

STUDY OF DOUBLE PASS ROUGHENED SOLAR AIR HEATER WITH DISCRETE MULTI V-SHAPED AND STAGGERED RIBS

Ph.D. THESIS

by

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STUDY OF DOUBLE PASS ROUGHENED SOLAR AIR HEATER WITH DISCRETE MULTI V-SHAPED AND STAGGERED RIBS

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Solar air collectors are specific types of heat exchanger devices that provide energy in the form of heat for the purpose of space Heating, drying agricultural products (paddy drying, fruit drying, timber drying, cash crop drying etc.) and some industrial applications or other locations normally requiring the use of conventional energy sources to maintain a constant temperature. Thermal performance of the conventional solar air heaters are relatively very low due to high thermal losses from the collector and less heat transfer rate between the absorber plate and flowing fluid and, which leads to increase in the temperature of the heated surface. Several efforts have been made to enhance the performance of solar air collectors by applying various design techniques and flow provisions. The double pass counter flow arrangement with artificial roughness on both sides of the heated surface is one of the important and attractive design improvements that have been proposed to achieve the objective of improved thermal performance.

From the review of the literature, it has been observed that, although a considerable amount of research work on heat transfer and pressure drop has been carried out on artificially roughened solar air collectors having different shapes and geometric parameters; However, it has been found that these studies are useful only for single pass solar air collectors in which the artificial roughness was created only one side (lower or upper) of the absorber plate. The literature survey also reveals that the multi V-shaped rib with gap is best among all roughness geometries followed by multiple v ribs, discrete v ribs, single v ribs, inclined ribs and transverse ribs.

Therefore, it is envisaged that the introduction of the staggered rib part in front of the space provided in the multi-V rib geometry will bring about considerable improvement compared to the simple discrete arrangement of multiple V-ribs with gap.

It is also observed from literature reviews on double pass collectors that, the thermal efficiency of the double pass collector was higher than the single pass collector due to the more surface area for heat transfer was provided by double pass collector. Most studies in case of double pass solar air collectors have been focused on packed / porous bed material, extended surfaces, i.e. fins and corrugated absorbers to improve thermal performance of the collector.

Although some studies are also available on the artificially roughened double pass solar air heaters which describe the heat transfer and pressure drop characteristic. But so far, no study is available to determine the thermohydraulic performance on basis of the optimum roughness parameters in case of artificially roughened double pass solar air heaters. Therefore, it is believed that the double pass solar air heater provided with a double-sided roughened absorber plate will highlight the considerable increase in the thermohydraulic behaviour of the collector. Therefore, the present work has been investigated a counter flow solar air heater provided with discrete multi V-shaped and staggered ribs roughness on two wide walls of the absorber plate.

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

- (i) To investigate experimentally the effect of discrete multi V-shaped ribs combined with staggered rib on heat transfer and fluid flow characteristics of a double pass solar air heater duct.
- (ii) To develop correlations for Nusselt number and friction factor for the double pass solar air heater roughened duct as function of roughness and operating parameters.
- (iii) To investigate the thermal performance of double pass solar air heater having absorber plate roughened with discrete multi V-shaped and staggered ribs.
- (iv) To investigate the thermohydraulic performance of solar air heater having artificially roughened absorber plate with discrete multi V-shaped and staggered ribs to obtain optimal roughness geometry.

In order to fulfill the above mentioned objectives, the experimental setup has been designed, fabricated and tested in accordance with the ASHRAE standard 93-77 recommended for data collection on heat transfer and friction characteristics of discrete multi V-shaped and staggered rib roughness on two heated broad walls of the rectangular duct. The range of roughness parameters has been decided on the basis of practical considerations of the system and operating conditions.

Total thirty one different combinations of the discrete multi V-shaped and staggered ribs have been investigated in present work including the various flow and roughness parameters.

The experimental investigation reveals that the Nusselt number increases with an increase in relative roughness width (W/w) and relative staggered rib size (r/e), attains a maximum value corresponding to W/w of 7 and r/e of 3.5 and then decreases with further increase in the W/w and r/e values. While, the friction factor increases monotonously with increases in all values of W/w and r/e . Heat transfer and pressure drop increase with increase in relative staggered rib pitch (p'/p) and attains a maximum value corresponding to $p'/p=0.6$ and then decreases with further increase in p'/p .

