Numerical study on fin and tube heat exchanger by using elliptical tube- vortex generator

M Sudharsan¹, M D Kathir Kaman¹ and M Cheralathan¹
¹Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai-603203
Email: sudharsan_ma@srmuniv.edu.in

Abstract. A three dimensional computational study of the thermo-hydraulic characteristic of the fin-tube heat- exchanger with the upward rectangular winglets vortex and the elliptical tube of various elliptical ratios are analyzed in the study. The ratios are b/a=1.0, b/a=0.333 and b/a=0.307. The numerical studies is performed with the Reynolds no (Re) within the range of 500-3000. The temperature contour and streamline patterns were presented to explain the reason for the pressure drop and heat transfer and to analyze the flow in different arrangement. It is demonstrated that the upward rectangular winglets vortex and the elliptical tube design in case of lesser pressure loss and less separate flow which is preferred in the heat- exchanger application in order to save energy.

1. Introduction
Various types of heat- exchangers have been designed and practiced to improve the performances of the heat- exchanger. The most used heat- exchanger is the heat exchanger with fins. The finned tube heat- exchanger has various applications, such as heating and cooling and in the vehicle radiator. In the fin-tube heat- exchanger, the fin increases the surface, which in turn increases the rate of transfer of convection heat. Over the years, numerous studies were conducted to improve the thermo-hydraulic performances of the finned tube heat- exchanger. Numerous studies have been conducted for different types of fins and fin spacing. Various studies show that the ellipticity influences the performances of the heat- exchanger. Ellipticity is the ratio between the major axis and the minor axis.

In recent years, vortex generators have been used extensively to enhance the performances of the heat- exchanger. Mechanisms such as mixing the mass flow, destabilizing the flow and changing the boundary layer result in heat exchange. The use of the vortex generator provides the three mechanisms which in turn enhance the performances of the heat- exchanger. The vortex generator are classified as,

a. Transverse vortex generator.

b. Longitudinal vortex generator.

The longitudinal vortex generator has its axes parallel to the direction of the main flow. The transverse vortex generator has its axes perpendicular to the direction of the main flow. Generally vortex generators are made by embossing, molding or punching the surface of the fin. There are various type of vortex generator like delta wing and the rectangular wing. If the tail of the wing is fitted to the fin known as wing and if the cord of the wing is fitted to the fin it is called as winglets.

Modi et al. [1] conclude that the rising wavy rectangular fins have an exceptional improvement in heat transfer compared to the alternative configuration of the square ailerons. The 45 ° fins are said to offer excellent typical performances compared to other positions consisting of 30 ° and 60 °. Dogan et al. [2] The overall thermo-hydraulic performances of the elliptical and circular tube heat-exchanger
was compared with the use of CFDs. Ellipticity varies from $b/a = 0.307-1$. Repeated for a unique variety of Reynolds no $Re = 2850, 750, 1940, 2415$. The elliptical phase tube is the highest design due to the low voltage drop and the less separated float. Siddhant et al. [3] three-dimensional numerical evaluation by CFD for tube and fin heat-exchanger for various elliptical ratios of 0.6, 0.7 and 1. Eight inclination perspectives $0^\circ$, $20^\circ$, $40^\circ$ are studied through various Reynolds no. air intakes in particular 1300, 1450 and 1600. The temperatures of the tube and fin wall are maintained at 373K. This article studies the influence of the tilt attitude and the elements of Re on Friction, colburn factors and performances index. Babak et al. [4] a three-dimensional CFD evaluation of the clean wavy fin heat-exchanger and elliptical tubes is performed. The vortex generator form used are rectangular trapezoidal ailerons (RTW), square perspective ailerons (ARW) and wavy angle square ailerons (CARW) with an ellipticity ratio of 0.65 to 1. The Reynolds range is from 500 to 3000. Wang et al. [5] A three-dimensional study of the CFD has an impact on the ellipticity ratio of the tube, on the rotation attitude of the tube $\Theta$ and on the spacing of the fins $H$ on the capacity of the heat switch. Levels of ellipticity ratio between 0.4-1.0. Reynolds no levels between 1300-2100 and the rotation attitude of the tube between zero and $90^\circ$. The yields are assessed through non-dimensional parameters together with colburn elements, friction factors and region of goodness. Modi et al. [1] CFD evaluation of the compact sinusoidal and elliptical elliptical square finned tube heat-exchanger (RWVG) with multiple Reynolds ranges, $Re = 400-3000$. The Vortex turbines used are corrugated, corrugated, corrugated and square fins. They are compared with the general criterion of thermo-hydraulic performances which includes the Nusselt range, the friction factors for stress drop ($\Delta P$) and the goodness factors of the area. The wavy and wavy rectangular fins have a slight pressure loss. M.D. Islam et al. [6] The effects of various angles of attack and blocking ratios of VGs oriented towards an easy conduit are studied. CFD evaluation, with and without VG, were performed for an air in flow with the Reynolds no. in the range 6000–33000 and for a regular heat flow in the floor of the tube version. The VGs are equipped in a round sample on the inner floor of the tube. The distinctive units of the delta winglets were characterized using four angles of attack $\beta$ ($0^\circ$, $15^\circ$, $30^\circ$ and $45^\circ$) and three block B ratios (zero.1, zero.2 and zero.3). The result of the Nusselt variety and the friction factor shows the influence of the VG on the overall thermal performances. Gaofeng Lu et al. [7] Numerical study on the function of the finned floor vortex generator of the finned tube heat-exchanger. The impact of curvature is assessed for corrugated VG. The effect of attack perspective for corrugated bark turbines is studied. The vortex structures around the vortex mills are analysed. The parameters of the corrugated VG are optimized.

