Influence of M shaped, Wedge shaped and Reverse Wedge shaped Turbulators in Solar Air Heater

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Abstract

A 2-dimensional numerical investigation has been conducted to examine the effect of three distinct turbulators (namely M shaped, Wedge shaped and Reverse wedge shaped) on the performance of solar air heater (SAH) for relevant Reynolds number ranges from 4000 to 18000. CFD code ANSYS FLUENT is used for simulation of turbulent airflow. For all three geometries constant ratio of e/D_h =0.021(where e=0.7 and D_h =33.33) and ratio P/e =14.285(where p=10) is used. Turbulence Kinetic energy and velocity contours for all turbulators have also been studied in this analysis. M-Shaped turbulators outperformed the other two turbulators with maximum value of THPP.

Keywords: CFD, Renewable Energy, Solar Air Heater, Turbulence Kinetic energy, THPP

DOI Number: 10.14704/nq.2022.20.9.NQ44269 **Neuro Quantology 2022; 20(9):2308-2312**

1 Introduction

Conventional sources of energy like coal, natural gas and oil have helped in the economic progress, but simultaneously they caused harm to the ecosystem and human health through climate change and global warming. So in place of them we may use sustainable energy resources to satisfy the world energy demands without damaging the environment. In addition, sustainable energy systems are usually small in size and are established at specific locations, which help in issues such as electricity distribution, environmental and capital cost. In contrast to large centralized power plant, sustainable systems such as windmills, photovoltaic arrays, biomass can be produced in a large lot at cheap rates and can be designed to fulfill the energy requirements of a particular location. [1] Out of all the sustainable sources of energy, solar power has drawn most attention because solar energy is available in abundance, it is free, clean and noiseless and does not cause any kind of pollution in the environment. Turbulators in different forms like ribs used in heat exchangers baffles and delta winglets used in solar collector, parabolic elliptical roughness [14], hollow tapered rings obstacles [15], vortex generator and perforated blocks/baffles are introduced which creates local wall turbulence or generation of vortex which results favorable good transferring rate related to heat with insignificant pressure penalty[4-7]. There are different methods of collecting solar energy, among these the most commonly used collector is flat plate solar collector because it has a simple design and it requires very little maintenance. Flat plate collectors are used in applications working at low to moderate temperature such as SAH [2] and solar water heater [3]. One of the big problems associated with SAH is its quite poor thermal performance due to the low heat transfer rate from the absorber plate to the cold air flowing through duct [4]. This problem is solved by using artificial turbulators like baffles, ribs. This roughness generates the turbulence inside the air duct, which results in the breaking of laminar sub-layer and so improves the heat transfer coefficient. But simultaneously artificial roughness results in the friction loss. So, the turbulators must only be provided in laminar sublayer. The idea of artificial turbulators was initially exercised by Joule [5] for improving the heat transfer rate for condensation of steam inside the tube. After that many experimental studies have been done on the use of artificial roughness. Nikuradse [6] developed a correlation for friction for flow over a sand grain roughness. The initial use of thin wires as an artificial roughness to enhance the thermal performance was done by Prasad and Mullick [7]. Chaube et al [8] have done a computational analysis to compare the performance of SAH while using 10 distinct turbulators.

They have used the SST k-ω model in FLUENT 6.1 to analyse nine different shapes of ribs while using 2D computational domain. They reported that Rectangular rib (1mm x 2mm) showed the top thermohydraulic performance when compared with all the other types of ribs under consideration for constant pumping power condition.Bisht et al. [9] conducted three dimensional computational study of solar air heater using v-shaped perforated baffles as turbulent promoters and reported the enhanced performance of solar air heater.The use of nano particles, PCM and other methods can also be used for heat transfer enhancement[10-12]. Kumar et al.[13] have carried out computational study of solar air heater utilizing broken curved ribs and fount enhancement in heat transfer.Bisht & Bisht[14] did twodimenional study of solar air heater and reported enhancement in heat transfer over smooth duct.

2. Computational domain and grid generation

A 2-dimensional numerical investigation has been conducted to examine how the performance of SAH will change by using three different types of turbulators. The turbulator geometries used in the present study are M-shaped, Wedge shaped and Reverse wedge shaped. The computational domain is of rectangular shape with length 640 mm and height 20 mm and is made up of three regions, namely, entrance region (L_1 = 245 mm), test region (L_2 = 280 mm) and exit region (L_3 = 115 mm) [15] . Turbulators are fixed beneath the absorber plate. In the present study constant (e/D_h=0.021) and constant (P/e=14.285) is taken for all three turbulators. Temperature of air at inlet is taken as 300 K.

In the pre-processing part of this study modeling of SAH is carried out in ANSYS Design Modular.[19-23] Meshing of computational domain is conducted on ANSYS ICEM platform. In this analysis computational study is conducted in ANSYS FLUENT code. Domain is developed by uniform structural quadrilateral mesh with y+=1. For getting the uniform meshing in the domain we have used face meshing with body sizing of 0.2mm.

