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Research Paper

EXPERIMENTAL INVESTIGATION OF HEAT ENHANCEMENT OF A SOLAR AIR HEATER DUCT WITH ARTIFICIAL ROUGHED RIB STRUCTURE

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The low value of convective heat transfer coefficient between the air and absorber plate is a major factor for low thermal efficiency of solar air heater. It can be enhanced by application of artificial roughness in solar air heaters. The use of artificial roughness in a solar air heater duct has been proposed to be an excellent option to enhance the heat transfer from absorber plate to the air. Present investigation has been carried out the analysis of flow structure over the rib roughened surface done by using 2-D particle image velocimetry (PIV). For this investigation the Reynolds number varies between 10000 to 11000 and the relative roughness and height kept as 0.0325 and 7.5 mm. The results is compare with simulate through experiment such as velocity component, velocity magnitude, vorticity, Reynolds stress.

Keywords: Particle Image Velocimetry (PIV), Solar air heater, Artificial roughness, Reynolds number, Heat transfer enhancement

INTRODUCTION

There is a direct relation between energy and prosperity of human being. Energy is playing an increasingly important role in industrialization and worldwide progress. The rapidly increasing in the population and desire for a higher standard of living which has led to very sharp increase in the consumption of conventional energy resources. Therefore only conventional sources of energyare insufficient to meet the growing demand of energy required in future as these sources are limited and exhaustible. The alternative sources of energy are needed to be exploited that meet the growing demand of energy. The solar energy is the one of the prominent option to achieve towards meeting the continually increasing demands.The solar collector is the most essential element in a solar energy system. The function of a solar collector is simple, it interceptsincoming radiation and changes it into a useable form ofenergy that can be applied to meet a specific demand. It is a sort of heat exchanger that exchanges heat between solar radiation and flowing fluid.

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In a fieldtest the effect of a 90° broken wire rib for a solar heater ductwas investigated by Bhagoria *et al.* and themaximum efficiency achieved in this case was recordedbetween 51-83.5% it was also calculated that at low-Reynolds's number (less than 5000)the smooth surface gavebetter result than the roughened surface. In addition to that itwas seen that when the flow was at comparatively low-Reynolds number, Nusselt's number increased sharply andbecame constant.Shear stress transport k-ù turbulence model was used by Chaube *et al.* To analyze heat transfer augmentationand flow characteristics due to artificial roughness in the formof ribs on a broad heated wall of a rectangular duct forturbulent flow (Reynolds's number between 3000-20,000).Thisresult was then compared with that for the smooth surface.Nine different shapes of ribs were used and were examined bythe SST k-ù model and the comparison was based on the heattransfer enhancement, friction characteristics and thecorresponding performance index with the pumping powerbeing the same.When the geometry of the roughness was made in the shape ofan arc combining it with the swirling motion to the arc,considering the detachment and reattachment of the fluidNusselt number was found to increase with the increase in Reynolds number in case where friction factor decreases withthe increase in Reynolds number for all the values of relativeroughness height (e/D) and relative arc angle (α/90). Thiswork was carried by Kumar *et al.* and the resultwas validated for smooth duct. Different CFD model resultswere compared by the help of Dittus-Boelter empiricalrelationship for smooth duct. Renormalization-group (RNG) k-ε model was found to have the best result among all themodels under the test in this experiment. Finally an overallenhancement ratio was established for the roughness geometry corresponding to relative roughness height and arc angle.

This paper presents a method for investigation on artificial roughness to the collector to enhance the heat transfer to solar air heater. The rib-groove structure are used the relative roughness pitch and height has been kept as 0.0325 and 7.5 mm with the variation of Reynolds number between 10000 to 11000 respectively.

