Heat Transfer and Fluid Flow Analysis in Plate-Fin and Tube Heat Exchangers with Different Shaped Vortex Generators

K. Thirumalai Kannan, B. Senthil Kumar

Abstract: Numerical analyses were carried out to study the heat transfer and flow in the plate-fin and tube heat exchangers with different shaped vortex generators mounted behind the tubes. The effects of different span angles a (α = 30°, 45° and 60°) are investigated in detail for the Reynolds number ranging from 500 to 2500. Numerical simulation was performed by computational fluid dynamics of the heat transfer and fluid flow. The results indicated that the triangle shaped winglet is able to generate longitudinal vortices and improve the heat transfer performance in the wake regions. The case of α = 45° provides the best heat transfer augmentation than rectangle shape winglet generator in case of inline tubes. Common flow up configuration causes significant separation delay, reduces form drag, and removes the zone of poor heat transfer from the near wake of the tubes.

Keywords: Vortex generator; Common flow up; Heat transfer enhancement; Plate-fin and tube heat exchanger

I. INTRODUCTION

Plate-finned-tube heat exchangers are one of the most used compact heat exchangers in automobiles, air conditioners, and chemical industries. For typical applications, the airside resistance generally comprises over 90% of the total thermal resistance. Therefore, enhanced surfaces are often employed to effectively improve the airside heat transfer performance of the plate-fin and tube heat exchangers. One frequently used method for heat transfer enhancement employs surfaces that are interrupted periodically along the stream wise direction. Typically, these surfaces are in the form of wavy, louver, slit, or offset strip fins. Despite the fact that interrupted surfaces can significantly improve the heat transfer performance, the associated penalty of pressure drop is also tremendous. Another common method is to apply vortex generators (VG), such as ribs, wings and winglets. Vortex generators usually are incorporated into a surface by means of embossing, stamping, punching, or attachment process. They generate longitudinal vortices which swirl the primary flow and increase the mixing of downstream regions. In addition, the vortex generator determines the secondary flow pattern. Thus, heat transfer enhancement is associated with the secondary flow with relatively low penalty of pressure drop A modified rectangular longitudinal vortex generator obtained by cutting off the four corners of a rectangular wing is presented. Fluid flow and heat transfer characteristics of longitudinal vortex generator mounted in rectangular channel are experimentally investigated and compared with those of original rectangular longitudinal vortex generator. Results show that the modified rectangular wing pairs have better flow and heat transfer characteristics than those of rectangular wing pair. Chunhua Min [1] The literature reporting the enhancement of heat transfer of using surface protrusion vortex generators is by Edwards and Alker [2]. They noted a maximum in-crease in the local Nusselt number of 40%. Eibeck and Eaton [3] conducted heat transfer measurement for a single longitudinal vortex embedded in a turbulent boundary layer. They interpreted their data in terms of vortex circulation and boundary layer thickness. Pauley and Eaton [4] extended this work to consider vortex pairs. Co-rotating pairs were observed to move together and coalesce into a single vortex as they were adverted downstream

In recent years, the use of vortex generators in channel flow applications has received considerable attention. Tigglebeck et al. [5] and Fiebig et al. [6] used the delta wing, rectangular wing, delta winglet, and rectangular winglet as vortex generators and utilized liquid crystal thermograph to measure the local heat transfer coefficient. Their results identified an increase in the local heat transfer coefficient in the order of several hundred percent and a mean heat transfer enhancement of more than 50%. Biswas et al. [7] studied the flow structure of an air stream over winglet pair type vortex generators. They found that the winglet pair produced a main vortex, a corner vortex, and an induced vortex. The main vortex was formed by flow separation at the leading edge of the winglet, while the corner vortex was generated by the deformation of the near wall vortex lines at the pressure side of the winglet. Gentry and Jacobi [8] studied the interactions of delta-wing type vortex generators with the boundary layer on a flat plate. Their results identified a 50–60% enhancement of the average heat transfer. Sohankar and Davidson [9] analyzed three-dimensional unsteady laminar flow and heat transfer in a channel with a pair of inclined block shape vortex generators. They found unsteady flow occurred at Re_H> 1000. When the thickness and span angle is increased, stronger and bigger stream wise vortices are formed downstream of the vortex generators.