The maximum value of Nusselt number has been found to be as 544.04 correspond to W/w of 7, r/e of 3.5 and p'/p of 0.6 for Reynolds number value of 20000, while the maximum value of friction factor has been found to be as 0.2316 correspond to W/w of 8, r/e of 4 and p'/p of 0.6 for Reynolds number value of 2000. Therefore, it is realized that the both Nusselt number and friction factor are strong function of the roughness and flow parameters.

For every experimental investigation, there are always some uncertainties occurring in the experimentation due to inaccurate measurements or improper calibration of the measuring instruments. In present investigation proper measurement and calibration of all the measuring instruments has been done and an error analysis has been employed to predict the uncertainty involved with experimental results based on the investigation of the collected data.

Further, the experimental results are used to develop the statistical correlations for Nusselt number and friction factor in terms of geometrical parameters namely, relative roughness width (W/w), relative staggered rib size (r/e) and relative staggered rib pitch (p'/p) as well as flow parameter i.e. Reynolds number (Re).

The developed correlations have been used to compute the thermal and thermohydraulic efficiency of the double pass solar air heater. A computer program in MATLAB 2013b has been prepared to calculate the thermal efficiency of the double pass solar air heater with and without artificial roughness. The influence of the roughness parameters on the thermal efficiency has been discussed in terms of temperature rise

parameters ($\Delta T/I$). It is observed that the thermal efficiency of the double pass solar air heater decreases drastically with an increase in temperature rise parameter. This may be due to reduction in temperature difference between the flowing air and the absorber plate when inlet fluid temperature increases. Hence, less heat energy is extracted by the flowing air from the absorber plate and the glass cover. Due to this, the average temperature of the absorber plate and glass cover increases which results in increase in the heat losses to the surroundings and decreases in the useful heat gain which causes reduction in the thermal efficiency and the thermal performance of the double pass solar air heater. It is also seen that the enhancement in the thermal efficiency of the double pass solar air heater has been achieved with use of the roughness geometry.

However, the enhancement in thermal efficiency is always accompanied by substantial increase in pumping power. It is therefore necessary to optimize the roughness parameters on the basis of thermo-hydraulic application which incorporates with both the enhancement of thermal performance and the pumping power. Therefore, the optimization of the geometric parameters of the roughness elements has been considered on the basis of the thermal efficiency (η_{th}), effective efficiency (η_{eff}) and exergetic efficiency (η_{exg}) criterions.

The values of these optimization criterions have been determined for all possible combinations of the roughness parameters for the selected range of the operating parameters i.e. temperature rise parameters ($\Delta T/I$) and Insolation (I). The combination of roughness parameters that yielded maximum value of thermal, effective and exergetic efficiency have been considered as optimum roughness geometry combination. Therefore, a single set of the optimum values of roughness parameters has been obtained for the entire range of the operating parameters on the basis of the thermal efficiency criterion.

It is also found that while considering the effective efficiency and exergetic efficiency as optimization criterions, the optimum values of roughness parameters depend on the design parameters. Therefore, no single set of the roughness parameters yields the maximum value of the effective and exergetic efficiency. Further, based on the effective efficiency criterion, the optimum values of the system and operating parameters have been found.

These values of the roughness parameters based on the effective efficiency criterion have been utilized to prepare the design plots for each roughness geometry parameters for a given values of operating parameters. A design procedure has also been suggested to determine the optimum values of roughness parameters of discrete multi V-shaped and staggered rib geometry used in double pass solar air heater for given values of the temperature rise (ΔT) and Insolation (I).

Summarizing, the double pass solar air heater increases the performance of the conventional solar collector without increasing system cost. The data on heat transfer and friction characteristics of an artificially roughened double pass solar air heater have been collected as a result of extensive experimentation. Experimental data have been utilized to develop the Nusselt number and friction factor correlations that are used to determine thermohydraulic efficiency. The design plots on the basis of the thermohydraulic optimization of the double pass system are prepared. These design plots can be used by the designer for the selection of optimum values of the set of roughness parameters that will yield best thermohydraulic performance of the roughened double pass system under the given operating conditions.