EXPERIMENTAL SETUP

For this investigation, a setup has been fabricated for flow field analysis using 2-D PIV system. It consists of a rectangular duct with entrance, test and exit sections, a blower, a control valve, a calibrated orifice-meter.The schematic flow sheet diagram has been shown in Figure 1. The ambient air enters from rectangular shape entrance of the duct. The other end of the duct through circular pipeline and transition section is connecting to a blower. A calibrated orifice-meter is fitted in the pipeline for airflow measurement. A digital micro manometer is used to measure the velocity and pressure drop across the orifice-meter. The duct used for this investigation has a rectangular cross-section with internal dimensions of 2600 mm x 720 mm x 31 mm (aspect ratio = 5.38), made of wooden panel of 19 mm thickness. It consist of three sections namely entrance section, test section and exit section having length of 800 mm, 1200 mm and 600 mm respectively. The exit section of 600 mm length is used after the test section in

Figure 1: Schematic View of Experimental Setup

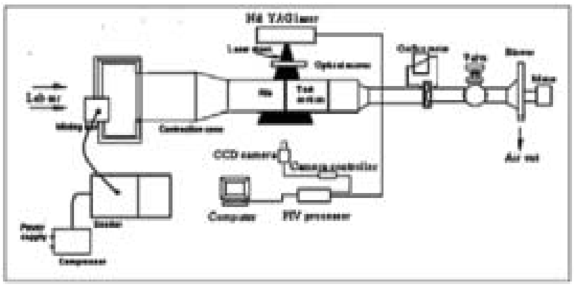
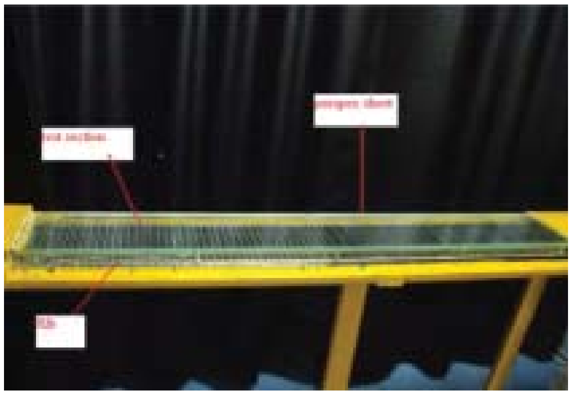


Figure 2: Photographic View of Test Section



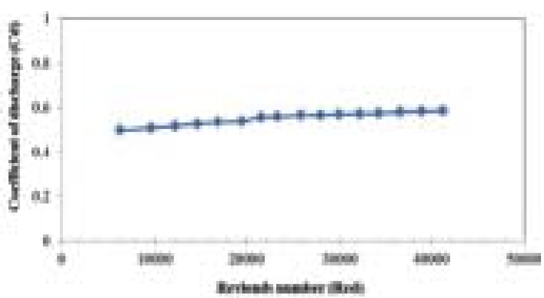
order to reduce any downstream flow effect. In the entrance section, an additional attachment called "plenum" is provided for proper mixing of the seeding particles with the working fluid (air). In order to visualize the velocities in the test section, its three sides (top, and two side walls) were made of transparent acrylic sheet, and the roughened plate is fixed at the bottom surface. The two dimensional Particle Image Velocimetry (2D-PIV) system was used to measure the flow field of the artificially roughened rectangular duct.

An aluminium plate in which artificially roughened at the wetted side and other three sides are smooth is used for flow investigation. For this analysis, it is placed in transverse direction of flow. The photographic views of test section are shown in Figure 2. A contraction cone is made before the test section is an important component of the wind tunnel design. The main function of contraction cone is to reduce the non-uniformity due to development of boundary layer along the wall of the test section. A honeycomb structure is fitted in the front of the test section. This honeycomb section makes the flow straight and the screen diffuses the small eddies generated at the end of honeycomb. Honeycomb has been prepared by straw for the purpose of uniform flow.

