On the solar air heater thermal enhancement using differently shaped ribs combined with delta-winglet vortex generators

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Introduction

Air pollution, global warming and other issues caused largely by the burning of fossil fuels and the emissions of greenhouse gases could lead to potentially catastrophic changes in the Earth's climate and then threaten human health. Solar energy, which is a radiant light and heat from the sun, is an important source of renewable energy. A simple utilization of the sunlight is a solar air heater. It is the main component of the solar thermal systems which collects the heat by absorbing the radiant sunlight, and then heats the moving cool air as shown in Fig. 1. The solar heated air can be used in various applications [1-3], such as process heating (i.e., drying laundry, crops and timber), space heating, pre-heating ventilation makeup air, etc. They are among the highly efficient and economical solar thermal technologies because of the simple duct and the endless air on human timescale. But the relatively low thermal conductivity of the air results in a heat transfer rate of solar air heating lower than that of solar water heating. Thus, the thermal enhancement for solar air heater is needed.

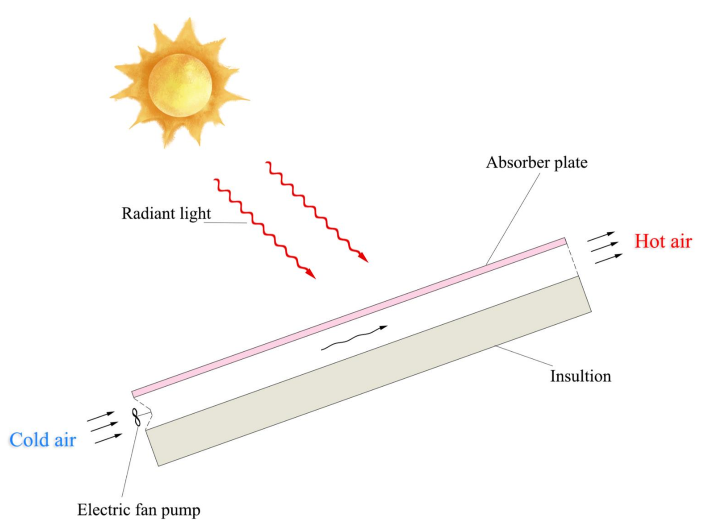

Fig. 1. Schematic of a solar air heater.

Physical models

The solar air heater is a rectangular duct, which includes absorber plate, insulation plate and sidewalls. Fig. 2 shows a schematic of the heating air channel with DWVGs pair and the V-shaped truncated ribs.

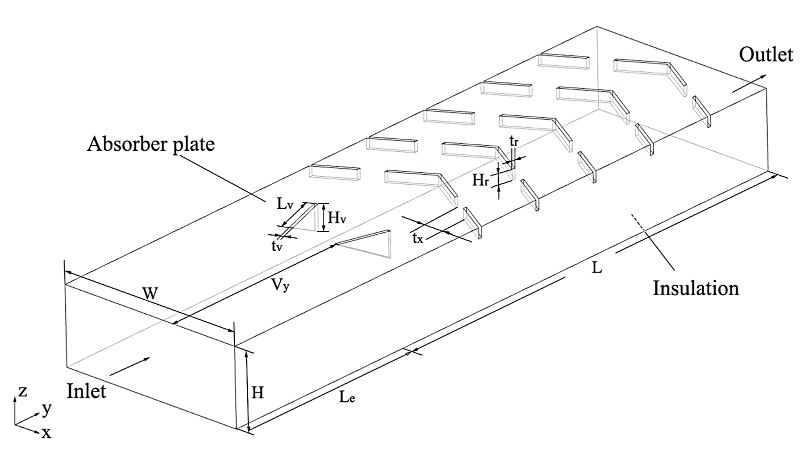

Fig. 2. Solar air heater.

In this study, four different types of ribs combined with a delta-winglet vortex generators pair are placed on the absorber plate. The studied cases are described in Fig. 3.

