study explores the potential of using artificial neural networks (ANNs) and wavelet neural networks (WNNs) to model a novel solar air heater (SAH) system. The SAH system features an innovative design, where an absorbing plate made from aluminum cans is inserted into a double-pass channel in a flat-plate SAH. Given the complexity of the SAH system, traditional modeling methods fall short, but ANNs and WNNs offer a superior ability to generalize and adapt to multifaceted input data. By leveraging these advanced modeling techniques, the researchers aimed to develop an efficient and accurate predictive tool for the SAH system. After fine-tuning the architecture and training parameters of the ANN and WNN models, the team evaluated their performance using various statistical validation metrics.

Anil Kumar et. al. [23] A groundbreaking mathematical model has been developed to predict the thermal efficiency, heat increase and external temperature of the latest solar collectors, especially for attics. This innovative model simulates the behavior of solar thermal generation under a variety of conditions and provides unprecedented knowledge of solar thermal behavior. To confirm its accuracy, the model's predictions were compared with actual data from the drying process of roof operations using solar collectors, which resulted in impressive results. Additionally, the researchers used the model to investigate the effects of airway and wind speed efficiency on overall efficiency within the collector, unlocking valuable knowledge about solar collector design and performance optimization.

Bekzod Abdukarimov et. al. [24] When it comes to boosting the performance of solar air heater ducts, one effective strategy is to introduce artificial roughness in the form of repeated ribs. Over the years, numerous studies have explored the impact of various artificial roughness geometries on heat transfer and friction characteristics within these ducts. This paper aims to provide a comprehensive review of these studies, focusing on how different artificial roughness elements can enhance heat transfer coefficients while minimizing the penalty of increased friction factors. By analyzing correlations developed by various researchers, the authors compared the thermohydraulic performance of roughened solar air heater ducts, revealing a wealth of experimental and analytical studies that shed light on the complex interplay between heat transfer, friction, and duct geometry.

Sharad Kumar et. al. [25] As the world shifts its focus towards sustainable energy solutions, this article delves into the realm of energy-saving technologies, exploring innovative ways to harness solar power. The study examines various types of solar heating collectors, their operating principles, and structural designs, ultimately proposing a groundbreaking technology for drying agricultural products. Through a comprehensive analysis, the researchers investigated existing technologies, identified areas for improvement, and addressed reduction issues. Experimental trials were conducted across different seasons, putting the proposed technology to the test. A key focus of the study was the operation principle of a flat surface air heater, including a novel approach to shortening air canals to create a more efficient, full-length sunny air heater. By tackling local resistance ratio issues and optimizing temperature increases, this research paves the way for more effective solar energy solutions.

M. Akhbari et. al. [26] In this cutting-edge study, researchers leveraged computational fluid dynamics (CFD) to analyze the performance of a solar air heater duct featuring artificial roughness in the form of thin, circular wires arranged in an arc-shaped geometry. The investigation focused on how this unique geometry impacts heat transfer coefficients, friction factors, and overall performance, exploring a wide range of roughness parameters and working conditions, including varying Reynolds numbers and solar radiation levels. To ensure accuracy, the team employed different turbulent models, ultimately finding that the renormalization group (RNG) k-ε model yielded results that closely aligned with expectations. Using this model, the researchers predicted heat transfer and friction factor values within the duct, calculating an overall enhancement ratio to assess the combined effects of roughness and working parameters. The findings revealed a maximum overall enhancement ratio of 1.7, demonstrating the significant potential of this innovative design to boost solar air heater performance.

Rene Tchinda et. al. [27] In a bid to optimize solar air heater design, researchers constructed a pilot plant featuring a triangular channel solar air heater with a U-turn airflow pattern, and put it to the test under various operating conditions. To accurately predict the heater's performance, they developed a sophisticated mathematical model, complete with an innovative equivalent radiation-convection circuit. This new model proved to be a significant improvement over existing integral models, reducing error by 50% when predicting thermal efficiency and outlet air temperature. The study revealed that the system's maximum thermal efficiency is achieved at a specific air mass flow rate, and that a channel internal peak angle of 60° yields the highest thermohydraulic performance. Perhaps most impressively, the results showed that this novel solar air heater design requires less surface area than traditional flat plate solar air heaters to achieve the same level of thermal efficiency, making it a promising solution for sustainable energy applications.

Filiz Ozgen et. al. [28] Researchers have developed a mathematical model to calculate the thermal performance of a cutting-edge air heater, featuring a truncated compound parabolic concentrator and a flat, one-sided absorber. To bring this model to life, they created a computer code that uses an iterative solution procedure to solve complex energy equations and estimate key performance parameters. With this powerful tool, they explored how various factors, including air mass flow rate, wind speed, and collector length, impact the air heater's thermal performance. The results showed a remarkably accurate prediction of the solar heater's performance, with a mere 7% average error when compared to experimental data, demonstrating the model's reliability and potential to optimize solar air heater design.

H.M. Yeh et. al. [29] In a bid to boost the efficiency of flat-plate solar air heaters, researchers experimented with a novel device that inserts an absorbing plate made from recycled aluminum cans into a double-pass channel. This innovative approach significantly enhances collector efficiency by increasing fluid velocity and strengthening the heat-transfer coefficient between the absorber plate and air. The team designed and tested three types of absorber plates, including one with cans arranged in a zigzag pattern (Type I), another with cans lined up in order (Type II), and a flat plate without cans (Type III). Experiments were conducted with air mass flow rates of 0.03 kg/s and 0.05 kg/s, revealing that Type I achieved the highest efficiency at 0.05 kg/s.

Bhawna Agrawal et. al. [30] Researchers have explored a novel design for solar air heaters, where an absorbing plate divides the air duct into two channels for double-flow operation, complete with fins attached above and below the plate. This innovative setup aims to create a solar collector with a heat-transfer area twice that of traditional single-flow systems, potentially offsetting heat loss from the top when inlet-air temperatures exceed ambient temperatures. The study combined experimental and analytical approaches, yielding theoretical predictions that closely matched measured values. The results showed significant improvements in collector efficiency when using the double-flow device, especially when compared to single-flow systems operating at the same total flow rate. Interestingly, both theoretical predictions and experimental results indicated that the optimal airflow rate split between the upper and lower subchannels was around 50%.

II. Conclusion

Solar air dryers offer a promising solution for efficient and eco-friendly drying of various products, such as agricultural produce, herbs, and pharmaceuticals. By harnessing the power of solar energy, these dryers reduce reliance on fossil fuels, lower greenhouse gas emissions, and provide a cost-effective alternative to traditional drying methods. solar air dryers represent a sustainable and innovative solution for drying applications, contributing to a more environmentally friendly and food-secure future.

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