A Review Heat Transfer Enhancement in Solar Air Heater Duct with V-Down Perforated Baffles as Roughness Elements on Absorber Plate

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ABSTRACT

Solar air heaters are used to capture heat from solar radiation, give it to the working fluid and that hot fluid can be used in various applications. This article aims to present a review of the literature dealing with improvement methods, design configurations and applications of different types of solar air heaters (SAH). Different investigations have been made on SAHs either experimental or theoretical in order to improve their performance. Also it is found that to improve both the heat transfer and thermo-hydraulic performance of SAH, artificially roughened absorbers are used. Using artificial roughness, the results showed good enhancement of both Nusselt number and friction coefficient for a wide range of Reynolds number. As a result of these improvements, SAHs became more popular in more applications, with a good reduction in fuel consumption and costs of installation and operation.

Keywords: Solar Air Heater, artificial roughness, Thermal Efficiency, Mass Flow Rate

1. INTRODUCTION

Energy resources may be defined in two different ways conventional and non-conventional energy resources. It can be used in many kind of ways. The very simplest and the most economic way to utilize solar energy are to convert it into thermal energy for heating applications by using solar collectors. solar air heater is very useful in thermal energy application. It is most usage in the area of space heating, curing the timber and drying of agricultural products etc due to its simple construction and it is very easy to use. The thermal efficiency of solar air heater is low due to its low heat transfer coefficient between air and the heat absorbing plate. Artificial roughness provides on the absorber plate, due to this increase the heat transfer coefficient and thereby the thermal efficiency [1].

This review aims to merge the efforts of the researchers working on SAH and find the pathways to present it by means of robust applications to use, and thus to enhance the performance for consideration in the design and development. SAHs have been used at a wide range for energy saving specially for applications requiring low to moderate air temperatures [2]. They are also used effectively for some applications including space heating, textile, marine products, solar water desalination and crop drying. SAHs have many advantages compared to liquid heaters because of avoiding the problems of freezing or stagnation, leaks, damage and environmental or health hazard risk from the heat transfer medium. Moreover, they reduce costs of energy consumption for the application involved.

2. LITERATURE REVIEW

There are many uses and applications of solar air heaters that are used at low and moderate temperatures. Some of these are drying for industrial, agricultural purposes, space heating, and curing of concrete/clay building components.

Ajeet pratap singh et al. [1] investigated the performance enhancement of a curved solar air heater using CFD. In this paper, he report the investigation of various curved solar air heater designs that shows significant enhancement of heat transfer. It was observed that secondary vortex formation near the absorber wall increases the Nusselt number significantly. New correlations for friction factor and Nusselt number has been developed as a function of Reynolds number and various geometric parameters such as relative groove height and pitch ratios for different design of air heaters. It is hoped that data of parameters i.e. Nusselt number (*Nu*), outlet air temperature (T_o), thermal efficiency (η_{th}) and friction factor (*f*) presented in this paper would help researchers and industry in developing efficient designs of solar collectors.

Kumar et al. [2] investigated the effect of arc shape wire ribs arranged in 'S' shape on heat transfer and friction factor of air flowing in solar air heater as shown in fig. 1. These 'S' ribs induced the secondary flow which affects the main flow. Experiments were performed for different geometrical parameters include Reynolds number from 2400 to 20000, relative roughness height from 0.022 to 0.054, angle of attack from 300 -750 and relative roughness pitch in the range of 4-10 and relative roughness width from 1-4 at fixed aspect ratio of 12. From experimental investigation, it was observed that maximum enhancement of Nusselt number and friction factor 4.64 & 2.71 times respectively at arc angle of 600 , relative roughness width of 3, relative roughness pitch of 8 and relative roughness height of 0.043. The statistical correlation of Nusselt number and friction factor was developed with maximum deviation of 10.8% and 10% respectively

Raj kumar et al. [3] had investigated the heat transfer enhancement in solar air channel with broken multiple V-type baffle. Investigation deals with experimental analysis of the heat transfer behavior and optimum relative width parameter of the solar air channel of aspect ratio of 10.0 with 60° angled broken multiple V-type baffles. The current experiment enclosed a wide range of parameter such as Reynolds number varied from 3000 to 8000, relative width varied from 1.0 to 6.0, relative baffle height of 0.5, relative baffle pitch of 10.0, relative discrete distance of 0.67 and relative gap width of 1.0. The obtained experimental results showed that higher overall thermal performance occurred at a relative baffle width of 5.0. Also, the results reveal that the broken multiple V-type baffles are thermo-hydraulically superior as compared to the other baffles shaped solar air channel.