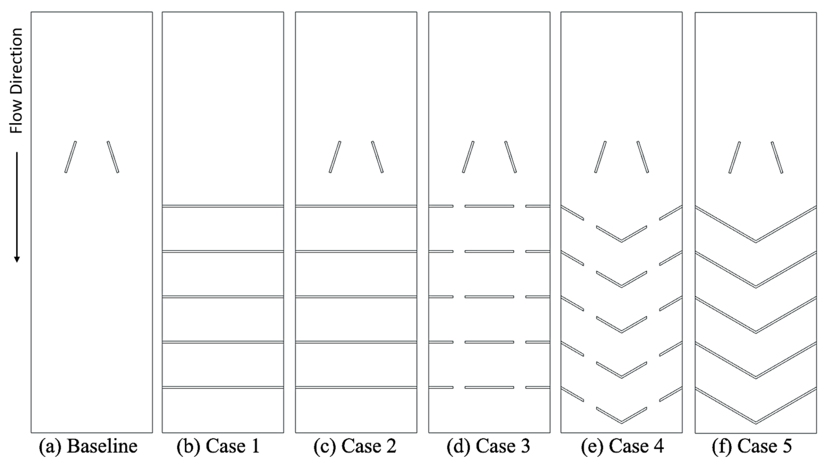

Fig. 3. Schematic of considered cases

CFD Validation

As the geometry is derived from the experimental study of Sharma et al. [4] is quite similar to that in the present study, one of their models, i.e., 90° truncated ribs array placed on the absorber plate in a solar air heater, is used to verify the accuracy of the turbulence model. The Reynolds number ranges from 4000 to 16,000 based on the experimental set up

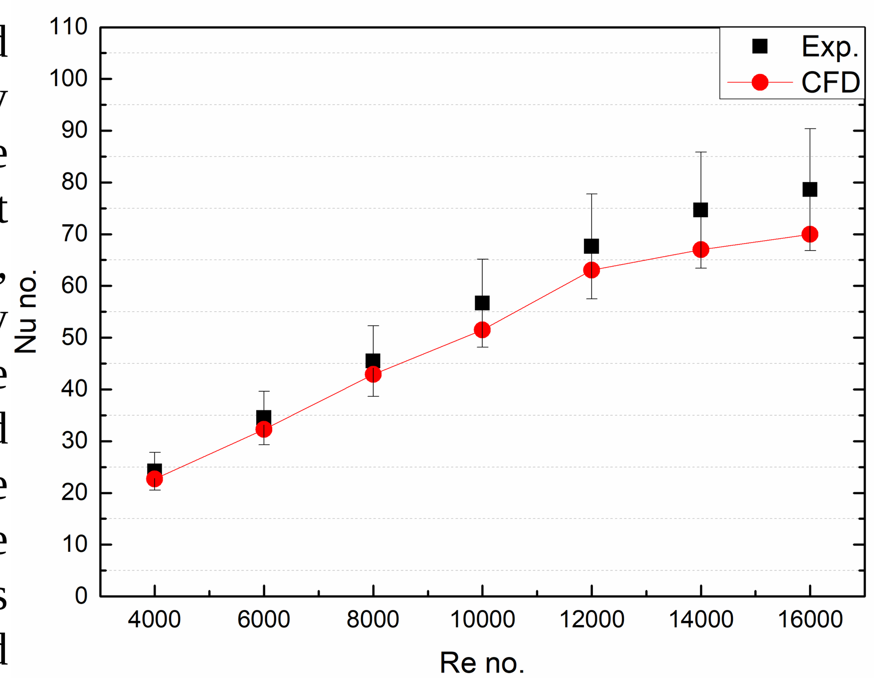

Fig. 4. The average Nu number comparison

Fig. 4 shows the area-average Nusselt number on the absorber plate CFD calculation and experimental study among 12 different Reynolds numbers. The results show that the calculations are in good agreement with the experimental work although a slight under-prediction occurs for high Reynolds number. The maximum deviation and the average deviation among all Reynolds numbers are 10.1% and 7.6%, respectively.