AIR-FLOW MEASUREMENT

A calibrated orifice-meter is used to measure the flow rate of air in the duct. For this purpose, orifice-meter is connected with an inclined U-tube manometer. A gate valve is provided in the pipeline for the controlling the air flow rate. For the measurement of flow in the pipe a 108 mm inner diameter of orifice plate is designed. The orifice meter is calibrated by measuring the flow distribution across the pipe cross-section by using a pitot tube at a distance of 110 mm towards the downstream side of the orifice meter. Velocity area integration method is used to evaluate the flow rate. U-tube manometer is using to mass flow rate by measure the pressure drop across it after

Figure 3: Calibration of Orifice-meter



calculating the coefficient of discharge. The flow rate is measured by pitot static tube to calibrate and evaluate the coefficient of discharge of orifice-meter for flow measurement. The calibration curves of the orifice meter are shown in Figure 3.

EXPERIMENT PROGRAM

All the experimental setup is assembled as per the lab layout. And checked all the electric circuit and electronic ports are well connected. To start the experiment first needed to calibration the setup by using of calibrating plate called target plate.For calibration it is must that target plate should be along the plane of laser sheet. It is examined by proper reflection of laser light from target plate. Now we fix the target plate and started the PIV system as sequence wise i.e. laser-camera-synchronizer-software.To create appropriate pressure in the atomizer for producing seeding particles by use of the compressor. After that, the atomizer nozzle is open by required density of seeding particle one by one. In the contraction section, the air is mixed with the seeding particle and mixture is flowing in the test section.The mixture is flowing in the test section is shown like as smoke flow.

Now by software, just on clicking capture it took the images of target plate which was subsequently used for calibration by special software menu. Thus we made calibration for our experiment. This was actually conversion of pixel parameter to mm parameter so that data was found in mm/pixel. Now again started taking images of the flow which is passing through test section. Now we captured various images pair, each pair timing between 50 micro-second. Now select the images for post processing then made vector field and then on pass validation we became sure that SNR value is very less which indicates good accuracy. After completion of experiment all the experimental data are import into tecplot software for plotting the graphs.

RESULTS AND DISCUSSION

In the present investigation have been discussed the effect of flow and roughness parameters on the velocity, vorticity and Reynolds stress for flow of air in the solar air heater duct. The graph of the velocity magnitude, vorticity and Reynolds stress at instant time and time average are plotted. It shows that velocity magnitude is 4 m/s at Re 10,000, is 4.4 m/s at Re 11,000 at instant time during the experiment.

Figure 4: (a) Velocity Magnitude at Instant Time at Re 10,000 (b) Velocity Magnitude at instant time at Re 11,000

