EFFECT OF RECTANGULAR SHAPED RIBS ARRANGED IN DIFFERENT PATTERNS ON THERMAL PERFORMANCE OF SOLAR AIR HEATER

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Abstract: ***A two-dimensional numerical study was done to predict the influence of transverse rectangular cross-sectioned ribs on a solar air heater's convective heat transfer properties. A rectangular duct was constructed and numerical analysis was carried out on square and thin (high aspect ratio) rib shapes arranged in different fashion, namely single wall, staggered and in-line ribs arranged on two opposite walls including the absorber plate. Air was the working fluid and constant heat flux was applied only on the absorber plate's top surface.***

1. INTRODUCTION

Augmentation of convective heat transfer of a rectangular duct with the help of baffles/ribs has been a common practice in the past few years. This concept is widely applied in enhancing the thermo-hydrodynamic efficiency of various industrial applications such as thermal power plants, heat exchangers, air conditioning components, refrigerators, chemical processing plants, automobile radiators and solar air heaters [1]. Solar air heater is a device used to augment the temperature of air with the help of heat extracted from solar energy. These are cheap, have simple design, require less maintenance and are eco-friendly. As a result, they have major applications in seasoning of timber, drying of agricultural products, space heating, curing of clay/concrete building components and curing of industrial products [2, 3].

The shape of a solar air heater of conventional application is that of rectangular duct encapsulating an absorber plate at the top, a rear plate, insulated wall under the rear plate, a glass cover over the sun-radiation exposed surface, and a passage between the bottom plate and absorber for air to flow in [4-8]. The detailed constructional details of a solar air heater are shown in fig. 1.1.

METHODOLOGY

Numerical Simulation

• Problem Formulation

The present work is concerned with carrying out two-dimensional simulations on an artificially roughened solar air heater, through which air of air flows. The air heater internal surface was roughened with the help of transverse-square and thin (high aspect ratio) ribs. The ribs were arranged in different patterns namely one wall only, staggered and in-line on both lower and upper faces.

• Computational domain

A rectangular section was considered. It consisted of three sections, test section of length L_2, entrance section of length L_1 and exit length of length L_3. The domain on which numerical simulations were performed was two-dimensional. It is because Chaube et al. [6] performed numerical simulations on their solar air heater of aspect ratio 7.5. They compared two- dimensional results with three dimensional results on the same geometry and did not find any considerable difference between the two. They explained their observation by claiming that for continuous transverse ribs, the secondary flow effect was negligible at higher duct aspect ratios.

• Best turbulent model selection

In order to determine which turbulent model would most accurately yield numerical results, the following methodology was adopted. CFD calculations were performed on a smooth duct (without ribs) and the friction factor and Nusselt number variation with "Re" results were extracted from the simulation. The outputs were then compared with the experimental data of Skullong et al. [1].

Results and Discussions

In this project, a computational model was constructed to measure a solar air heater's thermal performance. It consisted of baffles/ribs just below its absorber plate. This section presents detailed results of the average convective heat transfer characteristics.

- **Selection of most appropriate turbulent model**

For the smooth duct, the number of mesh cells was varied from 26280 to 186880 at a Reynolds number of 22500. It was observed in simulation results using SST-k-omega and RNG-k-epsilon turbulent model, there was less than 2% alteration in average Nusselt number after 143080 number of mesh cells. When the turbulent model was Realizable-k-epsilon, there was less than 2% alteration in average Nusselt number after 105120 number of mesh cells. Hence further simulations for different Reynolds number were performed using 143080 mesh cells with SST-k- omega and RNG-k-epsilon turbulent models and 105120 with Realizable-k-epsilon turbulence model. The Grid independence test results are represented in Fig. 4.1

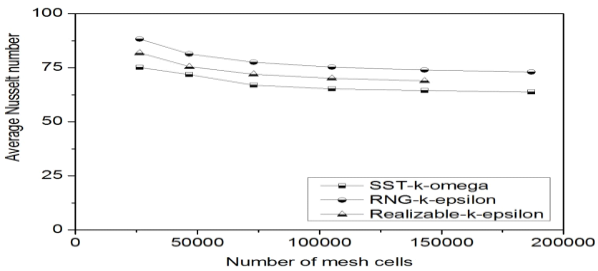


Fig. 4.1 Grid independence test results for selection of most appropriate turbulence model