On the based previous studies it understandable that the up waved rectangular winglets vortex generator enhance the rate of heat transfer. The thermo-hydraulic performances of the fin-tube heat-exchanger with up waved rectangular winglets vortex generator for different ellipticity ratio was studied.

2. Modelling

![Figure 1](image.png)

**Figure 1.** Design of the fin-tube heat-exchanger with up wavy rectangular winglets.
The fin tube heat-exchanger is designed with wavy rectangular fins as shown in Figure 1. The upstream inlet region, the extended down-stream region are provided. The rectangular inverted fins have an angle of 45°. The length of the fin is 180 mm. The upstream region is 16.73 mm long and the downstream region is 65 mm long. The radius of the tube is 5.28 mm. The distance between the pipes is 11.45 mm.

Air with ui speed is provided at the entrance. The inlet air temperature is maintained at 303K. And the temperature of the tube wall is kept at 350K. The corrugated rectangular fin vortex generator is designed and added for each tube at an angle of 45°. Aluminum is taken as the fin material and air as the working fluid.

2.1. Governing Equation

Continuity equation

\[ \frac{\partial U_i}{\partial X_j} = 0 \]  

(1)

Momentum equation

\[ \frac{\partial}{\partial X_j} \left( U_i U_j \right) = -\frac{1}{\rho} \frac{\partial p}{\partial X_j} + \frac{\mu}{\rho} \nabla^2 U_i - \frac{\partial}{\partial X_i} \left( \overline{U_i U_j} \right) \]  

(2)

Energy equation

\[ \frac{\partial}{\partial X_j} \left( \overline{U_i U_j} \right) = \frac{k}{\rho C_p} \nabla^2 T - \frac{\partial}{\partial X_i} \left( \overline{U_i T} \right) \]  

(3)

The computation is done with energy equation on and with k-ε RNG model with standard wall condition.

2.2. Boundary Condition

| Boundary Condition | Condition |
|--------------------|-----------|
| Velocity inlet and Temperature | u=ui and Ti=303K |
| Pressure outlet | P=Patm |
| Wall | Tube wall at constant temperature Tw=350K |
| Symmetry | Symmetry condition between two fins. |

2.3. Numerical Approach

The numerical analysis is done using ANSYS 18.1. The geometry is designed in CATIA (design software) and imported as a step file. The fine and uniform meshing is done with 9879 elements. The computation is done for the given governing equation and the boundary condition. The fin-tube with circular tube cross section and with up wavy rectangular winglets is commutated for the Reynolds no. 700. Then the same setup is studied for different Reynolds no. values such as 1000, 1300, 1700 and 2100. The procedure is repeated for different ellipticity such b/a= 0.5, 0.333, 0.307. Where ‘a’ is major axis and ‘b’ is minor axis of elliptic tube. The table 1 shows the boundary condition applied.
To validate this numerical model of fin-tube heat-exchanger with up waved rectangular winglets vortex generator the Nusselt no. that is obtained from the baseline case is compared with modi et al [8].

3. Results and discussion
3.1. Effect of winglets on flow structures

The heat exchange depends on the floating structure of the fluid, while the heat exchange depends on the floating structures of the fluid passing through the surface. The flow structures represented with the help of the circulation line model and the flow velocity of the fluid. From aerodynamic schemes, it’s observed that drifts separation occurs at the back of the tube. The recirculating sector is formed within the rear section of each round tube. The awakening region is created due to separation with the flow. It is found that the incoming air separates from the primary matrix of the raw tube and passes to the second one not cooked directly with the help of the passage of the wake site. The drift is reattached inside the front phase of the nearby tube which wraps a quarter of the recirculation bound on the desk between two adjacent tubes. This recirculation is greater within the elliptical tube. In the aerodynamic diagram, the fins were found to pass the arrow through the tubes. It improves the heat exchange of the tube. The elliptical tube has the highest air flow around the tube compared to the round tube.

Figure 2. streamline diagram for circular and elliptical tube cross section with up wavy rectangular winglets.

