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Thermo-hydraulic characterization of the smooth wavy fin-and-elliptical tube heat exchangers using new type vortex generators

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Abstract

In the present study, 3D computational analysis was performed to investigate heat transfer and pressure drop characteristics of flow in new Smooth Wavy Fin-and-Elliptical Tube (SWFET) heat exchanger model with new vortex generators. Performance results are presented in terms of non-dimensional parameters, friction factor f and Colburn j factor. Four new types of vortex generators were considered; rectangular trapezoidal winglet (RTW), angle rectangular winglet (ARW), curved angle rectangular winglet (CARW) and Wheeler wishbone (WW). Fluid flow and heat transfer are simulated and the results are compared. The $SST\ k-\omega$ turbulence model is used, with steady-state solvers to calculate pressure drop, flow and temperature fields. The influences of the geometrical factors of mounted vortex generators including attack angles of the winglets ($\alpha_{VG} = 15^{\circ}, 30^{\circ}, 45^{\circ}, 60^{\circ}$ and $75°$) and width/length aspect ratio ($w/l = 0.5, 1.0$) of the Wheeler wishbones in enhancing the heat transfer performance of a smooth wavy fin heat exchanger with a three-row staggered elliptical tube bundle are investigated. The Reynolds number ranges from 500 to 3000 based on the hydraulic diameter. A parametric study on the winglet vortex generators indicated that for the small attack angle, CARW vortex generators gives better thermohydraulic performance under the present conditions. The best thermal performance of the SWFET heat exchanger with winglet VGs in the larger attack angle, was obtained at RTW VGs arrangement. For the SWFET heat exchangers, the WW VGs with width/length aspect ratio of $w/l = 0.5$ provide the best heat transfer performance.

Keywords: Smooth wavy fin-and-elliptical tube heat exchanger; Vortex generators; Wheeler wishbone; Augmented heat transfer; $SST\ k-\omega$ turbulence model; CFD simulation

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1. Introduction

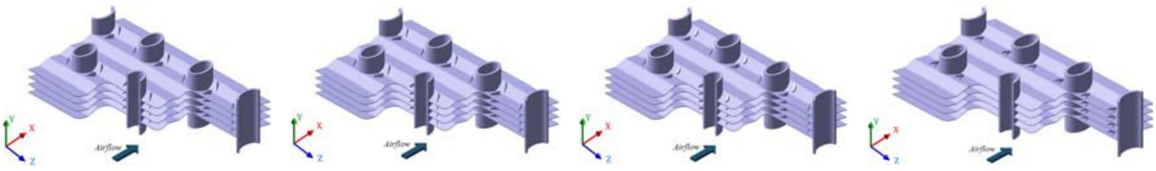
Finned tube heat exchangers (FTHEs) are employed in an extensive variety of commercial and engineering applications, *e.g.*, HVAC&R systems, petrochemical, aerospace, etc. The heat transfer coefficient on the air-side of FTHEs is generally very low due to the thermophysical property of air. Therefore, heat transfer enhancement on the air-side is essential. The heat transfer performance of FTHEs is highly dependent on the structure of fins because the dominant thermal resistance is generally on the air side (75% or more). The most effective way to enhance the heat transfer on the air-side of a heat exchanger is to modify the fin pattern and geometry by interrupting it periodically along the streamwise direction. Another innovative technique for enhancement is the use of flow manipulators known as vortex generators (VGs), i.e., winglets which intentionally produce streamwise vortices. Wavy fins are very special fin patterns that are developed to improve the heat transfer performance. The first pervasive research related to wavy fin was performed by Beecher and Fagan [1] investigating the effects of air velocity and the pattern of fin arrangement. Wang et al. [2] carried out a series of investigations in the wavy fin-and-tube heat exchangers. Yan and Sheen [3] compared plate, wavy and louvered fin performances by using performance evaluation criteria (PEC) techniques in their experimental study. In recent years, the practical usage of vortex generators in compact heat exchangers has received more attention. Applying vortex generators on heat transfer surfaces in FTHEs is an effective method to augment heat transfer. Torii et al. [4] reported experimental results of heat transfer and pressure loss in a fin-and-tube heat exchanger with inline and staggered set of tubes with delta winglet vortex generators of different configurations. The elliptic tube geometry has a better aerodynamic shape than the circular one; therefore, it is reasonable to expect a reduction in total drag force when comparing the former to the latter, both submitted to a cross flow free stream.

The foregoing literature review illustrates that in general most of the research work focused on simple and traditional winglet vortex generators such as delta winglets. Moreover, most of the research works were related to fin-and-tube heat exchangers with circular tubes and plain or interrupted fins. Indeed, investigations of a smooth wavy fin-and-elliptical tube heat exchanger with untraditional and new type of vortex generators have not been performed yet.

The purpose of the present work is to introduce four new types of vortex generators – rectangular trapezoidal winglet, angle rectangular winglet, curved angle rectangular winglet and Wheeler wishbone for application in a smooth wavy fin-and-elliptical tube heat exchanger. A numerical investigation is carried out to explore the effects of geometric shape of the vortex generators, attack angles of the winglets and width-to-length aspect ratios of the Wheeler wishbone on the heat transfer and fluid flow characteristics in the smooth wavy fin channels.

2. Model descriptions

A schematic isometric view of the core region of a smooth wavy fin-and-elliptical tube (SWFET) heat exchanger with new vortex generators under consideration in the present investigation is depicted in Fig. 1. In the present study, four kinds of vortex generators (VGs) are adopted, namely – 1) rectangular trapezoidal winglet (RTW), 2) angle rectangular winglet (ARW), 3) curved angle rectangular winglet (CARW) and 4) Wheeler wishbone (WW). Wishbone vortex generators were designed by Wheeler. Wheeler wishbone VGs are like planar forms with an "Ogee" shape. These generators consist of two joined sidewalls with included angles from 15° to approximately 60° with their apex pointing downstream. The wishbone vortex generators oriented with apexes pointing downstream (forward configuration) shed horseshoe vortices in boundary layers.

