A Review on Heat Transfer Enhancement of Wavy Fin and Tube Heat Exchanger by Using Vortex Generator's

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Abstract: *In this paper review is carried out on heat transfer enhancement of wavy fin and tube heat exchanger by using different arrangements of vortex generator. The heat transfer enhancement consists of main-flow enhancement and secondary flow enhancement. Wavy fin is the example of main flow enhancement method and intentional generation of vortices to enhance heat transfer is a secondary flow enhancement method. This study is useful to understand the potential of vortex generators to enhance heat transfer characteristics of wavy fin and tube heat exchanger.*

Keywords: **Wavy fin, Wavy fin and tube heat exchanger, Vortex generators.**

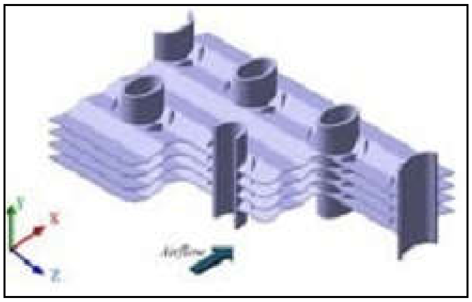
1. Introduction

Finned tube heat exchangers are used in variety of commercial and engineering applications like HVAC systems, petrochemical industries, aerospace, etc. The resistance for heat transfer is very high on the air-side of finned tube heat exchanger as the convective heat transfer coefficient is very low. To increase the heat transfer rate of finned tube heat exchanger the resistance on air side should be reduced. Here the performance of finned tube heat exchanger is mostly dominated by structure of fin. Therefore, to enhance heat transfer rate of finned tube heat exchanger the geometry of fins need to be modified.

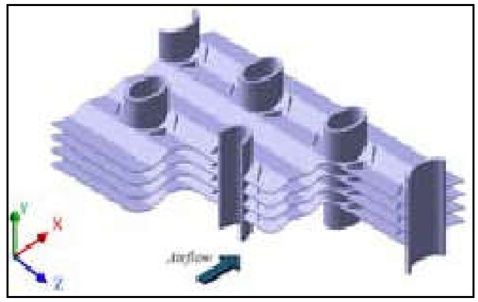
Y.b.tao et al [1][2] the use of wavy fin over the flat fin enhances heat transfer rate with increasing wavy angles with some penalty in pressure drop. Y.L. He et al [3] The distributions of local Nusselt number and fin efficiency on fin surface were studied at wavy angle equal to 0◦ (plain plate fin), 10◦ and 20◦ respectively. With the increase of Reynolds number, the effects of wavy angle on the distributions of local Nusselt number and fin efficiency are more and more significant. Igor Wolf et al. [4] studied numerically and experimentally physical process of heat transfer on the air-side of a wavy fin-and-tube heat exchanger by considering 19.2 ^{0} wavy angle geometric parameter for rows of circular tubes in a staggered arrangement. Compatibility between the results has been found. Jacobi and Shah [5] the heat transfer enhancement consists of main-flow enhancement and secondary flow enhancement. Louvered and slit fins and wavy fin are examples of main flow enhancement method. The intentional generation of vortices to enhance heat transfer is a secondary flow enhancement method.

2. Literature Review

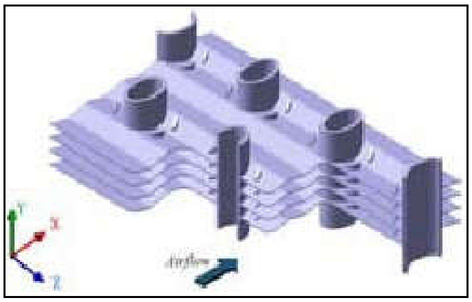
Babak Lotfi et al. [6] in this study Investigation of smooth wavy fin-and-elliptical tube heat exchanger with new vortex generators is carried out. Researcher presented Four different types of vortex generators(VGs) namely Rectangular trapezoidal winglet, angle rectangular winglet, curved angle rectangular winglet and wheeler wishbone as shown in figure 1 (a), (b), (c), (d) respectively.