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Fiebig et al. [10] and Valencia [11] considered the application of delta, rectangular, delta winglet, and rectangular winglet type vortex generators in fin-tube heat exchangers. These studies investigated various geometric parameters, including aspect ratio and angle of attack. It is shown that the ratio of heat transfer to flow loss was highest when a delta winglet vortex generator was used with an angle of attack of 30° and with an aspect ratio of 2. For the inline tube arrangement, the vortex generator increases the heat transfer coefficient by 55–65%, resulting in a corresponding increase of 20 - 45% in the apparent friction factor. Torii et al. [12] proposed a novel strategy that can augment heat transfer but nevertheless can reduce pressure-loss in fin-tube heat exchanger in a relative low Reynolds number flow, by deploying delta winglet-type vortex generators. In case of staggered tube banks, the heat transfer was increased by 10–30%, and yet the pressure loss was reduced by 34–55%. In the case of in-line tube banks, the heat transfer was augmented by 10–210% together with the pressure loss reduction of 8–15%. Wang et al. [13] utilized a dye-injection technique to visualize the flow structure for annular and delta winglet vortex generators. For the same winglet height, the delta winglet vortex generator shows more intensively vertical motion than that of annular vortex generator; while, the corresponding pressure drops of the delta winglet vortex generator are lower than those of annular vortex generator. Lin and Jang [14] numerically and experimentally studied the wave-type vortex generator in plate-fin and tube heat exchangers. Their study identifies a maximum improvement of 120% in the local heat transfer coefficient and an improvement of 18.5% in the average heat transfer coefficient. Reference to the journal of Jin-Sheng Leu [15] above details been concluded. Jin-Sheng Leu [15] indicated that the proposed heat transfer enhancement technique is able to generate longitudinal vortices and to improve the heat transfer performance in the wake regions. The case of $\alpha = 45°$ provides the best heat transfer augmentation. [16] K. Torii suggested the delta winglet with common flow up configuration will also provide best heat augmentation.

The foregoing literature review shows that no related comparison study of 3D numerical analysis for a different shaped vortex generator for a plate-fin and tube heat exchanger has been published. This has motivated the present investigation.

II. NUMERICAL SIMULATION

Numerical Simulation is to perform by a computational fluid dynamics for the heat transfer and fluid flow for the temperature distribution and local flow structure. The comparisons of heat transfer enhancement with flat tube-fin element with and without vortex generator enhancement under different shaped vortex generators carried out and optimized shape for heat transfer is been verified. The major parameters influencing the performance for vortex generator are the position, size and span angles. The present investigation mainly aims to evaluate the effects of span angle a on the thermal hydraulic characteristics. Three different span angles $\alpha = 30^{0,}\ 45^{0}$and $60^{0}$are investigated in detail for the Reynolds number ranging from 500 to 2500. Turbulent numerical simulations for the fluid flow and heat transfer over a 3-row tube is to be performed, and the effect of turbulence is simulated using computational fluid dynamics The conjugated convective heat transfers in the flow field and heat conduction in the fins are also considered.

