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Review Paper on the Use of Artificial Roughness inside a Solar Air Duct to Increase the Heat Transfer Rate Inside It

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ABSTRACT: The term solar air heating is a technology in which the radiant energy emitted by the sun is captured in an absorber and is used for space heating. Needless to say it is a renewable and pollution free method to produce space heating and when is used in commercial buildings or industries could be very cost effective. Improvement in the thermo hydraulic performance of a solar air heater can be done by enhancing the heat transfer. In general, heat transfer enhancement techniques are divided into two groups: active and passive techniques. Providing an artificial roughness on a heat transferring surface is an effective passive heat transfer technique to enhance the rate of heat transfer to fluid flow. In this paper, reviews of various artificial roughness elements used as passive heat transfer techniques, in order to improve thermo hydraulic performance of a solar air heater, is done. The objective of this paper is to review various studies, in which different artificial roughness elements are used to enhance the heat transfer rate with little penalty of friction.In this review paper, solar air heaters are discussed along with the problems associated, when use on large scale. Improvement in present technologies which are used for the manufacture of solar air heaters is the main area of focus in this paper and recent progress in enhancing the design of solar air duct are reported. Enhancement of effectiveness of the solar air heater which is in use today by applying small changes in the same so that the use of solar energy for space heating could be encouraged in lieu of using electricity was the main area of study in this paper. When being used for industrial purposes, however a lot of research work is still needed to be done.

INTRODUCTION: The rapid depletion of fossil fuel resources has necessitated an urgent search for alternative sources of energy. Of the many alternatives, solar energy stands out as the brightest long range promise towards meeting the continually increasing demand for energy. Solar energy is available freely, omnipresent and an indigenous source of energy provides a clean and pollution free atmosphere.

ADVANTAGES OF SOLAR ENERGY:

1. Solar Thermal Energy makes use of renewable natural resources which is readily available in most parts of the world.
2. Solar energy used by it creates no CO_2 or other toxic emission.

The simplest and the most efficient way to utilize solar energy are to convert it into thermal energy for heating applications by using solar collectors.

SOLAR AIR COLLECTOR:

The solar collector is the key element in a solar energy system.

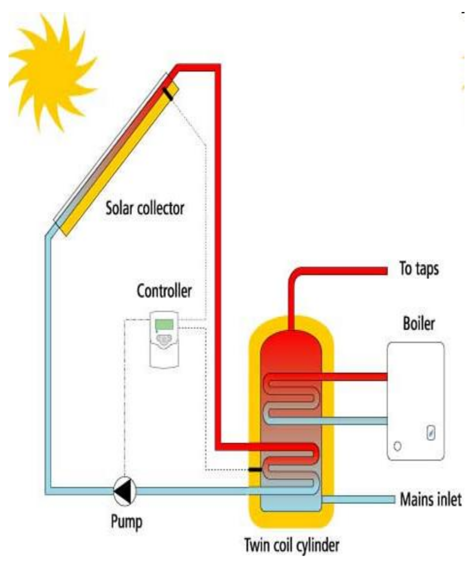

Fig 1. Solar Energy System

The function of a solar collector is simple; it intercepts incoming radiation and changes it into a useable form of energy that can be applied to meet a specific demand(fig.1).

SOLAR AIR HEATER:

A conventional solar air heater generally consists of an absorber plate with a parallel plate below forming a passage of high aspect ratio through which the air to be heated flows. As in the case of the liquid flat-plate collector, a transparent cover system is provided above the absorber plate, while a sheet metal container filled with insulation is 'provided on the bottom and sides. Solar air heaters, because of their inherent simplicity are cheap and most widely used collector devices. Solar air heaters are being used for many applications at low and moderate temperatures. Some of these are crop drying, timber seasoning, space heating, chicken brooding and curing / drying of building components. Solar air heaters, because of their inherent simplicity, are cheap and most widely used as collection device. The thermal efficiency of solar air heaters has been found to be generally poor because of their inherently low heat transfer capability between the absorber plate and air flowing in the duct. In order to make the solar air heaters economically viable, their thermal efficiency needs to be improved by enhancing the heat transfer coefficient and hence the heat transfer. The heat transfer between the absorber surface (heat transfer surface) of solar air heater and flowing air can be improved by either increasing the heat transfer surface area (by using fins), without enhancing heat transfer coefficient or by increasing heat transfer coefficient using the turbulence promoters in the form of artificial roughness on absorber surface. In this report the main focus will be on the second method i.e. by creating turbulence inside the duct with the help of the artificial ribs created on the contact surface. The convective heat transfer between two fluids or surfaces is governed by Newton's law of cooling which is

$$Q = hA\Delta t$$

Here Q is amount of heat transferred between the surfaces, h is heat transfer coefficient for the test section and Δt in the temperature difference between the two surfaces of the fluid.

By increasing the heat transfer coefficient the amount of heat transferred can be improved considerably.

A schematic of a typical solar air collector is shown in figure 2 which one can see solar rays are incident to the absorber directly and these absorbers supply this heat directly to the air flowing inside the duct and hence increasing the temperature of the supply air to the building.

Fig 2. Solar Air Heater

In order to attain higher heat transfer coefficient, the laminar sub-layer formed in the vicinity of the absorber plate is broken and the flow at the heat-transferring surface is made turbulent by introducing artificial roughness on the surface.

ARTIFICIAL ROUGHNESS:

Artificial roughness is basically a passive heat transfer enhancement technique by which thermo hydraulic performance of a solar air heater can be improved. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at the heat-transferring surface to be turbulent **[11]**. However, energy for creating such turbulence has to come from the fan or blower and the excessive power is required to flow air through the duct. Therefore, it is desirable that the turbulence must be created only in the region very close to the heat transferring surface, so that the power requirement may be lessened.