At 3, 20,000 grid cells and after it there is only 0.023 % variation in Nusselt number using RNG K-epsilon model. So for present study we have used 3, 20,000 meshing cells for all the different configurations. Figure 1 display the uniform structural meshing of duct with M-shaped turbulators.

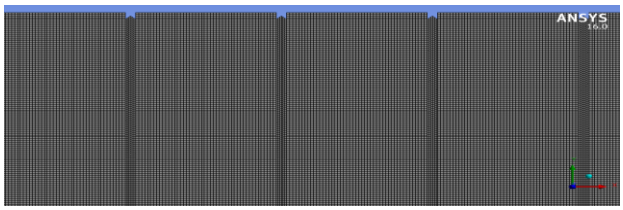

Fig.1 Meshing of SAH duct having M-shaped roughness.

2.1. Validation of results

Average Nusselt number is defined as (Eq.1)-

$$Nu_r = \frac{hD_h}{K} \quad (1)$$

The friction factor is defined as (Eq. 2)-

$$f = \frac{2(\delta p)D_h}{4\rho L_f V^2} \quad (2)$$

where,δp is the calculated value of pressure drop about the test section length, Lf.

Then the values obtained for Nur and f from equation 1 and 2 were compared with the values obtained from Dittus Boelter equation (Eq. 3) and Blasius equation (Eq.4) respectively. As shown in Figure 2 the numerical value comes almost close to that obtained from experimental correlation.

$$Nu_s = 0.023Re^{0.8}P_r^{0.4} \quad (3)$$

$$f_s = 0.0791Re^{-0.25} \quad (4)$$

THPP [16] is defined as (eq 5)-

$$THPP = \frac{Nu_r/Nu_s}{(f_r/f_s)^{1/3}} \quad (5)$$

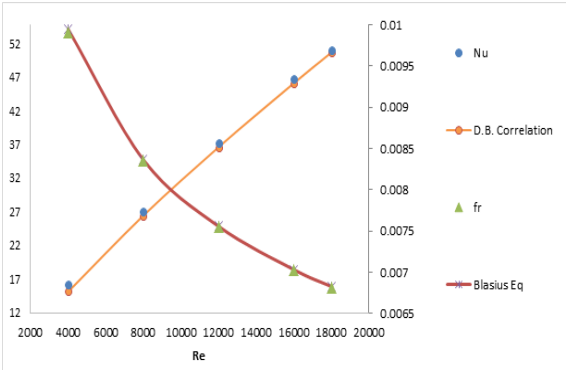

Fig.2 Effect of Reynolds no. on thermohydraulic properties for smooth duct.

3. Results and discussion

Figure 3 depicts the change of Nu and fr with Reynolds number. We can see that Nu increases

and fr decreases for whole range of Re for all the shapes.

Also we can see that the Nusselt no. for all three turbulators is better than Nusselt no. for smooth duct. This is because the roughness generates the turbulence inside the air duct, which results in the improvement of heat transfer rate between the plate and air. Similarly we can see from Figure 3 that friction factor for all three turbulators is more than friction factor for smooth duct.

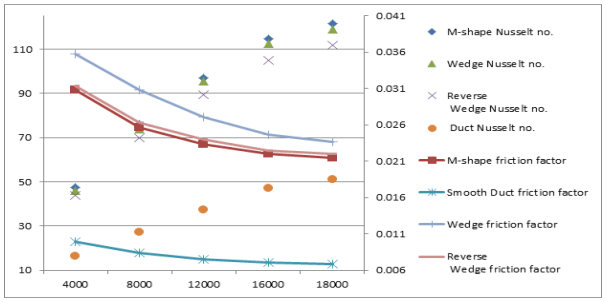

Fig. 3 Effect of Reynolds number on thermo-hydraulic performance

The comparison of THPP for all three roughnesses relative to the Reynolds Number is displayed in Figure 4. M-shaped turbulator outperformed other two turbulators, Figure 4 depicts that M-Shaping causes higher augmentation in heat transfer with low frictional penalty.

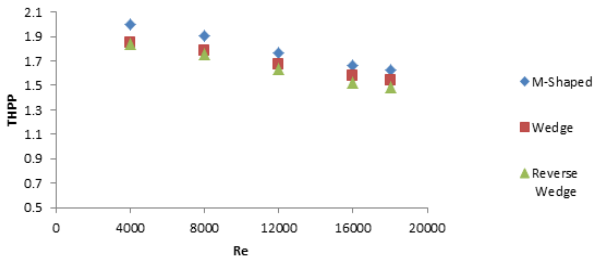

Fig. 4 Variation of THPP with Reynolds no.

