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A Review on Different Surface Material Patterns on Thermal Performance of Solar Air Heater

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Abstract

This work is concerned with a two-dimensional numerical study done to predict the influence of transverse rectangular cross-sectioned ribs on a solar air heater's convective heat transfer properties. Solar air heater is a useful device that can be utilized to augment the temperature of air by extracting heat from solar energy. It is a rectangular duct consisting of an absorber plate on its top and heat falls only on the top of absorber plate. When ribs/baffles are introduced just beneath the absorber plate, there is a considerable alteration in the thermal performance of air flowing through the rectangular duct. A comparison was made between the results of thin (high aspect ratio) and square ribs arranged in three patterns, namely, single wall arrangement, staggered arrangement and in-line arrangement on two opposite walls. This paper presents the review of literature about the solar air heater.

Keywords: Solar Air Heater, Absorber plate, Rectangular duct.

1. Introduction

Augmentation of convective heat transfer of a rectangular duct with the help of baffles/ribs has been a common practice in the past few years. This concept is widely applied in enhancing the thermo-hydrodynamic efficiency of various industrial applications such as thermal power plants, heat exchangers, air conditioning components, refrigerators, chemical processing plants, automobile radiators and solar air heaters. Solar air heater is a device used to augment the temperature of air with the help of heat extracted from solar energy. These are cheap, have simple design, require less maintenance and are eco-friendly. As a result, they have major applications in seasoning of timber, drying of agricultural products, space heating, curing of clay/concrete building components and curing of industrial products.

The shape of a solar air heater of conventional application is that of rectangular duct encapsulating an absorber plate at the top, a rear plate, insulated wall under the rear plate, a glass cover over the sun-radiation exposed surface, and a passage between the bottom plate and absorber for air to flow in. The detailed constructional details of a solar air heater are shown in fig 1.1.

Solar air heaters have higher thermal efficiency when the Reynolds number of air flow through their passage is 3000-21000. In this range, the duct flow is generally turbulent. Hence, all the research work pertaining to the design of an effective solar air heater involves turbulent flow. Conventional solar air heaters with all the internal walls being smooth usually have low efficiency. The solar air heater's internal surface can be artificially roughened by mounting certain ribs/obstacles of different shapes such as circular wires, thin rectangular bars, etc. periodically on the lower side of collector plate. This results in a considerable augmentation in the heat transfer rate, but at the same time leads to increase in friction factor thereby enhancing the pumping power requirements.

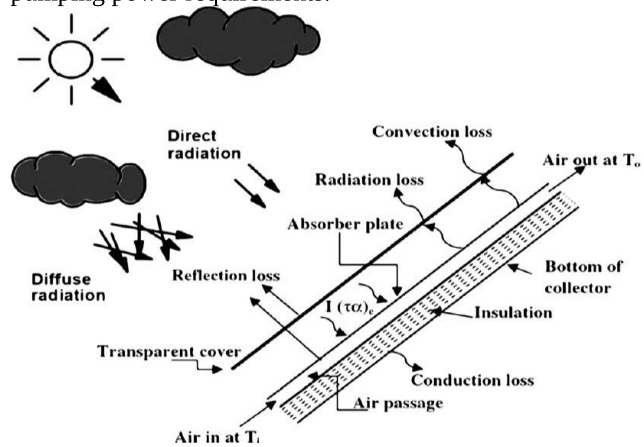

Fig. 1 Solar Air Heater Constructional Details

It is a well-known fact that the friction factor and convective heat transfer coefficient of turbulent flow are highly dependent on the surface roughness of the duct through which they pass [6]. Hence, artificially roughened solar air heaters must be designed in such a manner that their performance yields higher convective heat transfer rates from absorber plate to air low roughness to air flow. Extensive research is being conducted in this field by many authors, whose work generally involves performing experiments or carrying out numerical simulations with different types, sizes and patterns of ribs/ baffles and finding the right parameters at which the heater gives optimal performance (minimum friction loss and maximum heat transfer).