Arun K. Behura et al. [4] had investigated the Heat transfer, friction factor and thermal performance of three sides artificially roughened solar air heaters. The experimental results on heat transfer, friction factor and thermal performance of a novel type of three sides artificially roughened and glass covered solar air heater under fully developed turbulent flow conditions. The results on heat transfer and friction factor compare well with analytical values, for the range of the values of operating parameters. Such solar air heaters have higher value of heat transfer coefficient than those of one side artificially roughened solar air heaters in the range of 21–78% for the same values of operating parameters. The values of performance parameters, $F_R U_L$ and $F_R(\tau\alpha)$ and consequently those of F_R and F', have been found to be superior to those of one side roughened solar air heaters. Thermal performance equations in terms of the performance parameters have been derived. Enhancement of about 40–48% in thermal performance over those of one side artificially roughened solar air heaters has been achieved.

Anil kumar et al. [5] had studied the Convective heat transfer enhancement in solar air channels. Heat transfer enhancement in solar air ducts at low and moderate Reynolds numbers has been a major subject of intensive research over the years. Various techniques, based on both active and passive methods, have been proposed to enhance convective heat transfer in these applications. Among these methods are systems involving vortex generators such as ribs and baffles. Disturbance promoters increase fluid mixing and interrupt the development of the thermal boundary layer, leading to enhanced heat transfer. The objective of this article is to review various studies in which different turbulence promoter elements (ribs, baffles) were used to enhance heat transfer with a minimum pressure drop. Convective heat transfer coefficient and pressure drop correlations reported in literature are also presented. These correlations may be used to predict the overall thermal performance of turbulence promoters in solar air channels. In this work a comparative study are also carried out to select best rib and baffle roughness shapes for maximum heat transfer rate and minimum pressure drop losses. Critical reviews of the existing experimental and numerical studies in the literature are given, and various future possibilities in this area, such as the use of turbulence promoters in a solar air channels, are also addressed.

Abhishek saxena et al. [6] had designed and evaluated thermal performance of a novel solar air heater. In the present scenario, numerous applications perform on solar energy for cooking, heating and cooling, and power generation, globally. Solar air heaters are one of these applications purposely used for, drying, timber seasoning and space heating. In the present work, a solar air heater (SAH) has been designed to produce a good exhaust temperature for long hours especially in the case of poor ambient conditions or during off sunshine hours. A mixture of desert and granular carbon in the ratio of 4:6 has been used as thermal heat storage inside the SAH. Two halogen lights of 300 W are used to increase the exhaust temperature of the SAH by placing them in the inlet and outlet ducts. All the experiments have conducted on natural and forced convection for performance evaluation on two similar design solar air heaters (with and without heat storage). The comparisons are made with two similar design solar air heaters carrying desert and granular carbon, as an individual heat storing media, to find out an optimum design of a SAH with long term heating. The thermal efficiencies of the novel SAH range from 18.04% to 20.78% of natural convection and 52.21%–80.05% with forced convection.

Sukhmeet Singh et al. [7] had studied thermo-hydraulic performance comparison of rib roughness under investigation, 'V-down ribs with gap' and similar reported rib roughness geometries used in solar air heater duct. The present rib roughness has flow-attack-angle and relative roughness height of 60° and 0.043, respectively. The duct has aspect ratio of 12 and the Reynolds number ranged from 3000 to 15,000. The roughened wall was uniformly heated while the remaining three walls were insulated. These boundary conditions correspond closely to those found in conventional solar air heaters. Five rib roughened plates having relative roughness pitch of 4, 6, 8, 10 and 12 have been tested. The Nusselt number and friction factor were found to be highest for relative roughness pitch of 8. Maximum enhancement in Nusselt number and friction factor has been found to be 2.70 and 2.86, respectively. Thermo-hydraulic performance parameter ranged from 1.27 to 1.93. Thermo-hydraulic comparison with similar rib geometries show that the present roughness geometry performs better for Reynolds number range of 3000–12,000.

