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# Heat Transfer Enhancement and Pressure Drop Performance for Fin and Tube Compact Heat Exchangers with Radiantly Arranged Rectangular Winglet-Type Vortex Generators

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## ABSTRACT:

*In this paper, heat transfer enhancement has been numerically investigated for fin and tube compact heat exchangers with radiantly arranged rectangular winglets and has been compared with the existing structures. In the proposed structure, there are total 12 winglets, 3 on each tube arranged radiantly with an attack angle of 60 ° each. Investigation has been carried out on low Reynolds number from 400-800 heat transfer is compared with other structures without winglet as baseline arrangement, prevailing rectangular winglet arrangement and wavy down rectangular winglet arrangement. The simulation results show that the radiantly arranged winglet that guides the fluid from main flow to the wall creates collision and leads to turbulence behind the tube. It is found that newly proposed structure with radiantly arranged winglets has the highest heat transfer rate, as compared to the existing structures and this can replace the previous structures. The heat transfer characteristics and flow structures are numerically investigated in ANSYS.*

## KEYWORDS:

*Compact heat exchanger; Vortex generator; Heat transfer enhancement; Radiantly arranged winglets*

## CITATION:

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## ACRONYMS AND NOMENCLATURE:

| | |
|---|---|
| A | Total heat transfer surface area [$m^2$] |
| $C_p$ | Specific heat [J/kg K] |
| $D_c$ | Tube outside diameter [m] |
| $D_h$ | Hydraulic diameter [m] |
| f | Friction factor |
| h | Heat transfer coefficient [W/$m^2$ K] |
| k | Thermal conductivity [W/$m^2$ K] |
| N | Number of tube row |
| Nu | Nusselt number |
| $m_f$ | Mass flow rate [kg/s] |
| ΔP | Pressure drop [Pa] |
| *l* | Chord length of the winglet [m] |
| Pl | Longitudinal pitch [m] |
| Pr | Prandtl number |
| Pt | Transverse pitch [m] |
| Q | Heat transfer rate [W] |
| $U_m$ | Mean velocity at min. flow cross-section [m/s] |
| Re | Reynolds number (($\rho$ Um Dh)/$\mu$) |
| T | Temperature [K] |
| δ | Delta winglet thickness [m] |
| β | Attack angle of the delta winglet (deg) |
| μ | Dynamic viscosity [kg/ms] |
| ρ | Density [kg/$m^3$] |

## 1. Introduction

Compact heat exchangers are widely used in various types of applications. One of the most common types of heat exchanger is fin and tube compact heat exchanger. They have a wide range of applications such as in industries related to refrigeration, ventilation, air conditioning and other industries. Fin and tube heat exchangers consist of tubes with fin attached to the outside of tubes. The heat transfer rate increases due to the additional heat transfer surface due to finned tubes. During the past few years various researches have been carried out on enhancing the heat transfer rate using the vortex generator. Chen et al [1] investigated heat transfer performance and fluid flow characteristics using wavy-fin and found that both average Nusselt number and pressure coefficient increase with the increase in wavy angle at the same wavy height. Fiebig et al [2] investigated and found that the drag produced was directly proportional to the area of the vortex generator where as it is independent of the shape and Reynolds number. Savino et al [3] investigated heat transfer and pressure drop analysis on a two dimensional fully developed region of wavy channel and revealed that the commencement of 3D effects has an important impact on Nusselt number and overall friction factor.

Chen et al [4] numerically investigated that vortex generator in staggered arrangement has more heat transfer enhancement than that of vortex generator in inline arrangement. Biswas et al [5] numerically investigated that arrangement with winglet type vortex generator have higher heat transfer. Tiggelbeck et al [6] compared the heat transfer and flow characteristics in a channel flow using delta wings, rectangular wings, a pair of rectangular wing and a pair of delta wing. They found that winglet have better heat transfer enhancement than wings alone. Allison and Dally [7] experimentally analysed the performance of fin and tube radiator using delta winglet vortex generator, arranged in a flow up composition and located upstream of the tube. The flow is directed onto the surface of the tube in order to increase the localized velocity gradients and Nusselt number in this region. Results showed that the heat transfer capacity on the winglet surface is 87% and pressure drop of louver fin surface is only 53%.