Fig. 4.2 shows that as the Reynolds number incremented, the average Nusselt number increased for all the three turbulent models. The reason why this trend was observed was that as the Reynolds number increased, the flow became more turbulent (more dominance of inertial effects over viscous effects) and hence the heat transfer rate increased. Furthermore, it could be seen that the turbulent model that was the closest to Skullong et al. [1]'s output and theoretical results in the best manner was SST-k-omega. The error associated was less than 3 %. Hence, SST-k- omega turbulent model was used for simulating the roughened ducts.

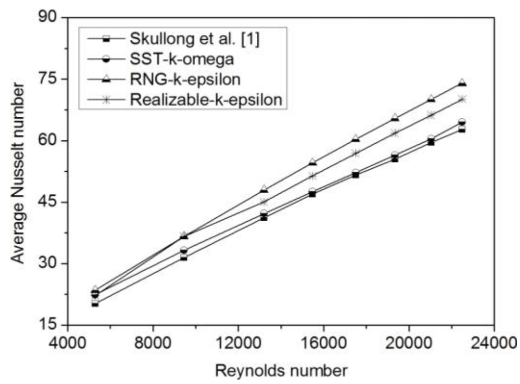


Fig. 4.2 Comparison of smooth duct results for different turbulent models

- **Numerical simulations on ducts with different shaped ribs**

This section presents detailed results of average convective heat transfer characteristics of the heater, for different shaped ribs.

- **Grid Independence test results for all the different geometries**

Figure 4.3 shows the results of grid independence tests conducted on different geometries. The turbulent model used was SST-k-omega for all the cases, since in the previous section it was proved that SST-k-omega most accurately simulated a solar air heater. The best mesh size was extracted from the Grid Independence test when there was less than 2 % variation in results on further increasing the number of mesh cells after this mesh size. Table 4.1 gives the range in which the number of mesh cells was varied and the most appropriate number of mesh cells for each configuration.

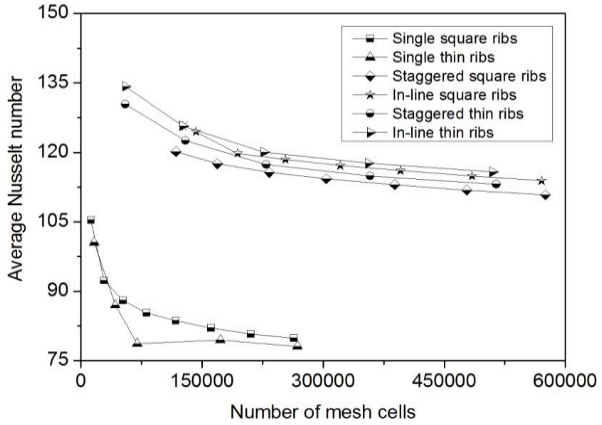


Fig. 4.3 Grid independence test results for different rib arrangements

Table 4.1 Grid Independence test results

Rib configuration	Range of mesh cells	Best number of mesh cells
Single square	12516 – 268396	210636
Single thin	16500 – 268366	172620
Staggered square	117644 – 575320	477864
In-line square	142316 - 570576	484284
Staggered thin	55048 – 514568	357962
In-line thin	54934 - 509856	355882