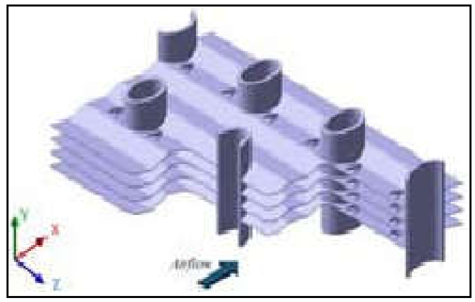
(a) Rectangular Trapezoidal Winglet



(b) Angle Rectangular Winglet



(c) Curved Angle Rectangular Winglet



(d) Wheeler Wishbone

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

The results are presented in the form of Colburn factor j and friction factor f versus Reynolds number at two different angles of attack, $\alpha_{VG} = 30^0$ and 60°. To evaluate the heat transfer and pressure drop performance “area goodness factor” and “volume goodness factor” are used. For $\alpha_{VG} = 30^0$ The case of curved angle rectangular winglet shows the highest value of j/f for the two various winglet VGs arrangements and also the j/f ratios of the cases of curved angle rectangular winglet and angle rectangular winglets are higher than those of the Rectangular trapezoidal winglet arrangement. volume goodness factor is the heat transfer power per unit temperature and per unit volume is plotted versus the fan power per unit core volume and observation shows that the curved angle rectangular winglet case has relatively higher heat transfer power per unit temperature and per unit volume value than the angle rectangular winglet and Rectangular trapezoidal winglet arrangements at $\alpha_{VG} = 30^0$. For all arrangements at $\alpha_{VG} = 60^0$, the ratio of j/f for Rectangular trapezoidal winglet and angle rectangular winglet VGs are higher than the curved angle rectangular winglet VGs arrangement. From volume goodness factor it can realize that the Rectangular trapezoidal winglet case has a higher value than the other arrangements occurred at $\alpha_{VG} = 60^0$. WW VGs with $w/l = 0.5$ case gives a better overall performance of j/f than the other cases of WW VGs also transfers the highest heat flux per unit volume for the same pumping power.

Ali Sadeghianjahromi et al. [7] Numerically Investigated the effect of punching out delta winglets on wavy fins of a wavy fin and tube heat exchanger. Simulation is carried out by ignoring radiation and natural convection effect also air was considered as in compressible working fluid with constant properties and flow is steady , three dimensional and turbulent. continuity, momentum, and energy equations were considered as governing equation and RNG k-ε model was selected for study. The geometric parameters are considered as per the table 1. The air inlet velocity u_{in} = 0.5–4 m/s were considered.

Table 1. Geometrical parameter values

Parameter	Parameter Nomenclature	Parameter values
Tube collar outside diameter	Dc (mm)	10.38
Number of tube rows	N	1
Fin thickness	t (mm)	0.12
Fin pitch	Fp (mm)	1.62
Longitudinal tube pitch	Pl (mm)	19.05
Transversal tube pitch	Pt (mm)	25.04
Waffle height	h (mm)	1.18
First part projected wavy length	Xf1 (mm)	4.76
Second part projected wavy length	Xf2 (mm)	4.76

In this study , two pairs of common flow down delta winglets are punched out perpendicular to the wavy fins and are located behind the tubes. attack angle of Vortex generator (α_{VG}) is 30^0. Chord (l) of delta winglets is 5 mm and their height (H) is 1.1 mm, respectively

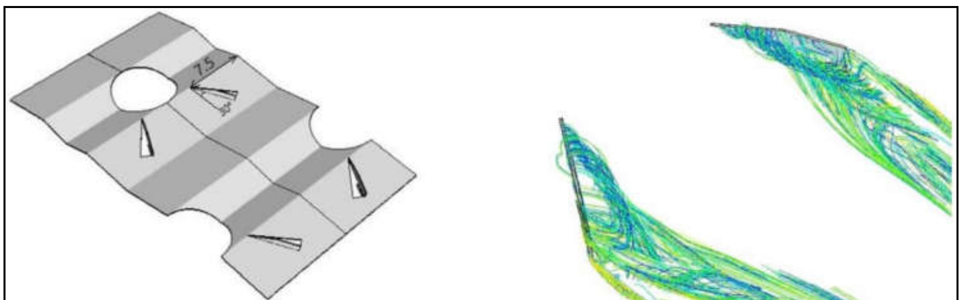
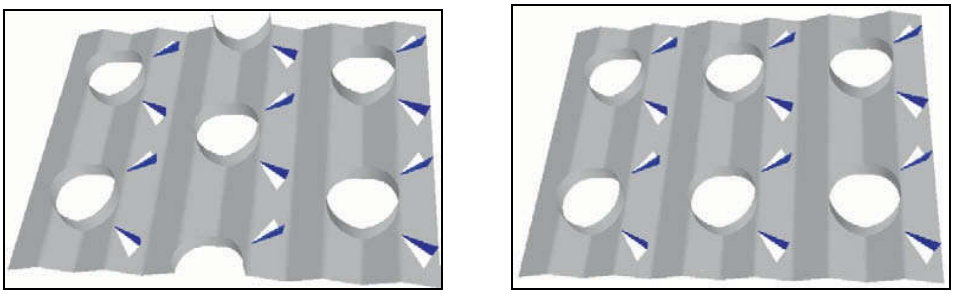


