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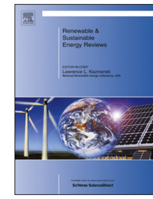

Heat and flow characteristics of air heater ducts provided with turbulators—A review

Tabish Alam [a,*], R.P. Saini [a], J.S. Saini [b]

[a] Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India
[b] Mechanical & Industrial Engineering Department, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

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ABSTRACT

The use of turbulators in different forms of ribs, baffles, delta winglets, obstacles, vortex generator, rings and perforated blocks/baffles is an effective way to improve the performance of heat exchangers and solar air heaters. Investigators studied the effect of these turbulators for heat transfer and friction characteristics in air ducts. An attempt has been made in this paper to carry out an extensive literature review of turbulators used to investigate heat transfer augmentation and flow structure in air ducts. Based on the review it is found that perforation in ribs/baffles/blocks and combination of combined rib and delta winglet leads to the better thermo-hydraulic performance. The correlations presented by various investigators, in terms of non-dimensional parameters for heat transfer and friction factor in solar air heaters and heat exchangers have also been presented.

Contents

1. Introduction

Uses of energy are increasing with the population growth of the world with limited resources of energy such as crude oil, natural gas, coal and nuclear energy, etc. Continuous use of these resources would lead to dissipation. Conventional energy degradation with the consumption of fossil fuels is an intimidation to life on this earth. In view of earth's depleting fossil fuel reserves, researchers are stimulated to develop renewable energy available on earth. Of many renewable energies, solar energy is an epochal alternative as an unlimited source of energy which can fulfil the need of our daily life. The most dexterous way to utilise solar energy is to transform it into thermal energy by using solar air heater. Solar air heater is simple and less sophisticated in nature due to its simple design and low cost. The thermal efficiency of solar air heater is considered to be very low because of high thermal resistance or low heat transfer capability between absorber plate and flowing air in the duct. Various enhancement techniques are employed to make the solar air heater efficient. Enhancement techniques essentially reduce the thermal resistance in a conventional solar air heater by promoting higher convective heat transfer coefficient with or without increase in surface area. Number of techniques have been investigated and are available for enhancing the heat transfer rate in solar air heaters. Many investigators used fins, artificial roughness, and corrugated absorber plate to reduce the thermal resistance. Turbulators in the form of delta winglet, vortex generator, obstacles and perforated baffles/ribs/blocks

* Corresponding author. Tel.: +91 9411007747; fax: +91 1332 273517.
E-mail address: tabish.iitr@gmail.com (T. Alam).

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have been used for enhancing the convective heat transfer coefficient by creating turbulence at heat transfer surface. In this paper, an attempt has been made to review the investigation carried out by various investigators for heat and flow characteristics in ducts provided with different types of turbulators viz. solid ribs, perforated baffles/block/ribs, rings, vortex generator, obstacles and delta winglets.

2. Concept of turbulators using in air heater ducts

Turbulators in dynamic flow field of air create turbulence in flow and improve the heat transfer exchange by convection. The presence of the turbulators in fluid flow results in enhancement of heat transfer from the absorber plate with high penalty of pressure loss. The turbulators can create one or more combinations of the following conditions favourable to heat transfer rate with minimal pressure penalty such as (i) breaking the sub-laminar boundary, (ii) increasing the turbulent intensity, (iii) increase in heat transfer area, and (iv) generating of vortex and/or secondary flows. The turbulators of larger height are responsible for high heat transfer but are also responsible for high pressure drop. Due to recirculation of flow, hot zone is developed behind these elements leading to deterioration of heat transfer from these zones. Thus attempts have been made by the researchers in order to solve this problem by providing perforations in the ribs/block/baffles. The perforations enhance the heat transfer from these zones and reduce the pressure drop across the channel. The perforations in elements allow a part of the flow to pass through these perforations and mix with the main flow to create a higher level of mixing and turbulence. Nikuradse [1] attempted to develop temperature distribution and velocity in roughened air ducts and various researchers conducted experimental investigations on turbulators. Dipprey and Sabersky [2] experimentally investigated three sand grain roughened tubes and one smooth tube. Measurements of heat transfer and friction coefficients were obtained with distilled water flowing through electrically heated tubes. Increment in heat transfer due to roughness was found as high as 270%. Similar study carried out by Gomelauri [3] in which, roughened annulus tubes were examined. Kolar [4] tested roughened tube which was formed by cutting 60° triangular threads inside the tube. Sheriff and Gumley [5] investigated regular geometry to study the effect of roughness on heat transfer and friction factor. Webb et al. [6] investigated heat transfer and friction factor in tubes having repeated ribs. The heat transfer and friction factor correlations were developed for turbulent flow [7]. Heat transfer correlation was based on application of a heat–momentum transfer analogy proposed by Dipprey and Sabersky [2]. Developed correlations were used to define the performance advantage of roughened tubes in heat exchanger design in comparison to similar smooth tubes [8]. Donne and Meyer [9] performed the experiments to measure the heat transfer and friction coefficients of roughness with single rods contained in smooth tubes. Bergles et al. [10] reported enhancement techniques in heat transfer coefficient for heat exchangers. Thereafter many experimental investigations on enhancement of heat transfer have been performed in the area of heat exchanger, gas turbine, the aerofoil cooling system, gas cooled nuclear reactors and solar air heater.

