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Thermal behavior in solar air heater channel fitted with combined rib and delta-winglet ☆

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ABSTRACT

Effects of combined ribs and delta-winglet type vortex generators (DWs) on forced convection heat transfer and friction loss behaviors for turbulent airflow through a solar air heater channel are experimentally investigated in the present work. Measurements are carried out in the rectangular channel of aspect ratio, $AR = 10$ and height, $H = 30$ mm. The flow rate is presented in the form of Reynolds numbers based on the inlet hydraulic diameter of the channel ranging from 5000 to 22,000. The cross-section shape of the rib placed on the absorber plate to create a reverse-flow is an isosceles triangle with a single rib height, $e/H = 0.2$ and rib pitch, $P_l/H = 1.33$. Ten pairs of the DW with its height, $b/H = 0.4$; transverse pitch, $P_t/H = 1$ and three attack angles (α) of 60°, 45° and 30° are introduced and mounted on the lower plate entrance of the tested channel to generate longitudinal vortex flows. The experimental results show that the Nusselt number and friction factor values for combined rib and DW are found to be much higher than those for the rib/DW alone. The larger attack angle of the DW leads to higher heat transfer and friction loss than the lower one. In common with the rib, the DW pointing upstream (PU-DW) is found to give higher heat transfer rate and friction loss than the DW pointing downstream (PD-DW) at a similar operating condition. In comparison, the largest attack angle ($\alpha = 60°$) of the PU-DW yields the highest increase in both the Nusselt number and friction factor while the lowest attack angle of the PD-DW provides the best thermal performance.

1. Introduction

One of the commonly used passive heat transfer enhancement techniques in single-phase internal flows in channel solar air heaters is the use of ribs placing periodically in the absorber plate. For decades, ribs [1] have been used in thermal systems due to their high thermal loads and decreased dimensions. The use of ribs completely makes the change of the flow field and thus the distribution of the local heat transfer coefficient. Periodically mounted ribs in the absorber plate of solar air heater channels can help to interrupt hydrodynamic and thermal boundary layers leading to an increase in heat transfer rate. Several studies have been carried out to investigate the effect of rib geometry and arrangements on heat transfer and friction loss for roughened surfaces of heat exchanger channels or solar air heaters. Saidi and Sunden [2] and Tatsumi et al. [3] investigated numerically the turbulent flow and heat transfer behaviors in square ducts with ribs on two opposite walls and discrete angled ribs on one wall, respectively. They found that noticeable heat transfer enhancement is obtained downstream of the ribs due to strong secondary flow motion. Sahu and Bhagoria [4] examined broken transverse ribs in solar air heaters, reported that the roughened absorber plate yields the heat transfer rate at 1.25–1.4 times over the smooth rectangular duct and the maximum thermal efficiency is in the range of 51–83.5%. Mittal et al. [5] studied and compared the absorber plate with six different types of roughness elements. Their results showed that the channel with inclined ribs including V-shaped ribs performs better heat transfer rate than others. An experiment of Aharwal et al. [6] was conducted to study heat transfer behaviors of a solar air heater channel with inclined square split-rib with a gap on one wall and the results showed that the gap in the inclined rib enhances the heat transfer of the channel. The increase in Nu and friction factor was, respectively, in a range of 1.5–2.6 times and 2.3–2.9 times the smooth channel. The maximum Nusselt number and friction factor values were found for the gap at relative gap position of 0.25 and width of 1.0. Effects of transverse or porous ribs on thermal characteristics in rectangular channels were numerically studied by Yang and Hwang [7] and Luo et al. [8].

Varun et al. [9] investigated heat transfer and friction characteristics by using inclined/transverse ribs on the absorber plate of a solar air heater and reported that the best performance is at relative roughness pitch of 8. Momin et al. [10] experimentally studied on thermal characteristics of a solar air heater channel fitted with V-shaped ribs for $e/D = 0.02$–0.034 and the angle of attack (α) = 30°–90° for a fixed $P/e = 10$. They found that at $\alpha = 60°$, the highest Nusselt number and friction factor values obtained by the ribs are, respectively, 2.30 and 2.83 times the smooth channel. Promvonge and

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