Figure 2. Delta winglets and vortices generated alongside the wavy fin-and-tube heat exchangers.

Author presented resultant thermal resistance against pumping power for wavy fins with and without delta winglets and observe that the designs offers 7% and 6% reductions in thermal resistance for *pumping power* 0.001 W and *pumping power* 0.005 W, respectively. Here author remarked that the Longitudinal vortices formed by delta winglet produces swirled flow and This swirled flow can effectively increase mixing of air flow which leading to heat transfer augmentation. Figure 2(b) shows the airflow pattern caused vortices generated by vortex generators.

Liting Tian et al [8] Presented investigation of punching delta winglets on the wavy fin surface. The heat transfer and fluid flow characteristics of the wavy fin-and-tube heat exchanger with delta winglets were numerically studied and also comparisons between staggered and in-line arrangements were performed. Figure 3.shows fin pattern in staggered and inline arrangements exchanger with delta winglet longitudinal vortex generators which was considered for investigation. Both the pattern had three-row round tubes in staggered or in-line arrangement. Two delta winglets were punched out from the wavy fin symmetrically behind each round tube.

The geometric parameters for wavy fin and tube heat exchanger were considered as; tube outside diameter =10.55 mm, longitudinal tube pitch =21.65 mm, transverse tube pitch = 25 mm, fin pitch= 3.2 mm, fin thickness = 0.2 mm, wavy angle of the fin =15^0 and delta winglet were considered as; base length and height of delta winglet = 5 mm and 2.5 mm, respectively. Here the delta winglet is punched from wavy fin the width of the delta winglet is equal to the fin thickness and the attack angle of the delta winglet was 30^0. The tube is assumed to be constant temperature because of relatively high heat transfer coefficient on the inner wall of the tube and the high thermal conductivity of the tube wall. Author mentioned that due to the fin thickness, the air velocity profile is not uniform at the entrance of the channel formed by the fins.



Staggered arrangement In-line arrangement

Figure 3. Schematic view of a wavy fin with delta winglets.

The air flowing over a fin surface having very small temperature difference so the air considered as incompressible with constant physical property. The flows through the computational domain were assumed to be three-dimensional, turbulent, steady and no viscous dissipation. Continuity, momentum (Reynolds-averaged Navier–Stokes (RANS) equations) and energy equation were considered The governing equations for the fluid domain. RNG k - ϵ turbulence model applied to include the effect of turbulence on the flow field. For the model the solid is assumed isotropic, fluid–solid conjugate heat transfer is taken into account, thermal contact resistance between the tube and the collar is ignored, and the energy equation solved in solid domain (fins and delta winglets). The required boundary conditions for the model are described in three regions (1) In the upstream extended region that is domain inlet, (2) In the downstream extended region (domain outlet), (3) In the fin coil region. Also on the delta winglet surfaces, no-slip conditions for the velocity were specified, heat convection to the delta winglets and heat conduction in the delta winglets were considered simultaneously. The Colbum factor j and friction factor f were used to describe the heat transfer performance and pressure loss characteristics. To validate model grid independence was investigated. To carry out investigation three sets of grid number with increasing order were studied and result of test shown the error less than 2% for Nusselt number and friction factor.