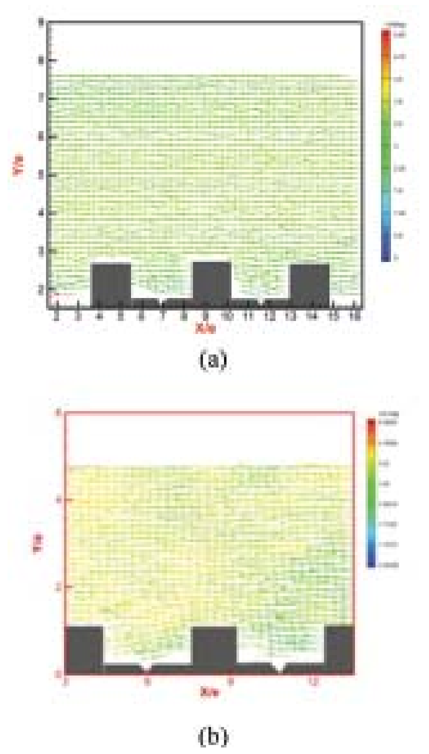
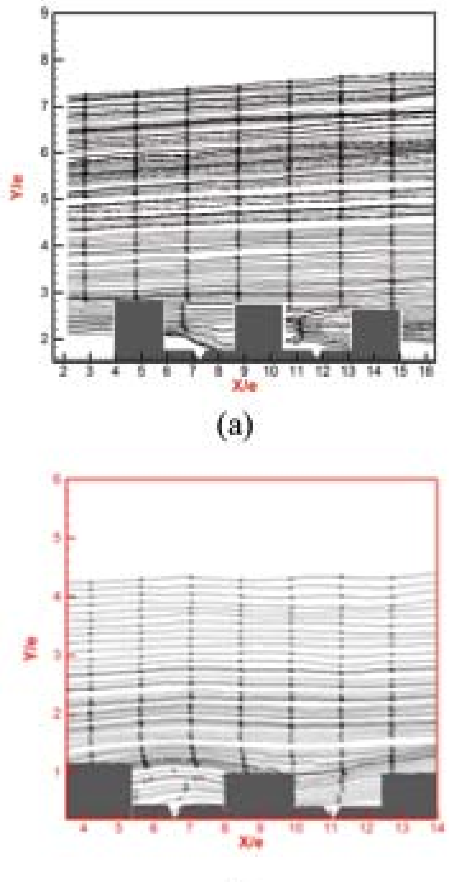
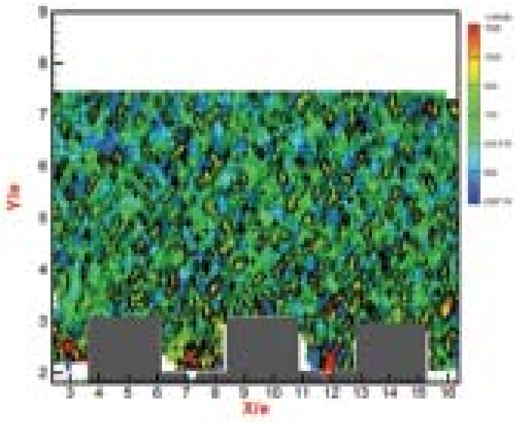


Figure 5: (a) Streamline at Instant Time at Re 10,000 (b) Streamline at Instant Time at Re 11,000



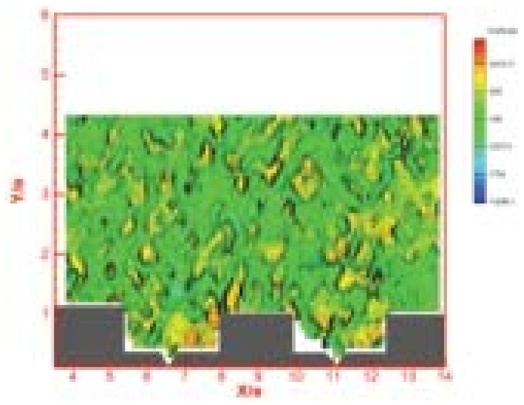
(a) (b)

Figure 6: (a) Vorticity Counter at Instant Time at Re 10,000 (b) Vorticity Counter at Instant Time at Re 11,000



(a)

Figure 6 (Cont.)



(b)

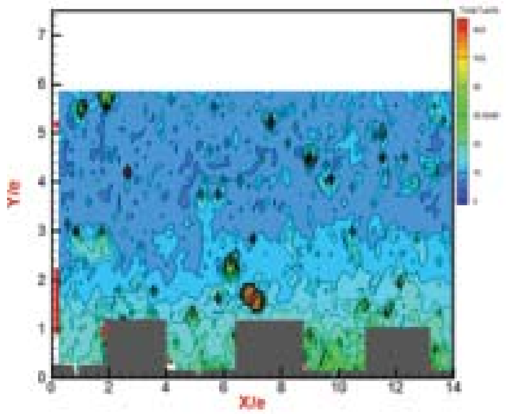
In the above Figures of velocity magnitude shows that at Reynolds no.11,000 the turbulence around the rib and groove is more than the others Reynolds number. Higher turbulence means higher heat transfer enhancement. The streamline are shown in the flow disturbance. Streamline are plotted by integrating the velocity field.