Torii et al [8] proposed a novel technique in staggered arrangement heat transfer was enhanced by 30-10% and pressure loss was reduced by 55-34%. For inline arrangement heat transfer was enhanced by 20-10% and pressure loss was reduced by 15-8%. He et al [9] found that pressure drop can be reduced by changing the arrangement of same numbers of rectangular winglet pairs. The objectives of the current work are:

- Computational fluid dynamics analysis on a fin and tube compact heat exchanger with radiantly arranged rectangular winglets.
- To make a comparison between the heat exchanger with radiantly arranged winglets and with the conventional arrangements.
- To examine the advantages of employing the proposed structure over the conventional structures.

## 2. Model description

The geometry has been developed on ANSYS student version [11]. The diameter of the tube fin Dc is 10.5 mm. The transverse tube pitch is 25.4 mm. The longitudinal tube pitch is taken as 22 mm. Four referenced structures were considered for comparison. Fig. 1 shows a baseline case with four tube fins without any winglet, four tubes surrounded by rectangular winglets placed at an attack angle of 30 degrees each, wavy up rectangular winglets, mounted on 4 tube fins at an attack angle of 30° and wavy down rectangular winglets mounted on four tube fins at an attack angle of 30°. In other configurations, there is only one winglets mounted on each tube fin. In the proposed structure as shown in Fig. 2, we have used three rectangular winglets on each tube fin, arranged radiantly at an attack angle of 60° each [10]. The fluid is considered to be incompressible along with the constant thermo-physical effects. The flow inside the fin channel is considered as laminar and steady state because of the low inlet velocity of air and small space.

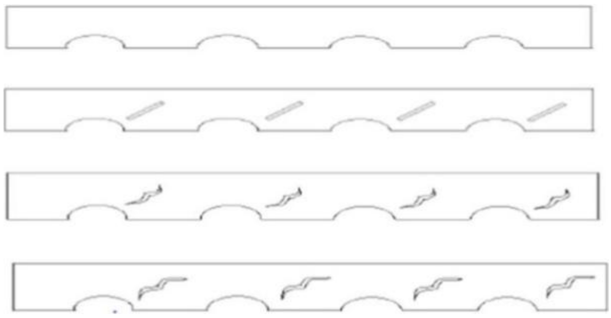

**Fig. 1: Computational domain of fin and tube compact heat exchangers with different winglet arrangement**

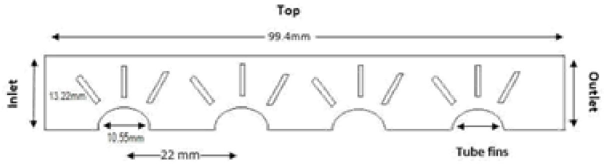

**Fig. 2: 2D Schematic diagram of a compact heat exchanger with radiantly arranged rectangular vortex generator**

The governing equations for the CFD analysis are,

$$\frac{\partial \rho u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial(\rho u_i u_j)}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial \mathrm{p}}{\partial x_j} \tag{2}$$

$$\frac{\partial(\rho u_i \mathrm{T})}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{\mathrm{k}}{C_p}\frac{\partial u_j}{\partial x_i}\right) \tag{3}$$

The equations are utilized in the CFD analysis to compute the heat transfer and pressure drop. The velocity and temperature profile are known at the inlet zone. We use constant stream wise velocity at the inlet and other velocities are set zero. The temperature distribution is constrained. The constant temperature recommended at the inlet as $T_m$=300 K. The uniform velocity is U=$U_{in}$. At the outlet, the stream wise variables are taken as zero. At the sides, symmetrical boundary conditions are considered as zero. The gradient of variables such as velocity and other variables are set to be zero. Velocity components are kept zero as no-slip boundary conditions has been considered at the wall. The temperature distribution is $T_w$= 350 K.

ANSYS student version is used to retrieve the numerical solution. Finite volume method is employed to the computational domain in order to solve the differential equations with the boundary conditions. The computational domain uses Fluent 15 to discretize by non-uniform grids. Fig. 3 shows the irregular meshing of the computational domain. The number of cells near the tube fin and vortex are more. In order to solve the computational domain, we use SIMPLE scheme. To solve the energy and momentum equations, we use SECOND ORDER UPWIND and POWER LAW schemes respectively. The convergence criteria were set to be $10^6$ for all differential equations.