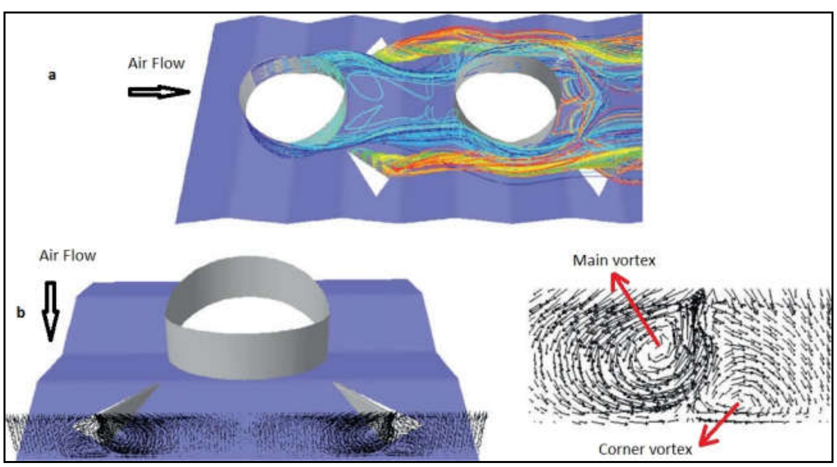


Figure 4. (a) Streamlines starting from the first row tube and delta winglets. (b) Secondary velocity vectors at the cross-section of x = 21 mm downstream of the first row delta winglet in wavy fin channel with in-line tube array.

Figure 4(a) shows the streamlines for the wavy fin channel with in-line tube array starting from the first row tube and delta winglets for Reynolds's number, Re_{Dc} = 3000. when the air flows over the delta winglet, the pressure difference between the front surface and the back surface generates the longitudinal vortices. The vortices having rotating axes parallel to main flow direction also develop downstream with main flow. Due to viscous dissipation the strength of the longitudinal vortices decreases downstream. Figure 4(b) shows the secondary velocity vectors behind the trailing edge of the first row delta winglet at a distance x = 21 mm. there are two vortices at the back of each delta winglet one is main vortex and other is corner vortex. The left main vortex rotates in a clockwise direction, while the right main vortex rotates in a counterclockwise direction. The main vortex is formed by flow separation at the leading edge of the delta winglet. The stronger main vortex induces secondary flow which causes the swirling motion and enhances the fluid transport from the mainstream region to the wake region behind the tube. The corner vortex are located outside of the main vortex has an opposite rotational direction to the main vortex.

The fin channel configuration and flow structure in it were changed with different arrangements of the tube bank. Determination of the average pressure at any cross-section is done through the area-weighted average static pressure at that cross-section. Due to drag effect formed by the tube the average pressure drop around the tube and slightly drop at the axial location corresponding to the delta winglet . The delta winglet shape is slender and also the projected area of the delta winglet is very small so that drag and the friction resistance contributed by the delta winglet are lower as compared with the drag of the round tube and the friction resistance of the wavy fin surfaces. For wavy fin with and without delta winglets, the pressure drop penalty of staggered arrangement is larger than in- line arrangement. There are many geometrical factors which can affect the fluid flow characteristics For the wavy fin-and-tube heat exchanger with delta winglets. The tube layout, the delta winglets and the wavy fin makes the air flow complex in the channel between the two neighboring fins For the in-line tube arrangement without delta winglets, the flow separates at the rear portion of a tube and reattaches at the front portion of the next tube. There were a large dead flow zones between the two adjacent tubes, which result in a large region of lower heat transfer between the tubes. When the fluid flows over the fins having delta winglets punched on the fin behind the tubes, the longitudinal vortices generated by the delta winglet increase the disturbance and mixing effects of the downstream air, and impetus the main-flow to mix with the fluid in the tube wake thus wake region size is reduced. In the staggered arrangement, for the wavy fin with delta winglets, the velocity of the wake flow is increased.