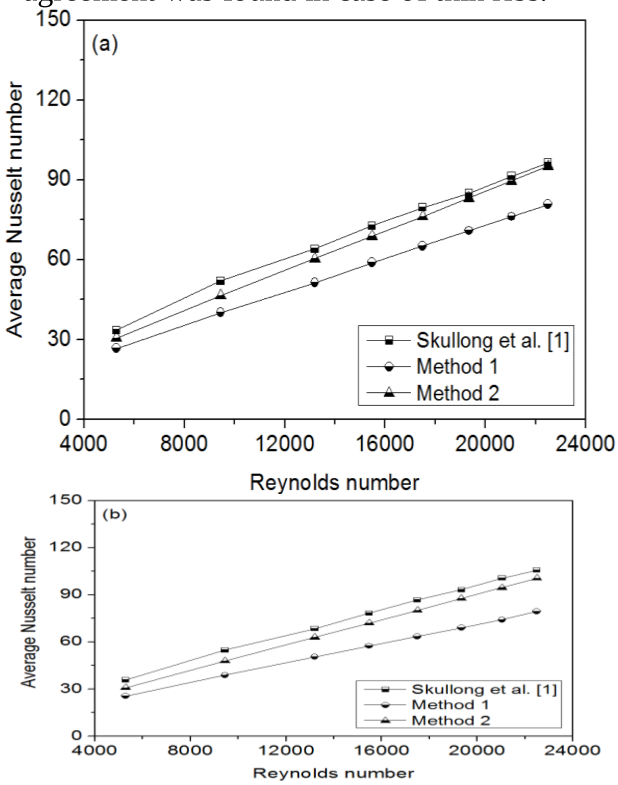
- **Simulation for different roughened ducts at different Reynolds number**

The best grid sizes were obtained by performing grid independence tests whose results were explained in the previous section. The average convective Nusselt number was measured using two methods. The first method (method-1) is given by equation 3.7 and takes the average of all

the local Nusselt numbers along the test section length. The second method (method-2) used Eq.

3.8 and it is the most widely employed method of calculating Nusselt number in experimental works. The second method was used by Skullong et al. [1,]. Fig. 4.4 clearly depicts the outcome of average Nusselt number alteration with Re for the geometries separately. As Re was raised, the average Nusselt number increased for all cases. The reason why this trend was observed was that as the Re was raised, the flow became more turbulent (more dominance of inertial effects over viscous effects) and hence the heat transfer rate increased.

There was a decent agreement when numerical outputs were compared with the experimental ones existing in the literature. Excellent matching between Nusselt numbers calculated using method 2 and the existing ones was observed for square ribs but good agreement was found in case of thin ribs.



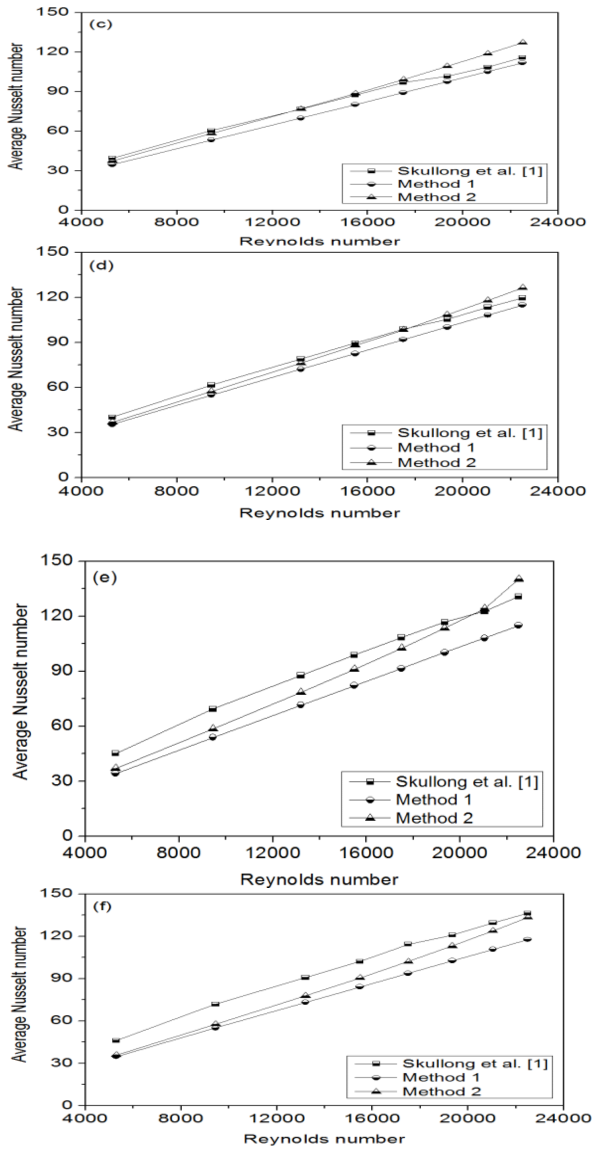


Fig. 4.4 Results of numerical analysis at different Reynolds number for (a) single square ribs, (b) single thin ribs, (c) staggered square ribs, (d) in-line square ribs, (e) staggered thin ribs and (f) in- line thin ribs.