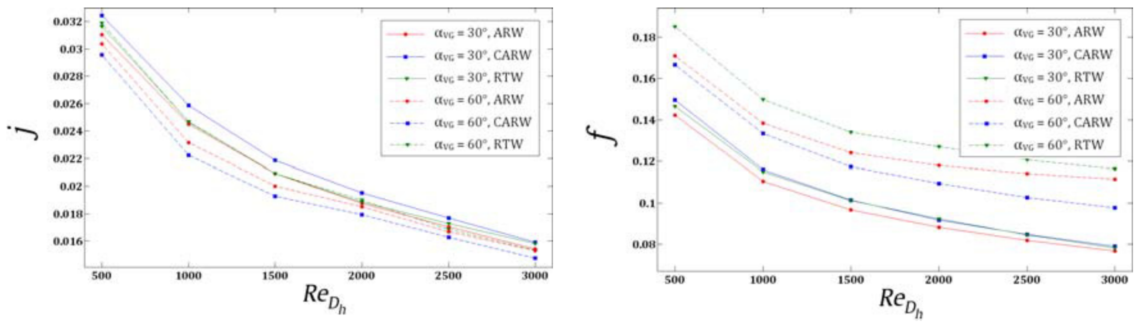


(a) Rectangular Trapezoidal Winglet (RTW) (b) Angle Rectangular Winglet (ARW) (c) Curved Angle Rectangular Winglet (CARW) (d) Wheeler Wishbone (WW)

Fig. 1. Isometric aligned section of core region of a smooth wavy fin-and-elliptical tube bank with mounted VGs.

3. Results and discussion

The aim of heat exchanger design is to get a high heat flux combined with a pressure drop as small as possible. Figure 2 shows the variation of the Colburn factor *j* and friction factor *f* versus Reynolds number at two different angles of attack, $\alpha_{VG} = 30^{\circ}$ and 60°. The performance evaluation criteria (PEC) of "area goodness factor" and "volume goodness factor" are used to evaluate the heat transfer and pressure drop performance. The *j*/*f* ratios of the cases of CARW and ARW are higher than those of the RTW arrangement occurred at $\alpha_{VG} = 30^{\circ}$. The case of CARW shows the highest value of *j*/*f* for the two various winglet VGs arrangements. Another criterion is the volume goodness factor where the heat transfer power per unit temperature and per unit volume (*Z*) is plotted versus the fan power per unit core volume (*E*). It was observed that the CARW case has relatively higher *Z* value than the ARW and RTW arrangements occurred at $\alpha_{VG} = 30^{\circ}$. For all winglet VGs arrangements at $\alpha_{VG} = 60^{\circ}$, the ratio of *j*/*f* for RTW and ARW VGs are higher than the CARW VGs arrangement. The volume goodness factor for different winglet VGs arrangements, and it can realize that the RTW case has a higher value than the other arrangements occurred at $\alpha_{VG} = 60^{\circ}$. As a consequence, WW VGs with $w/l = 0.5$ case provides a better overall performance of *j*/*f* than the other cases of WW VGs. As well as, provides the WW VGs with $w/l = 0.5$ transfers the highest heat flux per unit volume for the same pumping power per unit volume.



(a) Effect of α_{VG} on *j* (b) Effect of α_{VG} on *f*

Fig. 2. Effects on Colburn factor *j* and friction factor *f* at attack angles 30° and 60°.

4. Conclusions

In this paper, the overall performance of the SWFET heat exchanger is compared with VGs. Based on the facts found, the key and remarkable findings are summarized as follows:

It is shown that RTW VGs has better heat transfer enhancement at larger attack angles of the winglet VGs in the range 15° to 75° than CARW and ARW VGs. This is due to the fact that the RTW VGs have the largest area facing the air flow inducing the strongest streamwise vortices. These results indicate the advantages of using RTW vortex generators for heat transfer enhancement at larger attack angles. A parametric study of winglet vortex generators showed that when the attack angle of winglet VGs decreases in the range 15° to 75°, the area facing the prevailing and traditional winglet VGs normal to the incoming flow decreases. For the CARW VGs, however, due to the curvature of the structure itself, the largest projective area facing the airflow is found and accordingly streamwise vortices are created. Therefore, these results show the advantages of using CARW VGs at smaller attack angles for heat transfer enhancement. The Wheeler wishbone vortex generators were successful and significantly improved the enhancement of the heat transfer. The small width-to-length aspect ratio gives a better thermohydraulic performance, particularly at high Reynolds numbers, due to the smaller angle between the sidewalls.

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References

[1] Beecher DT, Fagan TJ. Effects of fin pattern on the air-side heat transfer coefficient in plate finned-tube heat exchanger. *ASHRAE Transaction* 1987;**93(2)**:1961–1984.

[2] Wang CC, Lin YT, Lee CJ, Chang YJ. An Investigation of wavy fin-and-tube heat exchangers; a contribution to databank. *Experimental Heat Transfer* 1999;**12**:73–89.

[3] Yan WM, Sheen PJ. Heat transfer and friction characteristics of fin-and-tube heat exchangers. *Int J Heat Mass Transfer* 2000;**43**:1651–1659.

[4] Torii K, Kwak KM, Nishino K. Heat transfer enhancement accompanying pressure-loss reduction with winglet-type vortex generators for fin-tube heat exchangers. *Int J Heat Mass Transfer* 2002;**45**:3795–3801.

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