Results

For 60° continuous V-shaped ribs, the interval flow become vertically induced by the mixing effect of the V-shaped geometry and DWVGs as shown Fig. 5. In addition, the potential energy of the vortex is released by the non-truncated ribs, which further pushes the fluid on both sides and enhances the local heat transfer significantly.

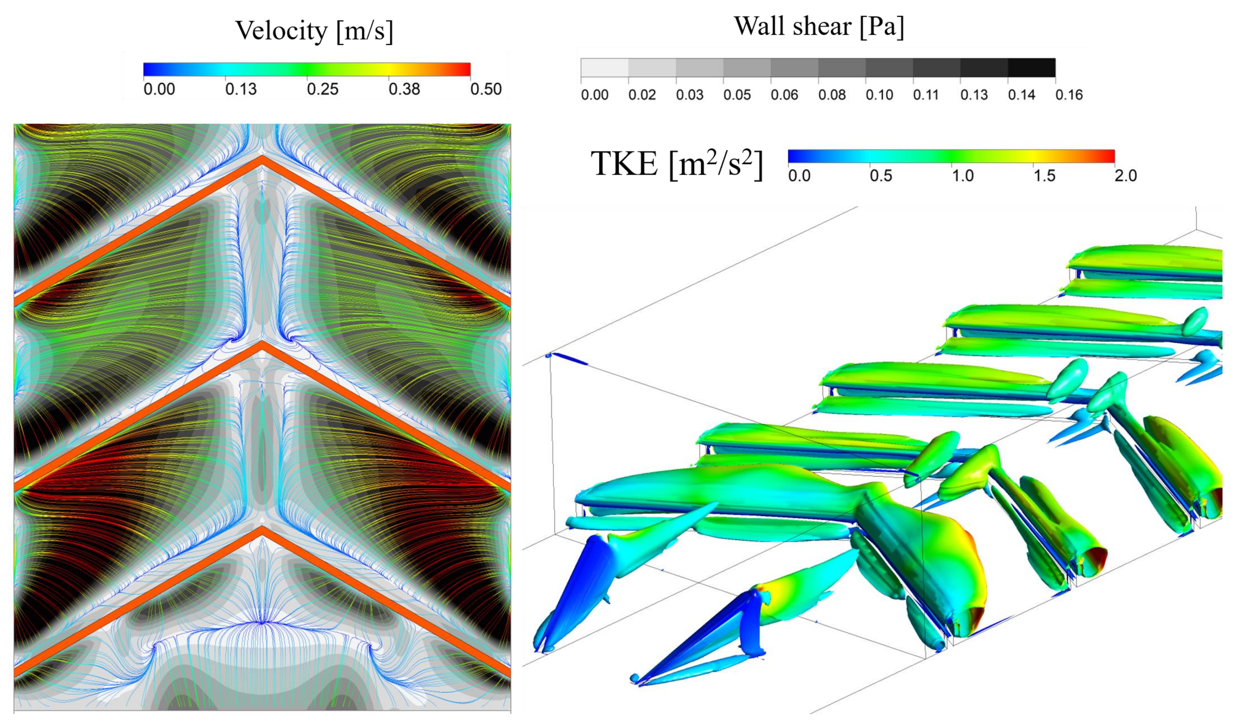

Fig. 5. Velocity-colored streamline at 0.05 mm away from the absorber plate, wall shear on the absorber plate between first three ribs and vortices evolution based on the Q-criterion in Case 5

Fig. 6 shows the Nusselt number on the absorber plate for the different cases. The 60° continuous V-shaped ribs provide the highest heat transfer coefficient due to the mixing effect of V-shaped ribs and DWVGs.