As shown in Figure 2, the upwardly corrugated rectangular vortex generator blocks the air flow and the air stream line covers more surface of the tube. Due to the efficient contact between the air flow and the outer surface of the tube, heat transfer from the tube is improved. Figure 3,4,5,6 shows the contour of the current line, temperature, pressure, speed, respectively, for Reynolds no. 700.
Figure 3. streamline contour with different ellipticity ratio for Reynolds no. 700.

Figure 4. temperature contour with different ellipticity ratio for Reynolds no. 700.

Figure 5. pressure contour with different ellipticity ratio for Reynolds no. 700.
3.2. Temperature distribution
The temperature contours shown in Figure 4 show the flow through the Reynolds tube no. 700. The heat dissipation of the tube with elliptical shape is better than the circular shape. The corrugated rectangular wing vortex generator separates the air flow from the inlet and recirculates around the tube. This recirculation removes more heat from the tube wall, which is best for elliptical tubes with the elliptical ratio of 0.333 and 0.307.

3.3. Effect on Nusselt no. (Nu)
The Figure 7 shows the variation in the Nusselt no. with respect to Reynolds no.. The Reynolds no. ranges from 700-2100. Higher the Reynolds no. the nusselt no. also increases. The ellipticity 0.307 and 0.333 shows higher value. Generally the elliptical tube values are higher compared to the circular tube cross section.

3.4. Effect on friction factor.
The Figure 8 between friction factors and the Reynolds no. is made. It shows that the circular tube has more friction factors value compared to elliptical tube. The friction factors also changes along the Reynolds no.. The ellipticity ratio of 0.333 and 0.307 has almost similar ellipticity ratio.
4. Conclusion
The upwardly rectangular fins influence the structural characteristic of the air flow, heat exchange and pressure of the heat-exchanger with fin. In the present study, a numerical investigation of fluid flow in the heat-exchanger with fin is performed for different sections of the tube with elliptical tube. The b/a ratio of elliptical tube used are 0.5, 0.333, and 0.307. The following conclusions were made for the present study.

The presence of the rectangular fins corrugated upwards improves the speed of heat exchange compared to the finned tube heat-exchanger of the non-finned type. The aerodynamic diagram of the finned tube with ailerons shows how the presence of rectangular ailerons alters the flow structures of the fluid, which in turn increases the speed of heat transfer.

Nusselt no which is taken with the respective Reynolds n. shows that ellipticity 0.307 and 0.333 gives better results than the other models. Ellipticity 0.307 has better results than others. The cross section of the elliptical tube provides better contact between the flowing fluid and the tube.

The graph between the friction factors and Reynolds no. shows that the friction factors are higher for the circular tube and decreases with increasing Reynolds no. The circular tube in turn has a higher pressure drop value due to the previous separation of flow, with a high blockage and flow separation ratio. Elliptical tubes have low friction factors compared to the tube with circular shape. The ellipticity ratio 0.333 and 0.307 has valves with almost similar friction factors.

5. References
[1] Ashish J Mod and Manish K Rathod 2019 Comparative study of heat transfer enhancement and pressure drop for fin-and-circular tube compact heat-exchangers with sinusoidal wavy and elliptical curved rectangular winglets vortex generator International Journal of Heat and Mass Transfer 141 310–326
[2] Sercan Dogan, Selcuk Darici and Muammer Ozgoren 2019 Numerical comparison of thermo-hydraulic performance for heat-exchangers having circular and elliptic cross-section International Journal of Heat and Mass Transfer 145 118731
[3] Siddhant Singh Yogesh, Arun SacoSelvaraj, Dinesh KumarRavi and Thundil Karuppa RajRajagopal 2018 Heat transfer and pressure drop characteristics of inclined elliptical fin tube heat-exchanger of varying ellipticity ratio using CFD code International Journal of Heat and Mass Transfer 119 26-39
[4] Babak Lotfi, Bengt Sundén and Qiuwang Wang 2016 An investigation of the thermo-hydraulic performances of the smooth wavy fin-and-elliptical tube heat-exchangers utilizing new type vortex generators Applied Energy 162 1282-1302

[5] Wang P, Jiang J, Li S, Luo X, Wang S and Zhao W 2019 An investigation of influence factors including different tube bundles on inclined elliptical fin-tube heat-exchanger Int. J. Heat Mass Transfer 142 118448

[6] Xu Y, Islam M D and Kharoua N 2017 Numerical study of wingletless vortex generator effects on thermal performances in a circular pipe Int. J. Therm. Sci. 112 304–317

[7] Gaofeng Lu and Xiaoqiang Zhai 2019 Effects of curved vortex generators on the air-side performances of fin-and-tube heat-exchangers International Journal of Thermal Sciences 136 509-518

[8] Dogan S, Ozgoren M, Solmaz O and Ozseker G 2016 Investigations of flow around cylinders having circular and elliptical geometries for multiple and staggered arrays via PIV method 8th Int. Ege Energy Symp. Exh., Afyon.