2. Literature review

Shreyas P et al. (2021) study is conducted for configurations of the absorber plate consisting of 5 mm, 8 mm, 10 mm and 12 mm vent diameters and the number of vents is varied as, 24, 36 and 54. The numerical CFD analysis is conducted for Reynolds numbers ranging from 3000 to 21,000. The CFD analysis is evaluated against the experimental results. The average increase in the thermal efficiency of 23.33% is obtained for the configuration with 8 mm diameter vents and 36 number of vents compared to the base model without the absorber plate. The average increase in thermohydraulic efficiency is 21.78% higher for the configuration with 36 vents and a vent diameter of 8 mm compared to the base model. The highest thermohydraulic efficiency of 72.8% is obtained. The thermohydraulic efficiency of the collector is directly proportional to the increase in vent diameter. The study infers that the circular geometry and vented absorber plate causes vortex formation resulting in increase in turbulence induced heat transfer.

Mesut Abuşka et al. (2021) enhance the thermal efficiency and to create proper volume for heat storage material in terms of the effectiveness of the SAH. The thermal efficiency for the absorber with conical obstacles was 14.0, 14.6, and 11.8% higher than the flat absorber plate for the mass flow rates, respectively. The results show that the number of Nusselt obtained in conical surface experiments was highest for all cases tested regardless of Reynolds number. The experimental results are compared with the numerical results obtained by the CFD method. The model results indicate good agreement with the experimental results. Also, the results show that the heat transfer in front of the conical elements is high, and the back is low; in the smooth absorber, a linear velocity distribution is seen along the channel; however, in the conical surface absorber, the velocity distribution due to turbulence is very variable.

Vijayakumar Rajendran et al. (2021) enhance a solar air heater's performance by integrating artificial roughness through baffles on the absorber plate. In this paper, the thermal and energy matrices analysis of a Solar Air Heater (SAH) roughened with V up perforated baffles have been investigated. The effect of various mass flow rates on the SAH was analyzed with and without baffles. Experimental outputs like outlet air temperature, useful energy (heat) gain and thermal efficiency were evaluated to confirm the performance improvement. The baffled absorber plate SAH was found to give the maximum thermal efficiency and useful energy gain of 89.3% and 1321.37 W at a mass flow rate of 0.0346 kg/s, 13% and 12% higher than SAH without baffle. This result showed that the V up-shaped ribs in flow arrangement provide better thermal performance than smooth plate SAH for the parameter investigated. Energy matrices analysis and carbon dioxide mitigation of the SAH system were also analyzed.

Gandjalikhan et al. (2021) discusses the effects of flapping flexible vortex generators on two-dimensional turbulent free convection air ow in a double-pass solar air heater. To this end, two thin elastic winglets used as vortex generators were attached to two absorber walls near the inlet section at an attack angle of 65 C. This novel concept was elaborated through transient numerical simulation of the flow based on the finite element method and fluid-solid interaction. In addition, an extensive comparison of four different configurations was made in this study. The absorber and outlet temperatures as well as the ow rate and velocity field were carefully calculated, numerical results of which confirmed the considerable enhancement of thermal performance compared to that of conventional parallel double pass heater. The improvement rate was up to 54% in the case of ΔT = Tout- Tin from 13 to 20^0C while reducing the flow rate by 33.6%. The present numerical results were validated based on the experimental and numerical data reported in the literature.

Ataollah Khanlari et al. (2021) demonstrated the importance of utilizing waste materials in renewable energy-based technologies and their applicability in thermal energy production. In the first step of the analysis, the applicability of tubular-type SAHs has been studied numerically. The experiments have been conducted at two tilt angles including 90° and 32° and also at three flow rates including 0.012, 0.010, and 0.008 kg/s. The experimental findings showed that the efficiency of metal SAH and plastic SAH varied in the range of 36.33-50.96% and 31.60-47.06%, respectively. Also, enviro-economic costs for metal and plastic SAH were achieved as 8.02 and 7.55 $/year. Besides, the experimental results were predicted with ANN and SVM algorithms. The prediction success of the algorithms is discussed with four metrics (R2, MAPE, RMSE, and MBE). The outcomes clearly demonstrate the successful application of this simple and cost-effective tubular-type SAH manufactured from waste materials.