Due to generation of longitudinal vortices for the wavy fin with delta winglets, the mixing between the main-flow with lower temperature and higher velocity and the wake flow with higher temperature and lower velocity is enhanced. So that the size of wake region behind the tube and temperature the temperature of fluid in wake region get reduced. In case of Wavy fin channel with delta winglet the mixing of cold fluid and heat is more sufficient and the temperature distribution in the outlet is more uniform as compared with the wavy fin without delta winglets. The temperature difference between the inlet and outlet of the fin channel with delta winglets increases hence the total heat transfer rate increased. Analysis shows that in both staggered and in-line arrays, adding delta winglets on the wavy fin surface can enhance the heat transfer of the wavy fin-and-tube heat exchanger. At the starting point of fin channels, the cool air comes in contact of heated surface hence the thermal boundary layer developed on fin surface, the local heat transfer coefficient value is very high and gradually decreases over a fin surface. In case of inline tube arrangement with wavy fin, the local heat transfer coefficient of the fin surface between the two adjacent tubes is lower due to the existence of the large wake region and in case of wavy fin with delta winglets, the longitudinal vortices modify the thermal boundary layer in the wake region and enhance the heat transfer between the two adjacent tubes, the local heat transfer coefficient has a peak value between the tubes, maximum increase of local heat transfer coefficient is up to 95% compared with the wavy fin without delta winglets. In case of staggered arrangement with wavy fin, the local heat transfer coefficient increases abruptly at the front stagnation point of each tube due to the formation of the vortex. Behind the tube in wake region the convective heat transfer is very less and in case of wavy fin with delta winglets the local heat transfer coefficient reaches a peak value due to the generation of longitudinal vortices, a maximum increase of local heat transfer coefficient is up to 80% compared with the wavy fin without delta winglets. Here we can say that in both cases that is staggered and in-line arrangement, the longitudinal vortices generated by the delta winglets enhances the heat transfer of the fin surface in the wake region where the heat transfer is the weakest in the wavy finand-tube heat exchanger.

The Colbum and friction factors for the wavy fin in staggered and in-line arrangements with and without delta winglets at Re_{Dc} = 3000 are gathered in Table 2. From the table values we can say that for staggered and in-line arrangement, the delta winglet enhances the heat of the wavy fin channel with the penalty of pressure drop. But here enhancement of heat transfer is more than increase of pressure drop. In case of in line arrangement, the j and f factors of wavy fin with delta winglet are 15.4 % and 10.5 % respectively more than wavy fin without delta winglet. In case of staggered arrangement, the j and f factors of wavy fin with delta winglet are 13.1 % and 7.0 % respectively more than wavy fin without delta winglet. Actually, heat transfer enhancement accompanied with increasing pressure loss and increase in pumping power. To evaluate overall performance are goodness factor is used and it defined as j/f which also provided in the table. In both the arrangement cases goodness factor is more for wavy fin and tube heat exchanger with delta winglet than without winglet.

Table 2. Summary of Colbum and friction factors for staggered and in-line arrangements at Re_{Dc} =3000.

Factor	Inline arrangement		Staggered arrangement	
	Wavy fin	Wavy fin with delta winglets	Wavy fin	Wavy fin with delta winglets
J	0.01116	0.01288	0.01392	0.01575
F	0.04748	0.05248	0.05499	0.05884
j/f	0.235	0.245	0.253	0.268

3. Conclusion

1. [6] Due to the largest area facing the air flow inducing the strongest streamwise vortices Rectangular trapezoidal winglet VGs has better heat transfer enhancement at larger attack angles of the winglet VGs in the range 15° to 75° than curved angle rectangular winglet and angle rectangular winglet VGs. curved angle rectangular winglet VGs advantages at smaller attack angles for heat transfer enhancement. In case of Wheeler wishbone vortex generators due to the smaller angle between the sidewalls, the small width-to-length aspect ratio gives a better thermo-hydraulic performance, particularly at high Reynolds numbers.
2. [7] Two pairs of punching out main flow down delta winglet vortex generators on wavy fins with attack angle of 30^0, up to 7% and 6% reduction in thermal resistance for Pumping power 0.001 W and 0.005 W is attainable, respectively.
3. [8] Delta winglets generate a main vortex and corner vortex. The intensity of main vortex is greater than corner vortex . The main vortex generated at the leading edge of the delta winglet and corner vortex generated at the junction of

the front face of the winglet and the fin surface. The longitudinal vortices decrease the wake zone size behind the tube and also increase the flow velocity in the wake region. Hence longitudinal vortex increases the heat transfer of the fin surface in tube wake region. with increase in heat transfer delta winglets also increases the pressure drop but increase of the heat transfer is larger than that of pressure drop. for both the inline and staggered tube arrangement delta winglet significantly enhance the heat transfer of the wavy fin-and-tube heat exchanger, and improve the overall performance of the heat exchanger.

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