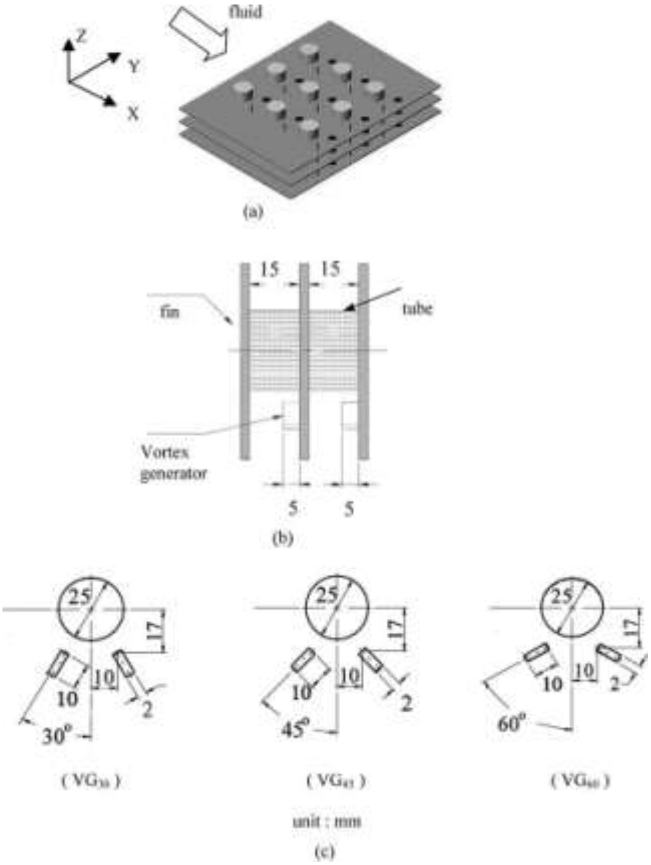

Fig.1. Physical model and relevant geometrical dimensions of the vortex generators. (a) Physical model (top view), (b) side view, and (c) three different span angles.

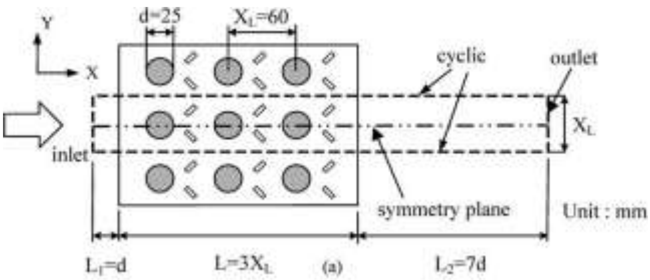

Fig 2. Computational domain,

The fluid is considered incompressible with constant properties and the flow is assumed to be turbulent, steady and no viscous dissipation. The conjugated convective heat transfers in the flow field and heat conduction in the fins are also considered. At this boundary, the flow velocity is assumed to be uniform, and the temperature inlet is taken to be 200C. The intensity of the turbulence at the inlet is set to 3%.

At the downstream end of the computational domain, located seven times the tube diameter from the last downstream row tube, stream wise gradient (Neumann boundary conditions) for all the variables are set to zero. At the solid surfaces, no-slip conditions and constant tube wall temperature Tw (700C) are specified.

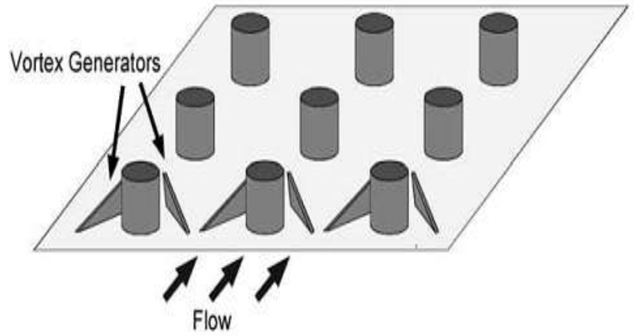

Fig.3. Common flow up configuration.

The delta winglet pair with ''common flow up'' configuration on the fin surface, as shown in Fig 3..With this configuration, the winglet pair can create constricted passages in aft region of the tube which brings about separation delay . The fluid is accelerated in the constricted passages and as a consequence the point of separation travels downstream. Narrowing of the wake and suppression of vortex shedding are the obvious outcome of such a configuration which reduce form drag. Since the fluid is accelerated in this passage, the zone of poor heat transfer on the fin surface is also removed from the near wake of the tube In case of a low Reynolds number flow in absence of any vortex generators, the poor heat transfer zone is created widely on the fin surface in the near-wake of the tube and may extend far downstream even to the next row of the tube bank. Hence it is expected that the present strategy may be more effective for a lower Reynolds number flow.

III. CALCULATION TO FIND HEAT TRANSFER (H)

The dimensionless time averaged equations for continuity ,momentum (Reynolds-averaged Navier–Stokes equations) and energy maybe ex-pressed in tensor form as:

$$\frac{\partial U_i}{\partial X_i} = 0 \quad (1)$$

$$\frac{\partial}{\partial X_j}(U_i U_j) = -\frac{\partial P}{\partial X_i} + \frac{1}{Re}[\nabla^2 U_i] - \frac{\partial}{\partial X_j}(\overline{u_i u_j}) \quad (2)$$

$$\frac{\partial}{\partial X_j}(\Theta U_j) = \frac{1}{Re\,Pr}[\nabla^2 \Theta] - \frac{\partial}{\partial X_j}(\overline{u_j \theta}) \quad (3)$$

The Reynolds number represents the ratio of the importance of inertial effects in the flow, to viscous effects in the flow.