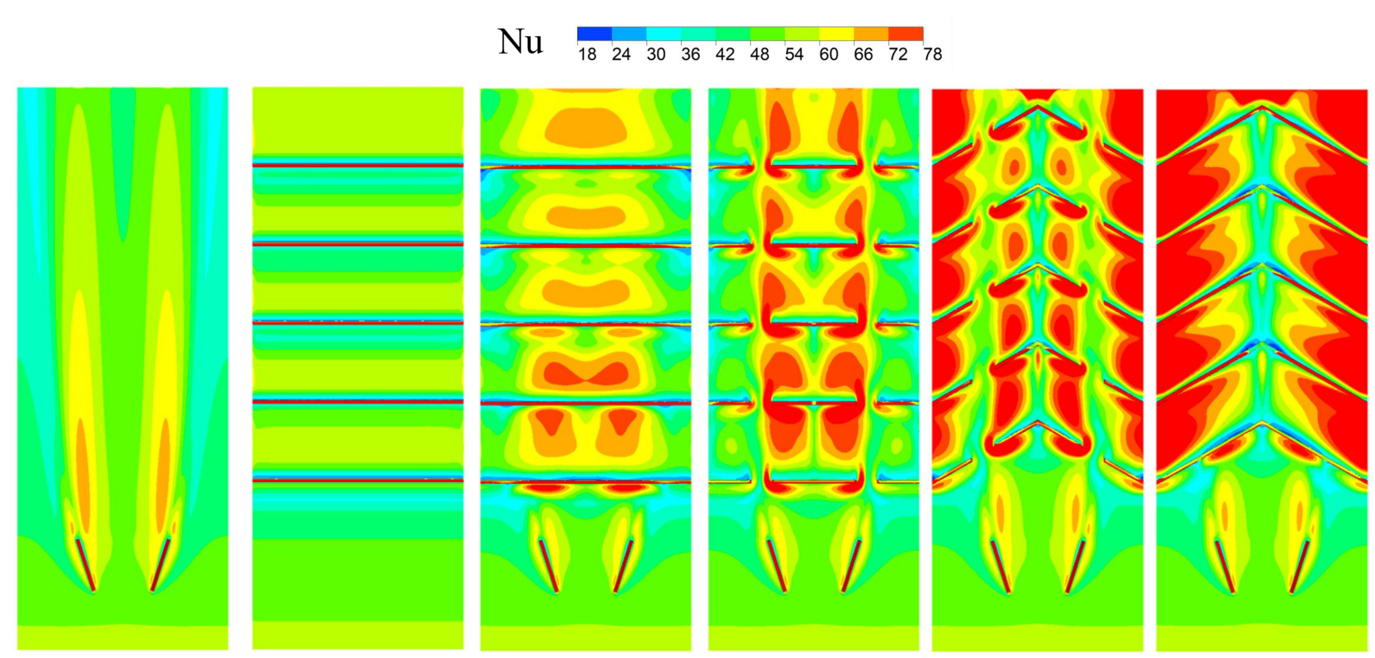

Fig. 6. Comparison of Nu number distribution among Baseline, Case 1, Case 2, Case 3, Case 4, Case 5 at Re = 12,000

Fig. 7 compares the dimensionless Nu number on the absorber plate among the different cases. The ability of placing only DWVGs pair or only ribs to enhance heat transfer is lower than that of mixed arrangement for all Re numbers. The DWVGs provide higher heat transfer performance at low Re number than ribs, but decrease significantly as the Re number increases while ribs present a more stable change. Case 5, i.e., V-shaped ribs combined with DWVGs, provide the best heat transfer performance at different Reynolds numbers. However, the introduction of the DWVGs pair can increase the pressure penalty as shown in Fig. 8. Compared to the mixed arrangement, only the 90° continuous rib array shows the lowest pressure drops, while the arrangement of V-shaped continuous ribs together with DWVGs stay with high value of the pressure drops.