In the streamline graph shows that at Re 10,000 the flow will start disturb at the inner wall and near the groove. At Re11,000 the flow will achieve the maximum vortex near the inner wall and from eddies at the groove.

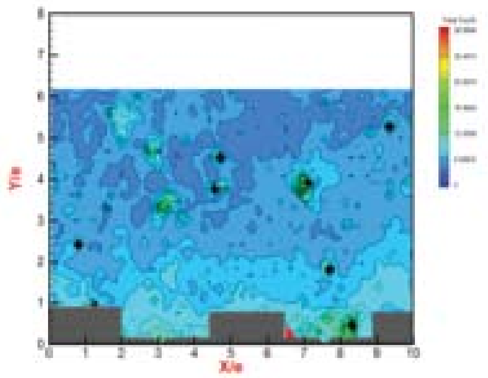
In the vorticity counter graph shows a strong vortex near the groove at Re 10,000. At the inner wall and the groove observed a vortex at Re 11,000.

Reynolds stress and turbulence intensity is measure from the velocity fluctuation in the flow. Fluctuation in velocity is measured by subtracting the mean component of velocity from instantaneous flow field. The turbulence intensity contour is plotted in plane x-y. It shows that turbulence intensity increases in the near wall region and maximum inside the shear layer and subsequently drops towards the free stream. Figure 7 shows the total turbulence intensity at time average at Re 10,000 and 11,000.

Figure 7: (a) At Time Average Total Turbulence Intensity at Re 10,000 (b) At Time Average Total Turbulence Intensity at Re 11,000



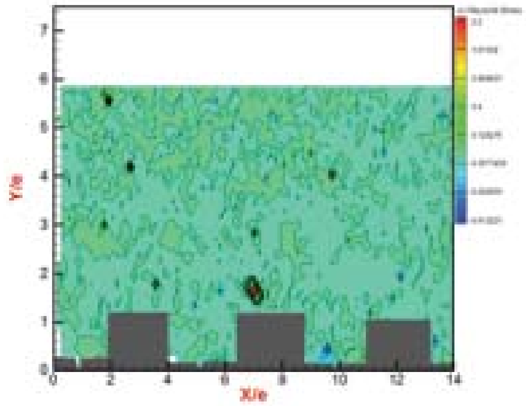
(a)



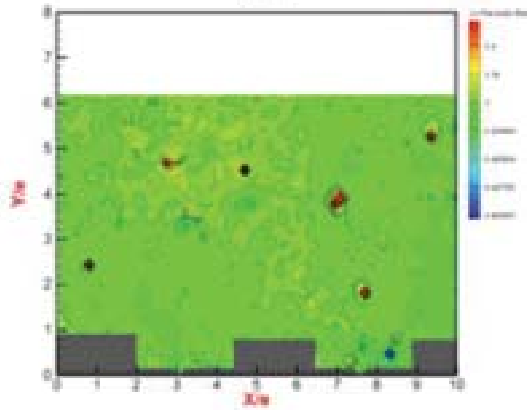
(b)

The contour plot of the Reynolds stresses in plane x-y. It is showing the strength of the separated shear layer. Significant negative values are reported in a small flow region above of the top upstream corner of the rib. This behaviour is due to the strong local acceleration. Figure 8 shows the average Reynolds stress at time average at Re 10,000 and 11,000.

Figure 8: (a) At Time Average, Average Reynolds Stress at Re 10,000 (b) At Time Average, Average Reynolds Stress at Re 11,000



(a)



(b)

CONCLUSION

The investigations on flow field analysis using rib-grooved as artificial roughness on the wetted side of one broad wall of the duct of solar air heater. The major conclusions drawn from this work are to increasing the Reynolds number the turbulence intensity is increasing. And at inside the shear sub layer it reaches its maximum value. To increasing the Reynolds number the flow gets more turbulent. From the average streamline graph, the reattachment line has shown at 4.5 – 5 times of the rib height way from the rib wall. To increasing the rib height the vortex are increased.

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