Reynolds number,

$$Re = \frac{\rho U L}{\mu}$$

Where U, is the flow velocity, R is the radius of the cylinder, and ρ and μ are the fluid properties

$$R_e = \frac{1.109 \text{ x } 0.025 \text{ x } 1.7}{1.941\text{x}10^{-5}}$$

Where hydraulic diameter (h_d) is 0.025, Velocity = 1.7

$R_e = 2428$

Nusselt number correlation for cross flow over tube banks for N>16 and 0.7 < Pr > 500 and Reynolds number greater than 1000 ,Nusselt number is given by

$Nu_D = 0.27\ Re_D^{0.63}\ Pr^{0.36}\ (Pr/Pr_s)^{0.25}$

$Nu_D = 0.27\ (2428)^{0.63}\ 0.7241^{0.36}\ (0.7241/0.7177)^{0.25}$

$Nu_D = 32.701$

hence $Nu_D = 32.701 \text{x } 0.86$

$Nu_D = 28.12$

To find Heat transfer

$Nu_D = h\ D/\ K$

$$28.12 = \frac{h \text{ x } 0.024}{0.02699}$$

h = 31.66 or 32

Heat transfer is been validated with the result which is obtained from the Computational Fluid Dynamics. It is found that the values are approximately equal as the value of h is 32.67466 in Computational Fluid Dynamic

IV. RESULTS AND DISCUSSION

Heat transfer: Delta winglets with common flow up configuration in a fin-tube bank in an in-line tube arrangement successfully Increase the average heat transfer by10%to20%, the result indicates triangle winglet of span angle of 45^0 provides the best heat transfer augmentation

Table – 1

Re	BASE	REC 45	TRI 45
500	3.5921	5.05958	5.27546
1000	5.39702	6.59559	7.28393
1500	7.24609	8.08042	8.98652
2000	8.23836	8.9811	10.1776
2500	9.22602	9.76331	12.4709

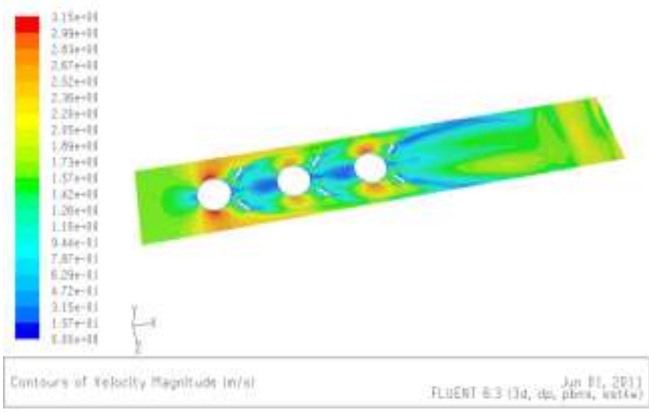

Fig.4 Velocity magnitude of rectangle 45 0

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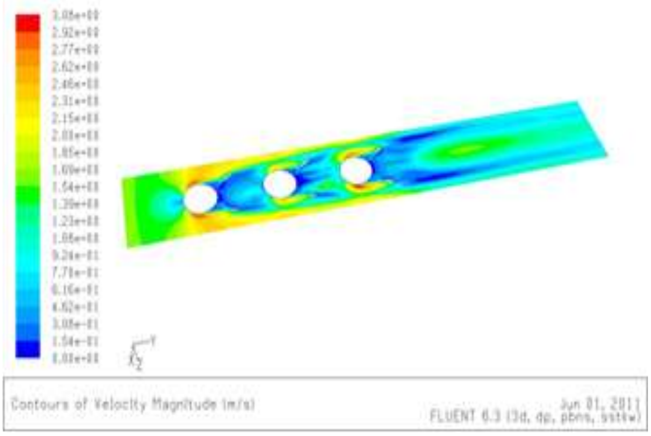