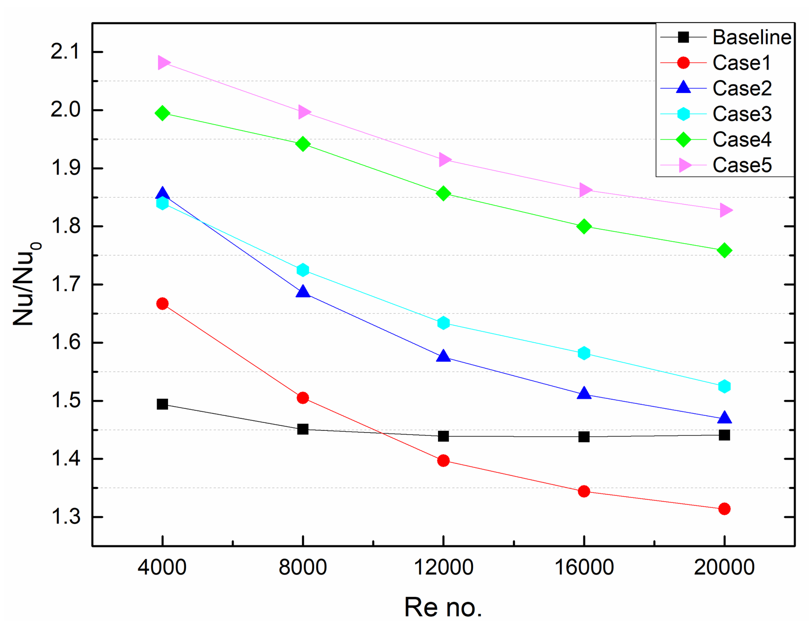

Fig. 7. Comparison of dimensionless average Nu number on the absorber plate

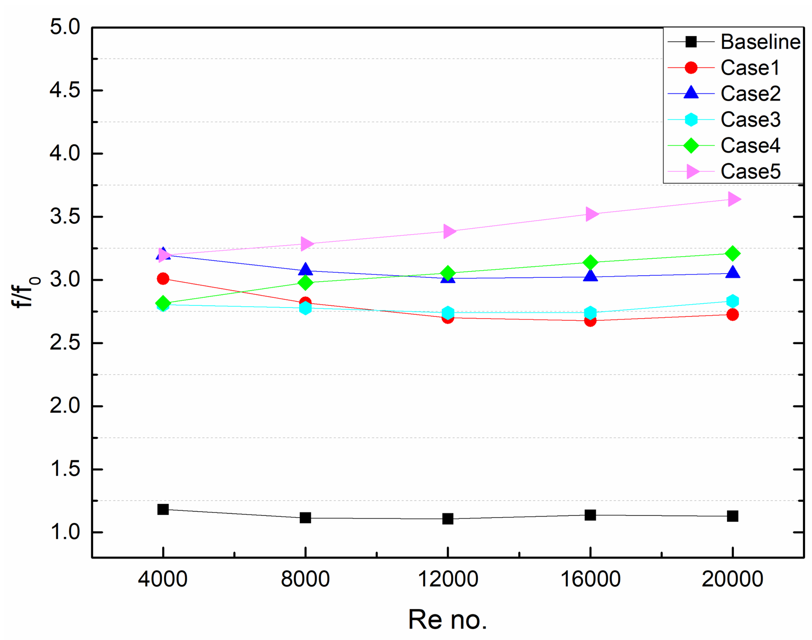

Fig. 8. Comparison of dimensionless friction factor

Conclusions

- The counter rotating vortices induced by DWVGs pair can provide the transverse reverse driving force to reduce the thickness of the boundary layer which helps to enhance the local heat transfer. The transverse vortices caused by ribs can enhance the heat transfer downstream of the ribs.
- The combination of DWVGs and ribs can effectively enhance the heat transfer by intensifying the turbulence because the driving force changes direction of the back flow induced by the ribs.
- The shape of ribs has a great impact on the flow and heat transfer of the absorber plate in the solar air heater. Among the studied cases, the 60° V-shaped ribs combined with the DWVGs pair provide the highest heat transfer performance with certain pressure penalty. The maximum augmentation of the heat transfer is achieved as 39.4% compared to the Baseline.

References

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