The percentage deviation of numerical results using method-2 from experimental results of Skullong et al. [1] was found to be approximately 5, 8.3, 5, 7.4, 8.5 and 11.4 for solar air heaters with single square ribs, single thin ribs, staggered square ribs, in-line square ribs, staggered thin ribs and in-line thin ribs respectively. Nusselt number calculated using method-1 was observed to be considerably lower than the experimental ones for all the case. The corresponding percentage deviations were calculated as 18.7, 27, 3.3, 7.4, 17 and 18.3 for solar air heaters with single square ribs, single thin ribs, staggered square ribs, in-line square ribs, staggered thin ribs and in-line thin ribs respectively.

- **Comparison of Nusselt number variation with Reynolds number for all the geometries**

Fig. 4.5 graphically outlines a comparison between Nusselt number and Reynolds number for all the geometries. It can be inferred from the graph that there was a considerable augmentation in Nusselt number for both thin as well as square ribs. Interestingly, thin ribs gave much better thermal performance than their square counterparts. In-line gave the highest Nusselt number for the complete Reynolds number range used in this simulation. The possible reason attributed to this phenomenon is due to the strong interruption of flow and diversion of its direction by in-line thin baffles. The ribbed configurations in the increasing order of Nusselt number are single thin ribs, single square ribs, staggered square ribs, in-line square ribs, thin staggered ribs and thin in- line ribs. The same pattern was observed in the experimental results of except that single thin ribs in the present work gave the lowest Nusselt numbers.

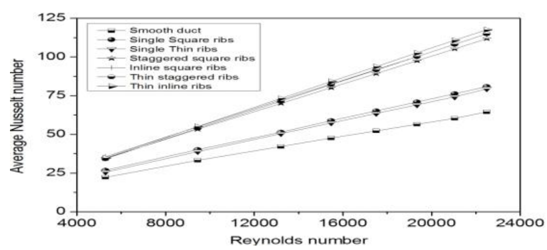


Fig. 4.5 Variation of Nu with Re for all the cases

CONCLUSION AND FUTURE SCOPE

A two-dimensional numerical study was done to predict the influence of transverse rectangular cross-sectioned ribs on a solar air heater's convective heat transfer properties.

A rectangular duct was constructed and numerical analysis was carried out on square and thin (high aspect ratio) rib shapes arranged in different fashion, namely single wall, staggered and in-line ribs arranged on two opposite walls including the absorber plate. Air was the working fluid and constant heat flux was applied only on the absorber plate's top surface. The output of numerical simulations drew the following conclusions

- On comparing simulation results, pertaining to smooth duct's average Nusselt number, for different turbulent models, it was found that SST-k-omega can best predict the thermal performance of the solar air heater.
- For all the cases considered in this study, increase in Reynolds number leads to augmentation in Nusselt number.
- When ribs/baffles are introduced just beneath the collector plate, there was a considerable alteration in the heat transfer coefficient of air.
- Two methods were used to calculate the average Nusselt number in which one method extracted the local Nusselt number at many points and on averaging these, gave the average Nusselt number and the other method resembled the one used in the existing experimental work. Good matching between existing experimental results and numerical outputs was spotted, when the second method was adopted to calculate the Nusselt number, thereby proving that CFD can be effectively applied for the design of solar air heaters. However the Nusselt number calculated using first method yielded values lower than the existing ones.
- The results revealed that the thin ribs yielded better performance than the squared ones. Similar results were also observed by Skullong et al. [1] in their experimental work.
- The staggered ribs gave lower Nusselt number than the in-line ones.
- Out of the three arrangements, the best thermal performance was given by thin inline ribs whose convective heat transfer coefficient was 1.83 times that of smooth duct.

Since, it was observed that high aspect ratio ribs allow higher convective heat transfer; hence it would be interesting to conduct research work on triangular shaped ribs having very low apex angles. The present work is expected to be very helpful for carrying out the new future project.

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