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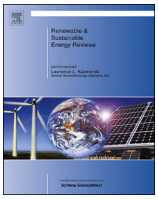

Heat transfer mechanism and energy efficiency of artificially roughened solar air heaters—A review

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ABSTRACT

Roughness applied on a broad wall of a solar air heater significantly enhances the heat transfer to the flowing fluid with the moderate rise in fluid friction. It is imperative to select the roughness pattern and its geometrical parameters, which are responsible for the change in fluid flow behaviour steering the level of heat transfer and friction. With a view to survey the mechanism of heat transfer governed by the fluid flow pattern over the roughened wall, the distinct roughness patterns used in solar air heaters are reviewed with a fresh perspective. The interpretation of the fluid turbulence and heat transfer mechanism in case of different rib geometries has been expatiated based on available literature. Optimally usable range of Reynolds number and Temperature rise parameter for roughness geometries are proposed on the basis of effective efficiency of roughened collector.

Contents

1. Introduction

In view of the rising demand of compact and efficient energy conversion and transportation devices, enhancement of heat transfer at a solid–fluid interface has been emerged as a broad area of investigation in the recent past. Several techniques of heat transfer enhancement based on passive methods have been continually explored for a variety of heat transfer applications. In passive method, heat transferring surfaces are artificially modified in a way to promote local wall turbulence, which leads to suppress the thermal barrier for heat transfer. Interrupted, serrated, and ribbed surfaces are identified as convenient and cost effective turbulators in many cases such as cooling of gas turbine blades, electronic equipments, nuclear reactors, and compact heat exchangers. Literature reveals that the use of artificial roughness in the form of repeated ribs enhances the thermal performance of the system at the cost of moderate loss of power in overcoming friction. It has been observed that the presence of periodically repeated ribbing roughness restarts the boundary layer by reattaching the flow after each separation and thereby increasing the local value of heat flux in the inter-rib region. To attain the desirable level of enhancement in the heat transfer at the cost of unwanted increase in the friction losses, it is advisable that the turbulence must be created only in the vicinity of the heat

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transferring surface i.e. in the viscous sub-layer only and the core flow should not be unduly disturbed. This can be done by keeping the height of the roughness elements of the order of the thickness of viscous sub-layer which is relatively small in comparison with the duct dimensions [1–8].

In view of the fact that the geometrical parameters of rib roughness have a strong influence on heat transfer and fluid friction, a majority of researchers was headed towards optimizing the geometrical parameters of roughness, i.e., roughness shape, pitch, height, and orientation with respect to flow direction, etc. Wright, Fu and Han [9]; Han, Zhang and Lee [10]; Han and Zhang [11] have tested a variety of rib roughness configurations to obtain the heat transfer and friction characteristics of artificially roughened ducts and channels. One of the prominent candidates for the application of artificial roughness is the solar air heaters due to its simplicity, economic viability and ease in operation. With a view to improve the thermal performance of solar air heaters, heat transfer rates to the air can be significantly increased by the application of roughness on the underside of the absorber plate. The heat transfer and friction characteristics of solar air heaters were investigated by modeling the collector as a rectangular channel having an artificially roughened top wall. Due to this reason, the heat transfer and fluid flow characteristics of solar air heater duct are different from two walls roughened channels and internally roughened tubes. Ribs of square, circular, semi-circular and wedge shapes have been applied in the form of transverse, inclined, V and multi V patterns with or without gaps. Roughness parameters like relative roughness pitch (p/e), relative roughness height (e/D), angle of attack (α) and aspect ratio of the duct have been identified as vital system parameters, largely affecting the thermo-hydraulic performance of the solar collectors.

In order to conceive the direction of future investigations, it is imperative to minutely analyze the process of heat transfer affected by the change in fluid flow behavior owing to specific roughness geometry. With a view to provide insight of the mechanism of heat transfer from a roughened surface, the literature on artificially roughened solar air heaters is reviewed with a different outlook for the benefit of ongoing and future researches. Besides this, the overall performance of the roughened solar air heater duct is examined with respect to varying operating conditions to ascertain the actual benefit of some of the prominent roughness geometries.

