ABSTRACT

In view of the world's depleting fossil fuel reserves, which provide the major source of energy, the development of non-conventional renewable energy sources has received an impetus. Solar energy is most important among renewable energy resources due to its quantitative abundance. The simplest and the most efficient way to utilize solar energy is to convert it into thermal energy for heating applications. The most important and basic components of the system required for conversion of solar energy into thermal energy is called solar collector. A solar collector is a device designed to absorb the incoming solar radiant energy converting into thermal energy at the absorbing surface and transferring this energy to a fluid flowing through the collector. Further flat plate solar collectors may be divided into two main classifications based on the type of heat transfer fluid used i.e. liquid heating and air heating collectors.

Solar Air heaters, because of their inherent simplicity, are cheap and most widely used collection devices. The primary disadvantage of solar air heaters is the need for handling relatively large volumes of air because of its low thermal capacity as working fluid. The thermal performance of a conventional solar air heater is poor because of relatively low heat transfer coefficient between absorber plate and the carrier fluid (air). Use of artificial roughness on the absorber plate has been found to be an effective method of enhancing heat transfer coefficient. However such an enhancement in thermal performance has been found to be accompanied by a substantial rise in pumping power required

to make the air flow through the collector. The endeavor, therefore, is to provide the roughness geometry in such a way as to keep pressure losses at the lowest possible level while maximum possible gain in heat transfer is obtained.

The review of literature shows that several investigators have carried out work on the performance of solar air heaters with roughened duct by providing various types of geometry of roughened elements. It was found that the use of thin circular wires and ribs of different geometrical shapes and orientation, transverse as well as inclined V-shaped, chamfered and combination of different geometries have been investigated. It has been observed that fabrication of absorber plates having ribs is a tedious task and may not be cost effective. Fixing of thin circular wires along the absorber plate is found to be easy accordingly, several investigators investigated such geometry in transverse and inclined orientations. However, no study has been reported for the arc shaped geometry as artificial roughness.

In view of the above, it was planned to carry out investigation on the following aspects;

1. To investigate experimentally the effect of arc shaped geometry of thin circular wire used as artificial roughness on heat transfer coefficient and friction factor in solar air ducts.
2. To develop correlations for heat transfer coefficient and friction factor in terms of roughness and operating parameters.

3. To investigate analytically the thermal performance of solar air heater based on the correlation developed for heat transfer.
4. To investigate the thermohydraulic performance of solar air heaters having arc shaped roughness geometry as artificial roughness and to find out the optimum roughness parameters of such a geometry.

The experimental work carried out in the present study is based on creating artificial roughness on absorber plate to enhance the heat transfer coefficient between air flowing in the duct having one side as absorber plate. The indoor test facility has been designed and fabricated to generate heat transfer data at different airflow rates for a range of roughness parameters in rectangular duct. The range of parameters considered under the experimental study is as given in Table 1.

Table 1: Range of parameters

S. No.	**Parameters**	**Range**
1.	Reynolds number(Re)	2,000 to 18,000
2.	Duct aspect ratio (W/H)	12
3.	Test-section length, L (mm)	1000
4.	Roughness height, wire diameter, e (mm)	1.0 to 1.98
5.	Hydraulic diameter of duct, D (mm)	46.86
6.	Relative roughness height, e/D	0.021 to 0.045
7.	Wire arc-angle, α (degree)	30^0 to 60^0
8.	Relative arc-angle, α/90	0.3333 to 0.6666
9.	Relative roughness pitch, p/e	10
10.	Insolation, I (W/m^2)	1000

The arc shaped parallel GI wires have been pasted on the inner surface of the absorber plate. The effect of relative roughness height, e/D and relative arc-angle, α/90 on heat transfer coefficient and friction factor with Reynolds number has been studied. Experimental data have also been collected for smooth ducts under similar conditions so that a comparison of heat transfer and friction characteristics of roughened and smooth ducts can be made.

It has been found that the enhancement of Nusselt number and friction factor as a result of providing artificial roughness has been found to be strong function of flow and roughness parameters. The effect of system and operating parameters on heat transfer and pressure drop for the roughened duct of solar air heaters were also discussed. However, the system designer requires the correlations for Nusselt number and friction factor in order to predict the thermal and thermohydraulic performance of the solar air heater having roughened duct provided with artificial roughness in the form of arc shaped small diameter wires. Therefore, correlations for Nusselt number and friction factor as function of system and operating parameters have been developed from experimental data. The developed correlations are as given below;

Correlation for Nusselt number:

$$Nu = 0.00105\,(Re)^{1.139}\,(e/D)^{0.377}\,(\alpha/90)^{-0.120}$$

Correlation for friction factor:

$$f = 0.144(Re)^{-0.171}(e/D)^{0.177}(\alpha/90)^{0.119}$$

It is found that the correlation predicts the values of friction factor reasonably well in the range of parameters investigated.

The analytical determination of thermal performance has been carried out on the basis of correlation develop for Nusselt number. A procedure for computing the thermal performance of solar air heater having roughened as well as smooth ducts has been outlined.

The effect of roughness and operating parameters on thermal performance has been examined and a comparison of performance of roughened solar air heater with that of conventional solar air heater having smooth duct has been made to determine the enhancement as a result of using of artificial roughness. It has been found that the best performance of the roughened solar air heater corresponding to the roughness parameters that yield maximum heat transfer coefficient.

It has been pointed out that it is desirable that the geometry of roughness elements is selected so as to increase the heat transfer while keeping the pumping losses as low as possible, i.e. the thermohydraulic performance of the system with such a geometry is the best. Thermohydraulic performance of solar air heater having roughened duct with arc shaped roughness elements has been discussed. Thermohydraulic performance is determined in terms of effective efficiency of solar air heater with roughened absorber plates. It is determined by taking into consideration of actual thermal energy gain and equivalent thermal energy required to generate power required for pumping air through the solar air collector. In order to determine the optimum values of roughness parameters the composite performance plots having effective efficiency and thermal efficiency versus temperature rise parameters are prepared. The optimum roughness geometry parameters corresponding to maximum effective efficiency for specified operating conditions have been determined on the basis of thermohydraulic conditions. It was found that effective efficiency increase as the temperature rise parameter decreases, attains maximum and then decrease. It has also been observed that for high values of temperature rise parameter the thermal efficiency and effective efficiency values are approximately the same and hence the optimum roughness parameters can be selected on the basis of maximum thermal efficiency.