Figures (5-7) show the velocity contours for all three roughnesses. Velocity contours show the formation of eddy adjacent to the rib when the flow is stabilized. Due to the sudden expansion of fluid at the downstream of rib, a separation is created. This results in the increase of velocity of flow at top surface of rib due to which turbulence increases. Because of this vortices are created at top surface of rib which transfers heat from the absorber plate to the fluid flowing through the duct. The ribs interrupt the formation of boundary layer. This results in the increase in turbulent kinetic energy.

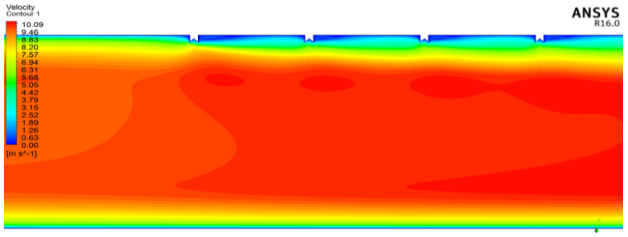

Fig. 5 Velocity contour for M-shaped roughness.

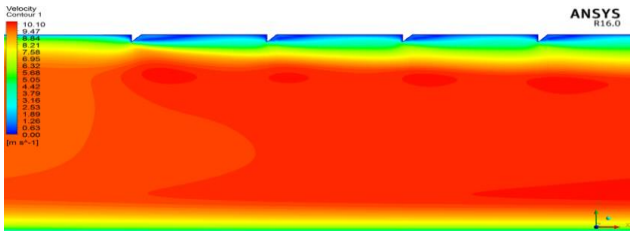

Fig. 6 Velocity contour for reverse wedge shaped roughness.

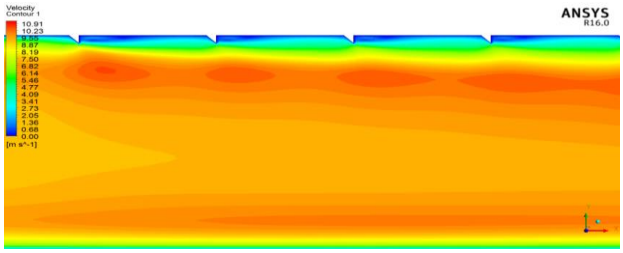

Fig. 7 Velocity contour for wedge shaped roughness.

Figures (8-10) show the turbulence kinetic energy contours for all three roughnesses. M-Shaped has series of similar and repetitive turbulence kinetic energy profile, that just show the intensification of turbulence by the turbulator hence that heighten the heat transfer rate. Heat transfer augmentation is better in M-shaped than the other two turbulators.

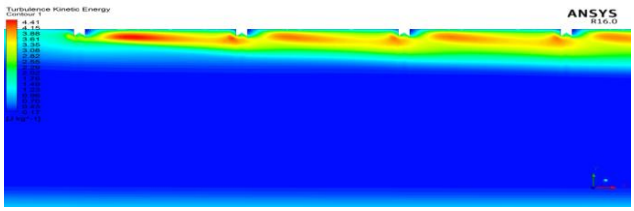

Fig. 8 Turbulence Kinetic Energy contour for M-Shaped shaped roughness.

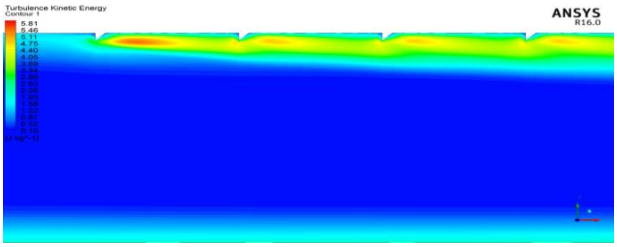

Fig. 9 Turbulence Kinetic Energy contour for reverse wedge shaped roughness.

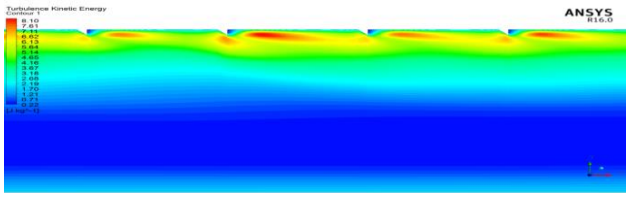

Fig. 10 Turbulence Kinetic Energy contour for wedge shaped roughness

4. Conclusion

An intensive 2D CFD study of SAH duct roughened with three kinds of turbulators is conducted in FLUENT. The major outcomes of this numerical study are outlined below.

[1] Uniform structural hexahedral mesh is achieved for all the turbulators.

[2] K-epsilon turbulence model used in verification and validation of computational domain.

[3] THPP is best obtained for M-Shaped turbulator that show higher heat transfer rate with minimum frictional losses.

[4] In post processing results of numerical study show by turbulence kinetic energy contours, M-Shaped turbulator show better repetitive attachment and detachment of flow.

Hence M-Shaped turbulator could be considered for future experimental investigation of solar air heater.

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