3. Types of turbulators used in air heater duct

There are various types of turbulators evaluated and examined by various investigators in order to enhance the heat transfer. Surface geometry modifications in the form of turbulators change flow pattern on the heated surface and enable mixing of faster fluid region with the slower fluid region. Wakes at downstream side of turbulators introduced longitudinal trailing vortices in the boundary layer which break-up the laminar sub-layer or viscous sub-layer and increase the turbulence near the surface. Investigators have used turbulators in the form of solid ribs/baffles/blocks, perforated ribs/perforated/blocks, delta winglets, obstacles and vortex generator, etc. The classifications of different types of turbulators are shown in Fig. 1.

3.1. *Solid ribs/baffles/blocks*

Turbulators in the form of transverse, angled, V-shaped and W shaped ribs were widely investigated. These ribs may be used as continuous, broken and combination of both. Geometric parameters such as channel aspect ratio (AR), rib aspect ratio, rib height to channel height ratio, rib height to pitch ratio, channel width to height ratio, rib height to passage hydraulic diameter (e/D_h), rib angle of attack (α), rib positions, rib shape and type of rib (solid, perforated and slit rib, etc.) have pronounced effects on both local and overall heat transfer coefficients. Local Nusselt number distribution over flat and ribbed surface in a flow channel had been reported by Das [11].

Han et al. [12] investigated the turbulators ribs in rectangular channels of narrow aspect ratios and found that narrow aspect ratio channels gave better heat transfer than the wide aspect ratio channels for a constant pumping power. Han et al. [13] further reported that ribs at an angle of attack of 45° were found to have better performance at a given frictional power when compared with transverse ribs. Firth and Meyer [14] compared the heat transfer and friction performance for four different roughened

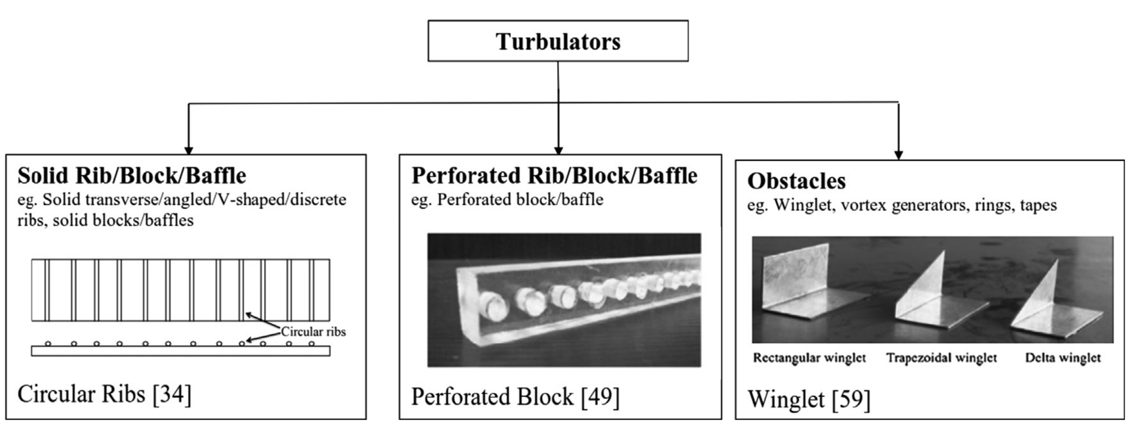

Fig. 1. Classification of turbulators used in air heater.