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# Experimental investigations of thermal and flow characteristics of curved trapezoidal winglet type vortex generators

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The performance of a pair of new vortex generators – curved trapezoidal winglet (CTW) has been experimentally investigated and compared with traditional vortex generators – rectangular winglet, trapezoidal winglet and delta winglet using dimensionless factors – $j/j_0$, $f/f_0$ and $R = (j/j_0)/(f/f_0)$. The results showed that delta winglet pair is the best in laminar and transitional flow region, while curved trapezoidal winglet pair (CTWP) has the best thermohydraulic performance in fully turbulent region due to the streamlined configuration and then the low pressure drop, which indicates the advantages of using this kind of vortex generators for heat transfer enhancement. Parametric study on CTWP showed that smaller attack angle ($\beta = 0^\circ =$ and $15^\circ$), larger curvature ($b/a = 1/2$) and larger angle of inclination ($\alpha = 20^\circ$) gives better thermohydraulic performance under the present conditions. An appropriate spacing between the leading edges of a pair of CTW VG should be considered for different flow regions. In addition, double rows of CTWP do not show better thermohydraulic performance due to the larger pressure drop and the spacing between the two rows of CTWP should also be optimized.



## 1. Introduction

Vortex generator is a kind of passive heat transfer enhancing device which are attached to the duct walls or fin surfaces and protrude into the flow at an angle of attack to the flow direction. The basic principle of vortex generators (VGs) is to induce secondary flow, particularly longitudinal vortices, which disturb or cut off the thermal boundary layer developed along the wall and remove the heat from the wall to the core of the flow by means of large-scale turbulence [1]. The earlier use of VGs on heat transfer enhancement (HTE) in literature may be reported by Johnson and Joubert [2]. They found that the air cooling effect of the cylinder surface was improved by using delta winglets. After that, many types of VGs have been investigated for enhancement of air-side heat transfer of thermal systems since the dominant thermal resistance is usually on the air-side for gas–liquid (or two-phase) heat exchangers. In addition to some specific VG shapes such as rods [3], bars [4,5], baffles [5,6], blocks [7–9] and twisted tapes [10], most researches focused on wings and winglets which could be easily punched or mounted on the channel walls or fins and could effectively generate longitudinal vortices for high enhancement of convective heat transfer.

Feibig et al. [11] experimentally investigated the HTE and drag effect by delta and rectangular wings and winglets in laminar channel flow and found that the HTE per unit vortex generator area was highest for delta wings closely followed by delta winglets; rectangular wings and winglets were less effective; the average heat transfer was increased by more than 50% and the corresponding increase of drag coefficient was up to 45%. Further experiment with double rows of delta winglets in transitional channel flow by Tiggelbeck et al. [12] showed that the ratio of HTE and drag increase was larger for higher Reynolds numbers. Experiments on VG in a water channel by Garimella and Eibeck [13] showed that HTE by a half delta wing increased with increasing Reynolds number in the laminar regime (up to 40%) but was lower in the turbulent regime, of the order of 5%. Feibig [14] pointed out that the winglets are more effective than wings, but winglet form is of minor importance. With a dye-injection technique, Wang et al. [15] visualized the flow structure for enlarged plain fin-and-tube heat exchanger with annular and delta winglet vortex generators. They found that for the same winglet height, the delta winglet showed more intensive vertical motion and flow unsteadiness than annular winglet, however, the corresponding pressure drop of the delta winglet was lower than that of annular winglet.

Kim and Yang [16] experimentally investigated the flow and heat transfer characteristics of a pair of delta winglet VGs. They found that the common-flow-down arrangement of VGs show

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