Tabish alam et al. [8] had experimentally investigated the effect of geometrical parameters of the V-shaped perforated blocks on heat transfer and flow characteristics of rectangular duct, has been investigated experimentally. The experimental investigation encompassed the geometrical parameter namely, relative blockage height (e/H) of 0.4–1.0, relative pitch ratio (P/e) of 4–12 and open area ratio (β) of 5–25% at a fixed angle of attack (α) of 60°. The effect of V-shaped perforated blockages has been investigated for the range of Reynolds number from 2000 to 20,000. The maximum enhancement in Nusselt and friction factor has been found to be 6.76 and 28.84 times to that of smooth duct, respectively. Thermohydraulic performance of V-shaped perforated blockages is also compared to that of V-shaped solid blockages for same geometrical parameters.

Sombat tamna et al. [9] had studied the heat transfer behaviors in a solar air heater channel with multiple V-baffle vortex generators. The article presents a study on heat transfer augmentation in a solar air heater channel fitted with multiple V-baffle vortex generators (BVG). During the test air was passed through the test channel under a uniform wall heat-flux of the absorber plate. The fluid flow and heat transfer characteristics are presented for Reynolds numbers based on the channel hydraulic diameter ranging from 4000 to 21,000. The V-baffles are applied at a relative baffle height (in terms of blockage ratio, $BR = b/H = 0.25$) and attack angle of 45° with respect to the main flow direction. The use of BVG in the channel is to generate multiple longitudinal vortex flows through the test channel to increase turbulence intensity and stronger mixing of fluid between the core and the near-wall flow. Influences of three different baffle-pitch to channel-height ratios ($PR = P/H = 0.5$, 1 and 2) on heat transfer and pressure drop in terms of respective Nusselt number and friction factor (or energy loss for propelling air through the channel) are examined. Three BVG arrangements, namely, one BVG wall (or single BVG), in-line and staggered BVGs on two opposite walls are also investigated. The experimental result reveals that the smaller PR provides the highest heat transfer and friction factor for all BVGs. The in-line BVG yields higher heat transfer and friction loss than the staggered and the single BVG. However, the single BVG with $PR = 0.5$ yields the highest thermal performance. To shed light of heat transfer mechanism, a numerical work is also conducted to investigate heat transfer and flow friction characteristics in the channel fitted with 45° BVGs and in comparison, the numerical results are in good agreement with experimental data.

Foued chabane et al. [10] had experimentally studied the heat transfer and thermal performance with longitudinal fins of solar air heater. The thermal performance of a single pass solar air heater with five fins attached was investigated experimentally. Longitudinal fins were used inferior the absorber plate to increase the heat exchange and render the flow fluid in the channel uniform. The effect of mass flow rate of air on the outlet temperature, the heat transfer in the thickness of the solar collector, and the thermal efficiency were studied. Experiments were performed for two air mass flow rates of 0.012 and 0.016 kg s^{-1}. Moreover, the maximum efficiency values obtained for the 0.012 and 0.016 kg s^{-1} with and without fins were 40.02%, 51.50% and 34.92%, 43.94%, respectively. A comparison of the results of the mass flow rates by solar collector with and without fins shows a substantial enhancement in the thermal efficiency.

Anil Singh Yadav [11] had numerically investigated the thermo-hydraulic performance analysis of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate is conducted to analyze the two-dimensional incompressible Navier–Stokes flows through the artificially roughened solar air heater for relevant Reynolds number ranges from 3800 to 18,000. Twelve different configurations of equilateral triangular sectioned rib (*P/e* = 7.14–35.71 and *e/d* = 0.021–0.042) have been used as roughness element. The governing equations are solved with a finite-volume-based numerical method. The commercial finite-volume based CFD code ANSYS FLUENT is used to simulate turbulent airflow through artificially roughened solar air heater. The RNG k–ε turbulence model is used to solve the transport equations for turbulent flow energy and dissipation rate. A total numbers of 432,187 quad grid intervals with a near wall elements spacing of $y^+ \approx 2$ are used. Detailed results about average heat transfer and fluid friction in an artificially roughened solar air heater are presented and discussed. The effects of grid distributions on the numerical predictions are also discussed. It has been observed that for a given constant value of heat flux (1000 W/m^2), the performance of the artificially roughened solar air heater is strong function of the Reynolds number, relative roughness pitch and relative roughness height. Optimum configuration of the roughness element for artificially roughened solar air heater is evaluated.

