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Solar Air Heater performance analysis with rectangular staggered discrete rib roughened absorber plate using CFD approach

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ABSTRACT

It has been found that the conversion of solar radiation to thermal energy is poor in the conventional solar air heater due to the low heat transfer coefficient between the absorber plate and working fluid of the solar air heater. The use of artificial roughness on the absorber plate is one of the effective techniques to enhance the rate of heat transfer to flowing fluid in a solar air heater. In this paper, thermal performance of a solar air heater consists of rectangular staggered discrete rib roughened absorber plate is investigated theoretically. It has been observed that the artificial roughness applied on the absorber plate breaks the laminar sub layer, which reduces thermal resistance and increase heat transfer coefficient. Computational fluid dynamics solution is carried out using Ansys-Fluent software to analyze the performance characteristics of solar air heater for the range of input parameters such as gap position from the leading edge of the rib, staggered rib position from the gap in the rib and width of the staggered rib. Results show that rib pitch and height of the rib have significant effect on the heat transfer and fluid flow characteristics of the solar air heater. solar air heater with rectangular staggered discrete rib roughened absorber plate has been analyzed for the analysis of heat transfer and fluid flow characteristics. Effect of input parameters such as gap position from the leading edge of the rib, staggered rib position from the gap in the rib and width of the staggered rib are investigated in the present study.

Keywords: Thermal performance, fluid dynamics, rectangular staggered

INTRODUCTION

Solar air heater are the cheapest and extensively used solar energy collection devices employed to deliver heated air at low to moderate temperatures for various applications. These type of solar air collectors collect solar energy and covert this energy in form of hot air. Conventional type of solar air collector have lower thermal efficiency than concentrating type of solar air collectors, but because of low operating cost and maintenance cost, they are widely used as a heating media.It. has been found that the conversion of solar radiation to thermal energy is poor in the conventional solar air heater due to the low heat transfer coefficient between the absorber plate and working fluid of the solar air heater.The use of artificial roughness on the absorber plate is one of the effective techniques to enhance the rate of heat transfer to flowing fluid in a solar air heater. It has been observed that the artificial roughness applied on the absorber plate breaks the laminar sub layer, which reduces thermal resistance and increase heat transfer coefficient.

Types of Solar Air Heater

Flat-plate collectors solar air heater are very common and are available as liquid and air-based collectors. These collectors are better suited for moderate temperature applications where the demand temperature is 30-70^{0}C and/or for applications that require heat during the winter months. Generally flat plate solar air heater of many types such as single glass cover, double glass cover, single duct and double duct. Moreover, it also classified based on air flow type i.e single pass and double pass solar air heater. whereas, double pass solar air heater are further categorized as parallel flow, counter flow and recycle flow solar air heater.

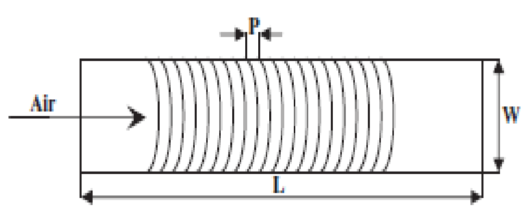
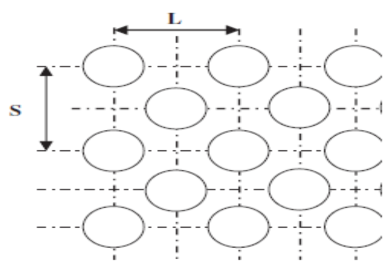
Objectives of present study

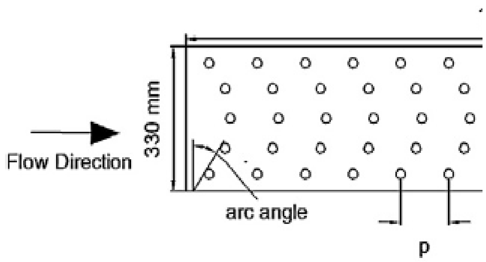
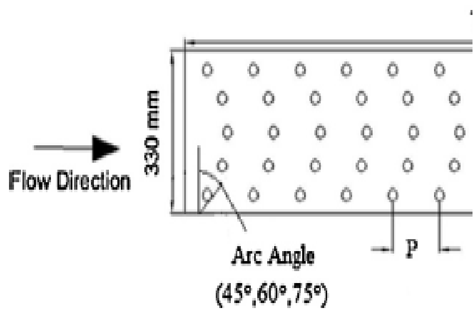
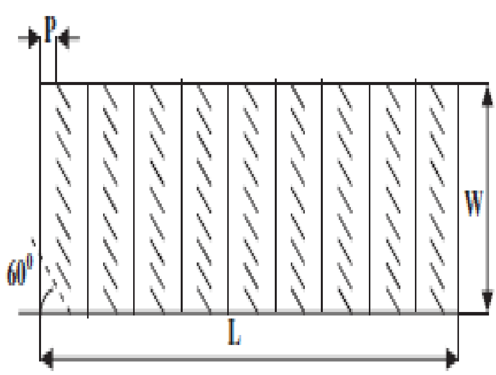
In the present work, the solar air heater having artificial roughness has been considered for thermal performance investigation. The use of artificial roughness on the absorber plate is one of the effective techniques to enhance the rate of heat transfer to flowing fluid in a solar air heater. The artificial roughness applied on the absorber plate breaks the laminar sub layer, which reduces thermal resistance and increase heat transfer coefficient. Therefore, the objective of the present study is to analyze the thermal performance of the rectangular staggered discrete rib roughened SAH using CFD technique.