Karmveer et al. (2022) artificial roughness on the absorber of the solar air heater (SAH) is considered to be the best passive technology for performance improvement. The roughened SAHs perform better in comparison to conventional SAHs under the same operational conditions, with some penalty of higher pumping power requirements. Thermo-hydraulic performance, based on effective efficiency, is much more appropriate to design roughened SAH, as it considers both the requirement of pumping power and useful heat gain. The shape, size, and arrangement of artificial roughness are the most important factors for the performance optimization of SAHs. The parameters of artificial roughness and operating parameters, such as the Reynolds number (Re), temperature rise parameter ($\Delta T/I$) and insolation (I) show a combined effect on the performance of SAH. In this case study, various performance parameters of SAH have been evaluated to show the effect of distinct artificial roughness, investigated previously. Therefore, thermal efficiency, thermal efficiency improvement factor (TEIF) and the effective efficiency of various roughened absorbers of SAH have been predicted. As a result, thermal and effective efficiencies strongly depend on the roughness parameter, Re and $\Delta T/I$. Staggered, broken arc hybrid-rib roughness shows a higher value of TEIF, thermal and effective efficiencies consistently among all other distinct roughness geometries for the ascending values of $\Delta T/I$. This roughness shows the maximum value of effective efficiency equals 74.63% at a $\Delta T/I = 0.01\ K \cdot m^2/W$. The unique combination of parameters $p/e = 10$, $e/Dh = 0.043$ and $\alpha = 60^\circ$ are observed for best performance at a $\Delta T/I$ higher than 0.00789 $K \cdot m^2/W$.

Asole et.al (2020) In this paper, results of CFD analysis on heat transfer and friction in rectangular ducts with broken double arc shape rib with staggered rib roughness has been presented. The rib roughness has relative roughness pitch of 10, arc angle of 30° and relative roughness height of 0.043. The relative gap position was varied from 0.30 to 0.60. The effects of relative gap position on Nusselt number, friction factor and thermo-hydraulic performance parameter have been discussed and results compared with smooth duct under similar conditions. The rough ribs were efficient enough to transfer the desired heat, but they are not economical and are very complex in design and construction. Whereas, roughness gives more area of contact.

Faris Aissaoui et al. (2017) developed a mathematical for simulating the influence of fins and baffles on the thermal performance behavior of single pass solar air collector system working in forced convection. Due to the lack of theoretical work in the case of single pass solar air heaters having artificial roughness, we have proposed a theoretical model which consists of dividing the collector into several differential elements along the panel. This model is based on a numerical solution of energy equations in each component of collector. The results obtained from the present work and results of others researches are in good agreement. Using energy analysis, influence of parameters such as width of baffles, distance between baffles, length of air heater and number of fins are presented. The obtained results would be useful to select the most efficient and design parameters.

3. Shock Waves in a Viscous Non-Ideal Gas

3.1 Shockwave

Isentropic flow is a flow with a fixed entropy. It has no irreversible loss and no additional heat. Isentropic flow is mathematically easy, but by reading it one can begin to discover interesting contradictory things that occur in the flow of a high Mach number. For example, when the flow requires acceleration, we automatically adjust the nozzle. However, it requires a nozzle to accelerate the supersonic flow from the magnetic valve. The reason for this lies in the conversion of energy. The shock wave is not an isentropic flow, described at the beginning of this chapter. But isentropic flow theory can be used to study the pressure of standing before and after a shock wave. With a change in stop pressure, one can calculate the entropy conversion in the shock wave [90]. At this stage, we take an isentropic flow that exceeds the control volume.

3. Problem Statement

From the study of various research papers we have obtained the following problems:

- Geometry was not suitable for higher heat transfer size and cost of heat transfer equipment was more.
- The main concern for the equipment design is to minimize the flow resistance while enhancing the heat transfer coefficient.
- Performance of heat exchangers can be improved by many augmentation techniques but increase in pressure drop is always a barrier for heat transfer enhancement.

4. Conclusion

Enhancement of heat transfer in solar air heater systems using corrugations has the dual benefit of enhanced heat transfer area and enhanced flow turbulence. A two-dimensional numerical analysis is done to predict the influence of transverse rectangular cross-sectioned ribs on a solar air heater's convective heat transfer properties. A rectangular duct was constructed and numerical analysis was carried out on square and thin (high aspect ratio) rib shapes arranged in different fashion, namely single wall, staggered and in-line ribs arranged on two opposite walls including the absorber plate. Air was the working fluid and constant heat flux was applied only on the absorber plate's top surface.

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