Fig. 5 Velocity magnitude of triangle 45 0

Pressure drop: Delta winglets with common flow up configuration in a fin-tube bank in an in-line tube arrangement indicates span angle of 450 provides less pressure drop

Table 2

Re	BASE	REC 45	TRI 45
500	0.63411	0.70487	0.69049
1000	1.51628	1.81508	1.63876
1500	3.48042	4.26515	4.06049
2000	5.53067	6.81389	6.20952
2500	8.53824	10.1411	9.25358

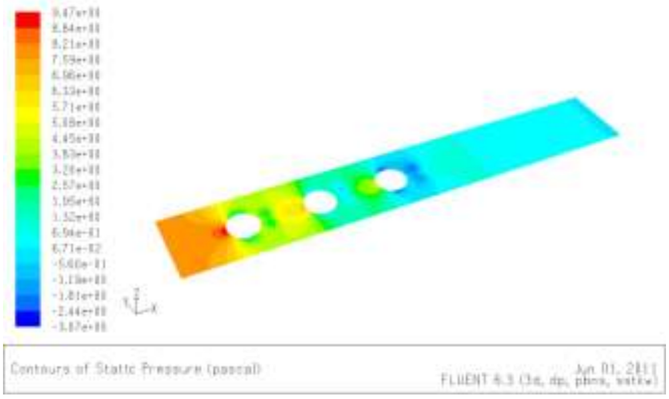

Fig .6. Static pressure of base fin geometry

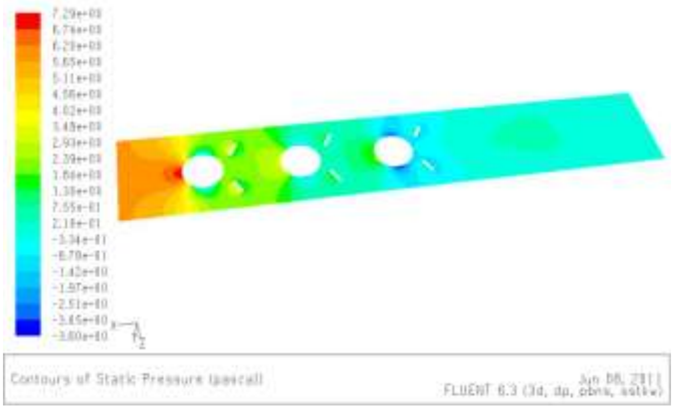

Fig. 7 Static pressure of rectangle fin geometry

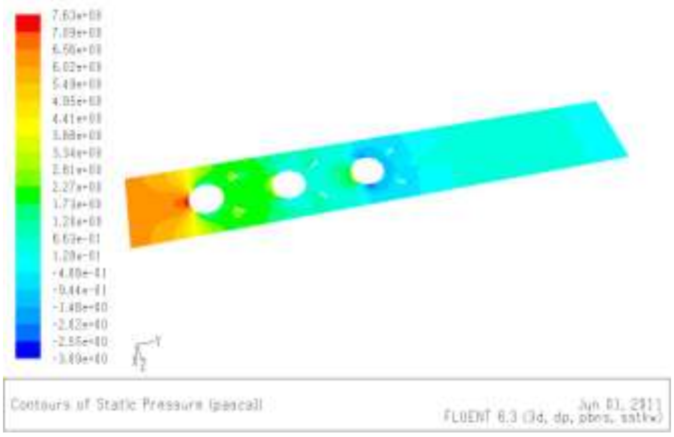

Fig. 8 Static pressure of triangle fin geometry

Table.3 Comparison of heat transfer (w/m2-k) vs. Span angle (degree)

FIN TYPES	30deg	45deg	60deg
BASE	32.67466	-	-
RECTANGLE	34.83991	39.09082	38.85518
TRIANGLE	37.73119	38.349	38.64773

V. CONCLUSION

Delta winglets with common flow up configuration in a fin-tube bank in an in-line tube arrangement successfully Increase the average heat transfer by10%to20%, the result indicates triangle winglet of span angle of 450 provides the best heat transfer augmentation comparatively with all other fin geometries.

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