This can be done by keeping the height of the roughness elements to be small in comparison with the duct dimensions. The key dimensionless geometrical parameters that are used to characterize roughness are :

1. Relative roughness pitch (p/e): Relative roughness pitch (p/e) is defined as the ratio of distance between two consecutive ribs and height of the rib.

2. Relative roughness height (e/D): Relative roughness height (e/D) is the ratio of rib height to equivalent diameter of the air passage.

3. Aspect ratio: It is ratio of duct width to duct height. This factor also plays a very crucial role in investigating thermo-hydraulic performance.

4. The shape of the roughness element: The roughness elements or the ribs can be 2D or 3D, transverse or inclined, continuous or broken with or without gaps between them.

The artificial roughness on absorber surface may be created, either by roughening the surface randomly with a sand grain/sand blasting or by use of regular geometric roughness known as ribs. It is well known that in a turbulent flow a laminar/viscous sub-layer exists in addition to the turbulent core. The artificial roughness on heat transfer surface breaks up the laminar boundary layer of turbulent flow and makes the flow turbulent adjacent to the wall. The artificial roughness that results in the desirable increase in the heat transfer also results in an undesirable increase in the pressure drop due to the increased friction; thus the design of the flow duct and absorber surface of solar air heaters should, therefore, be executed with the objectives of high heat transfer rates and low friction losses.

Artificial roughness up to laminar sub-layer to enhance heat transfer coefficient is used in various applications like solar air heaters, heat exchangers, nuclear reactors and gas turbine blade cooling channels. A number of experimental studies in this area have been carried out but very few attempts of numerical investigation have been made so far due to complexity of flow pattern and computational limitations. Hence, these investigations reveal that not only the rib geometry but also its geometrical arrangement play a vital role in enhancing the heat transfer coefficient. Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows **[1]**.Computers are used to perform the millions of calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. Even with high-speed super computer only approximate solutions can be achieved in many cases. CFD - a computational technology that enables one to study the dynamics of things that flow. Using CFD, one can build a computational model that represents a system or device that is required for study.

LITERATURE REVIEW:

Bhagoria et al. [12] used wedge shaped transverse integral ribs in solar air heater rectangular duct and concluded that maximum enhancement of heat transfer occurs at a wedge angle of about 10° while on either side of this wedge angle, Nusselt number decreases. The friction factor increases as the wedge angle increases. When a frictionless or smooth duct was compared to the one having ribs inside it an increase up to 2.4 times in Nusselt number was observed in addition to that friction factor raised up to 5.3 of the previous value. The maximum heat transfer was found to occur for a relative roughness pitch of about 7.5.

Saini and Verma [5] used solar air heater having roughened duct with dimple shaped geometry on absorber plate as artificial roughness. They concluded that the around a roughness height (e/D) of 0.0379and relative pitch (p/e) of10, Nusselt number attains a maximum value. When the relative roughness height (e/D) was changed to 0.0289 with the same relative pitch friction factor value was found minimum. Based on these experimental data they developed correlations for Nusselt number and friction factor for the investigated system which precisely predicted the values of Nusselt number and friction factor under the given range of parameters. In a field test the effect of a 90° broken wire rib for a solar heater duct was investigated by **Bhagoria and Sahu [10]** and the maximum efficiency achieved in this case was recorded between 51-83.5% it was also calculated that at low Reynolds's number (less than 5000)the smooth surface gave better result than the roughened surface. In addition to that it was seen that when the flow was at comparatively low Reynolds number, Nusselt's number increased sharply and became constant.

Kamali binesh[6] generated a computer code to perform a numerical simulation for optimizing the shape of two-dimensional channel with periodic ribs mounted on the bottom wall to enhance turbulent heat transfer. Reynolds-Averaged Navier–Stokes analysis was used as a numerical technique and the SST *k*- ω turbulent model with near-wall treatment as a turbulent model and validated the result by comparing with existing experimental data and semi-empirical correlations.. The simulations were performed for two rib shapes, trapezoidal with decreasing height in the flow direction with and without grooves between the ribs and gave a conclusion that chamfered rib-grooved roughness ducts have more heat transfer efficiency than the chamfered rib roughness ducts without the grooves.

Shear stress transport kω turbulence model was used by **chaube sahoo et al[9]** to analyze heat transfer augmentation and flow characteristics due to artificial roughness in the form of ribs on a broad heated wall of a rectangular duct for turbulent flow(Reynolds's number between 3000-20,000).This result was then compared with that for the smooth surface. Nine different shape of ribs were used and were examined by the SST kω model and the comparison was based on the heat transfer enhancement, friction characteristics and the corresponding performance index with the pumping power being the same.

When the geometry of the roughness was made in the shape of an arc combining it with the swirling motion to the arc, considering the detachment and reattachment of the fluid Nusselt number was found to increase with the increase in Reynolds number in case where friction factor decreases with the increase in Reynolds number for all the values of relative roughness height (e/D) and relative arc angle (α/90). This work was carried by **kumar and saini[7]** and the result was validated for smooth duct. Different CFD model results were compared by the help of Dittus-Boelter empirical relationship for smooth duct. Renormalization-group (RNG) k-$\mathcal{E}$ model was found to have the best result among all the models under the test in this experiment. Finally an overall enhancement ratio was established for the roughness geometry corresponding to relative roughness height and arc angle**[13].**

CONCLUSION: A review on various investigations proposed by researches on the use of artificial roughness created inside a solar air duct was carried. The main aim was to observe the effect of artificially created ribs of different shapes, sizes and with different orientations on the heat transfer inside the duct.

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