2. Artificially roughened solar air heater

In most of the studies pertaining to solar air heaters, a broad metallic wall of the duct is roughened either by gluing small-diameter wires or forming integral wedge or chamfered rib roughness by machining [1,2,12–34]. Indoor experimentations have been performed on the simulated test setup, designed in accordance with the guidelines suggested in ASHRAE standard 93-77 [35]. Fig. 1 shows the schematic diagram of the experimental setup employed for data collection by several investigators. It consists of rectangular wooden duct connected to a centrifugal blower by means of a circular pipe. The duct has mainly three sections: entry, test and exit sections. The upper horizontal wall of test section has been replaced by a metallic plate with blackened top, which resembles the absorber plate of solar collector. An electric heater is placed over the absorber plate to impress upon a uniform heat flux. The inlet section is provided to ensure the fully developed flow in the test section while the exit section facilitates proper mixing of air before exiting the duct. The duct is connected to the circular pipe fitted with an orifice flow meter and flow control valve to measure and control the flow through the system respectively. The other end of circular pipe is connected to the inlet of a centrifugal blower which exhales the air to atmosphere. The duct all along is insulated to minimize the heat loss to the surroundings.

The pressure drop across the test section is measured to quantify the fluid friction while the temperatures of absorber plate surface, inlet and exit air were measured to estimate the average heat transfer coefficient over the absorber plate surface.

Prasad and Mullick [1] were pioneers in applying the concept of artificial roughness to improve the thermal performance of solar air heater for drying purposes. They have investigated the effect of transverse rib roughness height and pitch on heat transfer and fluid flow. The small diameter circular wire ribs arranged in a transverse direction have been introduced as the elementary type of roughness, which has shown considerable enhancement in heat transfer over the non ribbed solar air heater duct [1,2,24,25]. Apart from circular and square ribs, other rib shape like a wedge [36] and chamfered ribs [37,38] have also been investigated to understand the effect of rib shape and their parameters on the thermo-hydraulic performance of solar air heaters.

Inclined rib roughness in the form of circular wires have further raised the level of heat transfer enhancement as compared to

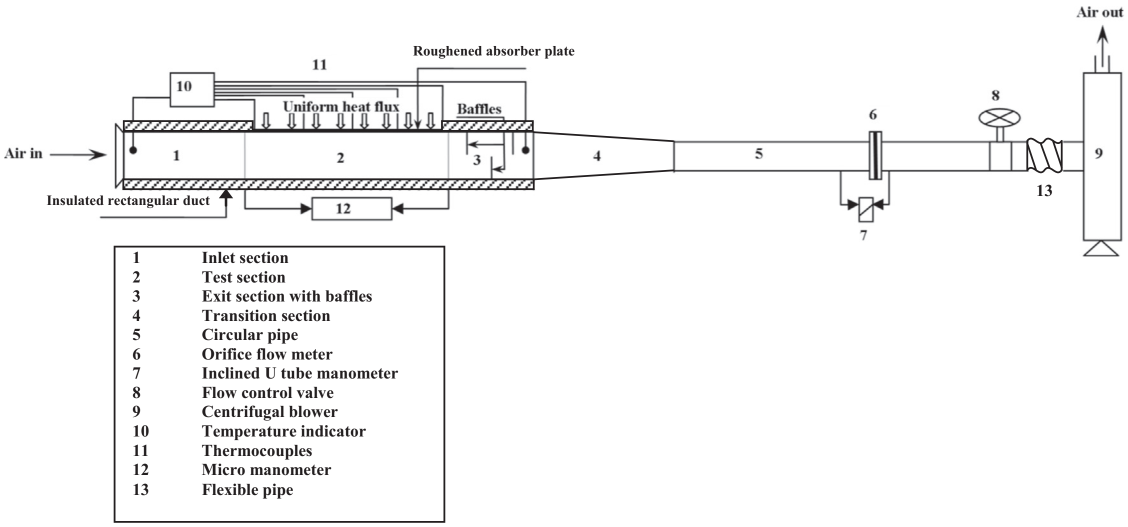

Fig. 1. Schematic diagram of experimental test set up.