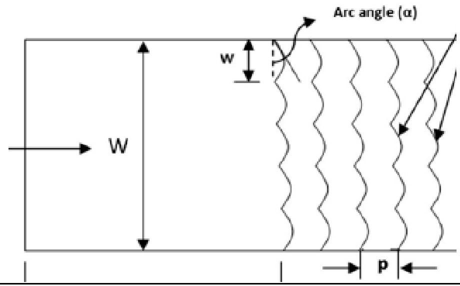
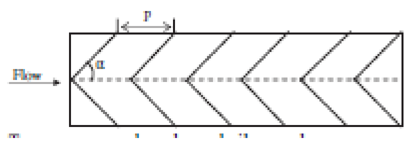
LITERATURE REVIEW

It was delineated in the literature that in order to attain higher convective heat transfer coefficient it is required that the flow at the heat transfer surface should be turbulent, which is the motivation of the present work to improve heat transfer rate from the absorber plate of the solar air heater. **Momin** et al. [2002] experimentally studied the effect of geometrical parameters of V-shaped continuous ribs on heat transfer and fluid flow characteristics of rectangular duct of solar air heater with absorber plate having V-shaped ribs on its underside, while, Aharwal et al. [14] have been studied heat transfer and friction characteristics of solar air heater ducts with integral repeated discrete square ribs on the absorber plate. **Yadav** et al. [2014] studied the effect of heat transfer and friction characteristics of the circular protrusion arranged in the arc fashion on the absorber plate of the solar air heater and found that the maximum enhancement in heat transfer and friction factor is 2.89 and 2.93 times as compared to the conventional smooth duct. Summary of the different roughness geometries expressing their heat transfer and fluid flow characteristics are presented in Table 1.1. Moreover, possible changes are suggested in the roughness geometries in order to enhance the heat transfer rate and lower the pressure drop. Comparison of the roughened solar air heater revealed that solar air heaters having absorber plate roughened with staggered discrete type roughness results higher heat transfer at a lower expense of pressure drop as compared to others. Therefore, in the present work an attempt has been made towards the thermal performance investigation of rectangular staggered rib roughened solar air heater. Study have been performed with the different roughness parameters for the enhancement of Nusselt number.

Table 1.1 Comprehensive review of few artificially roughened solar air heaters and proposed possible research gaps to improve their thermal performance.

S. No	Types of roughness	Authors	Finding
1.	Arc-shape parallel wire 	Saini and Saini [2008]	3.8 and 1.75 times enhancement in Nusselt number and friction factor respectively were reported over smooth duct.
2.	Protrusions 	Bhushan and Singh [2012]	Maximum enhancement of Nusselt number and friction factor has been found 3.8 and 2.2 times Respectively in comparison to smooth duct ....for.investigated range of parameters.

3.	Dimple shaped  	Sethi et al. [2012]	The maximum value of Nusselt number has been found corresponding to relative roughness height of 0.036, relative roughness pitch of 10 and arc angle of 60^o.
4.	Protrusions arranged in arc fashion  	Yadav et al. [2014]	A set of rib roughness parameters namely relative roughness pitch (P/e) of 12, relative roughness height of 0.03 and arc angle of 60^o, yields maximum exergetic efficiency for $\Delta T/G = 0.02\ Km^2/W$. For $\Delta T/G < 0.02\ K\ m^2/W$.
5.	Combination of transverse and inclined rib roughness  	Varun et al. [2014]	Best thermal performance was reported over smooth duct at P/e of 8.
6.	multiple arc shaped	Singh et al. [2012]	Maximum enhancement in Nusselt number and friction factor is 5.07 and 3.71 times respectively as compared to smooth one.

			
7.	V-shaped ribs 	Momin et al. [2002]	The maximum enhancement of Nusselt number and friction factor as a result of providing artificial roughness has been found to be respectively 2.30 and 2.83 times that of smooth duct for an angle of attack of 60^o.

METHODOLOGY

Thermal performance of artificially roughened solar air heater is studied using Ansys-Fluent, a commercial finite volume based solver.. The heat-transfer and pressure drop characteristics of staggered discrete rib roughened solar air solar are investigated for different roughness pitch, height, gap position from the leading edge of the rib, staggered rib position from the gap in the rib and width of the staggered rib.

Different range of rectangular transverse rib roughness parameters that have been used in present CFD investigation.). Computational domain of the solar air heater is varied for different values rib pitch, height of the rib, gap width, gap position from the leading edge, staggered rib position from the gap and width of the staggered. The range of Reynolds number (3800-18000) has been chosen for the present CFD analysis. The generated mesh has been validated by performing a grid independence test for the outlet air temperatures obtained from the CFD analysis. In order to conduct the grid independence test, size of the element has been varied and outlet temperature has been studied for fixed values of input variables.

CONCLUSION & FUTURE SCOPE

Thermal performance of the proposed artificially roughened solar air heater is measured in terms of friction factor and Nusselt number. It is predicted that as the pitch of roughness increases from 12-20 mm the friction factor and the Nusselt number of solar air heater decreases. The maximum friction is obtained at a roughness pitch of 12 mm, which is found to be 0.037, while the maximum value of Nusselt number is obtained as 46.32. This is because the increasing values of the roughness pitch decreases the pressure drop and heat transfer area which decreases the friction factor and Nusselt number, respectively.

Effect of input parameters such as such as gap position from the leading edge of the rib, staggered rib position from the gap in the rib and width of the staggered rib is only investigated in the present study and their optimum values are obtained as 40, 3 and 2.5 mm, respectively. The thermo hydraulic enhancement factor is found to be 2.41 at a Reynolds number of 8000. Moreover, similar study can be extended using different rib geometries and double air pass.

The present investigation leaves the following scopes for the future work. Study can be performed for the double pass Solar Air heater. Roughness can be applied on both side of the absorber plate. Exergy analysis cane be performed for the present work. Economic analysis can be investigated for the present work.

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