Anil P. Singh et al. [12] had experimentally investigated the effect of geometrical parameters of multiple arc shaped roughness element on heat transfer and friction characteristics of rectangular duct solar air heater having roughness on the underside of the absorber plate have been studied. The parameters were selected on the basis of practical considerations and operating conditions of solar air heaters. The experiments carried out encompasses Reynolds number (Re) in the range of 2200–22,000, relative roughness height (*e*/*D*) range of 0.018–0.045, relative roughness width (*W*/*w*) ranges from 1 to 7, relative roughness pitch (*p*/*e*) range of 4–16 andarc angle (α) ranges from 30 to 75°. The thermo-hydraulic performance parameter was found to be best for relative roughness width (*W*/*w*) of 5.

Karwa and Chitoshiya [13] experimentally investigated the thermo-hydraulic performance of solar air heater with 600 vdown discrete ribs roughness on rectangular duct at outdoor conditions. The experimental study covered the range of Reynolds number from 2750-11150 at a fixed relative roughness height, aspect ratio of 0.047 & 7.8 respectively. It was observed that the thermal efficiency due to roughness improved by 12.5-20% at different flow rate. Mathematical model of solar air heater using V-down roughness also given in this paper. Variation in experimental friction factor with predicted roughened and smooth duct were found 6.1% and 5.7% average deviation

Sanjay Yadav et al. [14] studied the effect of heat transfer and friction characteristics of turbulent flow of air passing through rectangular duct which is roughened by circular protrusions arranged in angular arc fashion. The roughened wall is uniformly heated while other three walls are kept insulated. The thermal and friction characteristics are governed by duct aspect ratio (*W*/*H*), hydraulic diameter (*D*), relative roughness pitch (*P*/*e*), relative roughness height (*e*/*D*), arc angle (α) and Reynolds number (Re). Experiments encompassed that the Reynolds number ranges from 3600 to 18,100, *P*/*e* ranges from 12 to 24, *e*/*D* ranges from 0.015 to 0.03 and arc angle of protrusions arrangement ranges from 45° to 75°. The maximum enhancement in heat transfer and friction factor is 2.89 and 2.93 times as compared with smooth duct. These experimental results have been used to develop correlations for Nusselt number and friction factor.

Anil Kumar et al. [15] experimentally investigated the heat transfer and friction in the flow of air in rectangular ducts having multi v-shaped rib with gap roughness on one broad wall. The investigation encompassed Reynolds number (*Re*) from 2000 to 20,000, relative gap distance (G_d/L_v) values of 0.24–0.80, relative gap width (*g*/*e*) values of 0.5–1.5, relative roughness height (*e*/*D*) values of 0.022–0.043, relative roughness pitch (*P*/*e*) values of 6–12, relative roughness width ratio (*W*/*w*) values of 1–10, angle of attack (α) range of 30°–75°. The optimum values of geometrical parameters of roughness have been obtained and discussed. For Nusselt number (*Nu*), the maximum enhancement of the order of 6.74 times of the corresponding value of the smooth duct has been obtained, however the friction factor (*f*) has also been seen to increase by 6.37 times of that of the smooth duct. The rib parameters corresponding to maximum increase in *Nu* and *f* were $G_d/L_v = 0.69$, $g/e = 1.0$, $e/D = 0.043$, $P/e = 8$, $W/w = 6$ and $\alpha = 60°$. Based on the experimental data, correlations for *Nu* and *f* have been developed as function of roughness parameters of multi v-shaped with gap rib and flow Reynolds number.

3. CONCLUSION

1. The use of artificial roughness in different forms and shapes are effective and efficient way to enhance the performance of solar air heaters.

2. Numbers of experimental 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.

3. A Relation between heat transfer and friction factor have been developed which are applicable to wide range of rib configurations and operating parameters.

4. The effective efficiency based criteria is found suitable for design of roughened solar air heater and design plots can be used to design the V down perforated baffled roughened solar air heater.

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