HEAT AND FLUID FLOW IN SOLAR AIR HEATER DUCT WITH MULTI V-SHAPED RIBS WITH GAP

A THESIS

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ABSTRACT

Energy is a basic ingredient needed to sustain life and development. The limitation of the extent of and highly polluting characteristics of conventional energy resources has led to a serious search for alternatives. Solar energy is the foremost source of unconventional energy which has adequate potential to fulfil all global present and future energy needs.

Flat plate solar air heater is undeniably one of the simplest and inexpensive devices widely used for air heating applications. The efficiency of solar air heater has been found to be low because of low convective heat transfer coefficient between absorber plate and the flowing air which increases the absorber plate temperature, leading to higher heat losses to the environment resulting in low thermal efficiency of such collectors. Use of artificial roughness in the form of repeated ribs has been found to be a convenient method.

A large number of investigations involving roughness elements of different shapes, sizes and orientations with respect to flow direction have been carried out in order to obtain an optimum arrangement of roughness element geometry. It was found that a transverse rib enhances the heat transfer coefficient by flow separation and generation of vortices on the upstream and downstream of rib and reattachment of flow in the inter-rib spaces. V-shaping of a long angled rib helps in the formation of two secondary flow cells as compared to one in case of an angled rib resulting in still higher heat transfer rate. A similar gap in both the limbs of V-rib further enhances the heat transfer by introducing similar effects in both the limbs. A recent investigation has revealed that the use of multi-v rib across the width of the plate substantially enhances the heat transfer by increasing the number of secondary flow cells several times. It is thought that producing gaps in all the limbs of Multi v-rib geometry will bring about

considerably large enhancement in comparison to that of simple single V-rib arrangement.

In view of the above, the present investigation has been carried out with the following major objectives:

1. Experimental investigation to study the effect of roughness and operating parameters on heat transfer and fluid flow characteristics in rectangular duct with absorber plates having Multi v-shaped rib with gap on its underside.
2. Development of correlations for Nusselt number and friction factor from the data obtained from the experimental investigations.
3. Investigation of the thermal performance of solar air heater having absorber plate roughened with Multi v-shaped rib with gap.
4. Thermo-hydraulic optimization of solar air heater having artificially roughened absorber plate with Multi v-shaped rib with gap to obtain optimal roughness geometry.

An experimental set up has been designed, fabricated and used for extensive data collection with respect to heat transfer and friction characteristics of Multi v-shaped with gap rib on one heated broad wall of rectangular duct. Data was collected on temperature rise of air, mass flow rate, heat flux and pressure drop across the duct as function of geometrical parameters of the Multi v-shaped with gap rib roughness and flow rate of air.

A total of forty one Multi v-shaped ribs with gap roughened absorber plates were tested in this experimental work covering different roughness geometry parameters.

It has been found that Nusselt number and friction factor are strong functions of roughness geometry and flow parameters. On the basis of this investigation it was found that the Nusselt numbers and friction factors are seen to generally increase with an increase in the value of relative roughness height (e/D). Nusselt number increases with an increase in relative roughness width (W/w) and attains a maximum value corresponding to relative roughness width value of 6 in the range of parameters considered. With further increase in relative roughness width, Nusselt number is found to decrease. However, it has been observed that friction factor increases with increase in relative roughness width and attains a maximum value corresponding to relative roughness width value of 10.

Nusselt number and friction factor increase with increase in relative gap distance (Gd/Lv) and attain a maximum value corresponding to relative gap distance value of 0.69 in the range of parameters considered. Nusselt number and friction factor increase with increase in relative gap (g/e) width and attain maximum value corresponding to relative gap width value of 1.0. These parameters have been found to attain maximum values when angle of attack (α) and relative roughness pitch (P/e) values are 60° and 8 respectively.

Based on the analysis of the errors in the experimental measurements through various instruments employed, the uncertainties in the calculated values of mass flow rate (m), Reynolds number (Re), Heat transfer coefficient (h), Nusselt number, friction are estimated as ±1.65%, ±5.69%, ±5.65%, ±5.67% and ±3.51%, respectively.

Experimental data on Nusselt number and friction factor has been utilized to develop correlations for Nusselt number and friction factor in terms of relative roughness height (e/D), relative roughness width (W/w), relative gap distance (Gd/Lv), relative gap width (g/e), angle of attack (α), relative roughness pitch (P/e) and Reynolds number (Re).

The effect of roughness geometry and operating parameters on thermal efficiency has been investigated and thermal performance of roughened and smooth collectors has been compared in order to determine the enhancement in thermal performance on account of the use of this roughness geometry. The enhancement factor has been found to lie in the range of 1.14 to 1.74 in the range of parameters of the investigation.

In view of the fact that the purpose of a solar air heater is to transfer maximum amount of solar energy absorbed by the absorber plate to the air flowing through it which can be achieved by enhancing the rate of heat transfer by the use of artificial roughness as discussed above. However the increase in thermal performance is always accompanied by substantial increase in pumping power. It is therefore necessary that the roughness geometry must be optimized on the basis of thermo-hydraulic considerations that take into account both the enhancement of thermal performance and the increase in pumping power.

The following three criteria have been proposed to be considered for the optimization of roughness parameters of solar air heater:

(i) Thermal Efficiency, η_{th} (ii) Effective efficiency, η_{eff} (iii)Exergetic efficiency, η_{exg}

For given values of operating parameters (temperature rise parameter, $\Delta T/I$ and insolation, I) values of optimizing parameter values were computed for all possible combinations of roughness geometry parameters. Based on these values, the sets of roughness parameters that yielded maximum value of optimizing parameters were determined corresponding to each of these three optimizing parameters. It needs to be pointed out that the thermal efficiency criterion has been discussed for the purpose of comparison.

Optimizing parameters i.e. effective efficiency and exergetic efficiency, these optimum sets of roughness parameters were found to depend on the operating parameters (temperature rise parameter, $\Delta T/I$ and Insolation, I).

For given values of temperature rise parameter ($\Delta T/I$) and insolation (I), a set of roughness geometry parameters can be obtained from the design plots prepared for each roughness geometry parameter on the basis of effective efficiency criterion. A design procedure has been proposed to determine the optimum values of roughness parameters for a Multi v-shaped rib with gap roughened solar air heater for given values of the temperature rise and insolation.

Summarizing, it can be stated that an experimental investigation has been carried out on an artificially roughened solar air heater duct to investigate the usefulness of Multi v-shaped with gap rib roughness on the absorber plate. Empirical correlations have been developed for estimation of Nusselt number and friction factor based on the experimental data observed for different roughness parameters and operating conditions. Prediction of thermal performance of roughened solar air heater has led to the conclusion that this roughness geometry can yield an enhancement of thermal efficiency in the range of 1.14 to 1.74. Optimum values of these parameters have been obtained based on the criteria of thermal efficiency, effective efficiency and exergetic efficiency of the artificially roughened solar air heater. Design plots have been prepared which can be utilized to obtain set of optimum values of roughness parameters that will result in the best thermo-hydraulic performance. A design procedure has been specified to arrive at the optimum roughness geometry for given set of operating parameters of the collector.