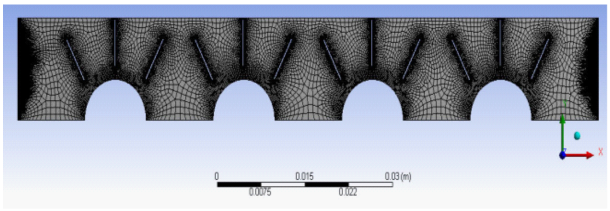

**Fig. 3: Meshing of radiantly arranged rectangular winglet case**

## 3. Results and discussions

Fig. 4 shows the temperature contours around four tubes in a compact fin and tube heat exchanger with different winglets and arrangements. For relatively low Reynolds number, the different forms of winglet and arrangement certainly changes the temperature distribution in the heat exchanger. It also intensifies the local heat transfer over the tube bank. The results show that radiantly arranged rectangular winglet type heat exchanger provides best transfer performance as the average temperature difference in and out flow of air is larger in the radial arrangement case. Furthermore, the heat transfer enhancement is greater in radial arrangement of rectangular winglet.

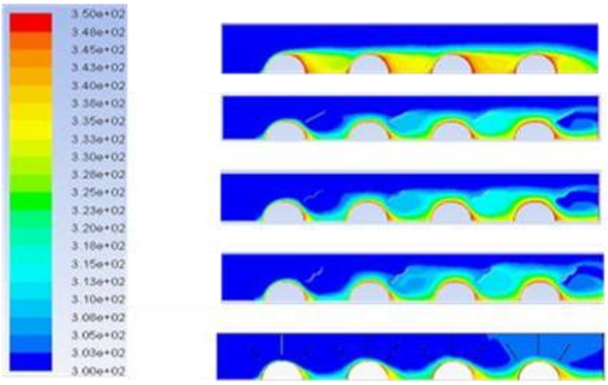

**Fig. 4: Temperature distributions across tube bank at Re = 400**

Figs. 5 and 6 show the plots of variation of Nusselt number with Reynolds number for the existing structures and the proposed structure respectively. Nusselt number increases along the Reynolds number range. Nusselt number increases for radial rectangular arrangement compared to the baseline, rectangular, wavy up and wavy down forms. Therefore, the proposed structure has the best heat transfer performances for the contemplated Reynolds number range (400-800).

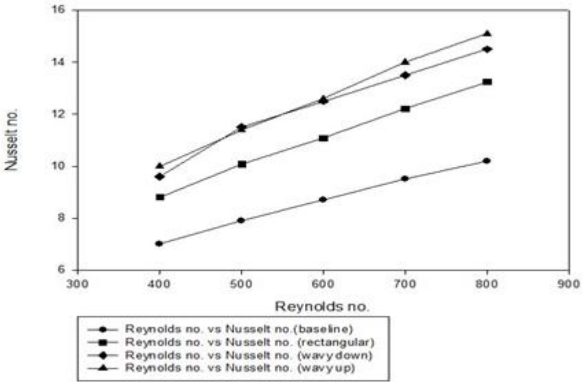

**Fig. 5: Nusselt number vs. Re for the existing structures**

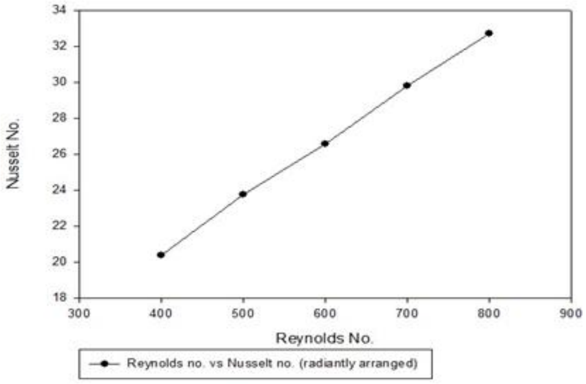

**Fig. 6: Nusselt number vs. Re for the proposed structure**

Fig. 7 illustrates the pressure drop contours on the four tubes in compact fin and tube heat exchanger for different types of winglet arrangements. Pressure drop along the flow is seen in all cases at Re = 400. Figs. 8 to 11 show the pressure drop and friction factor results from the simulations. Reviewing these graphs, it is clearly evident that the proposed structure characteristics are better than those of the existing structures.

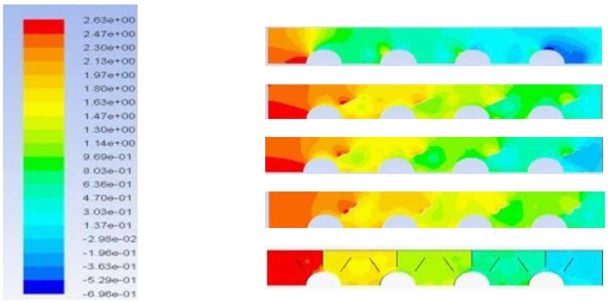

**Fig. 7: Pressure contour at Re = 400**

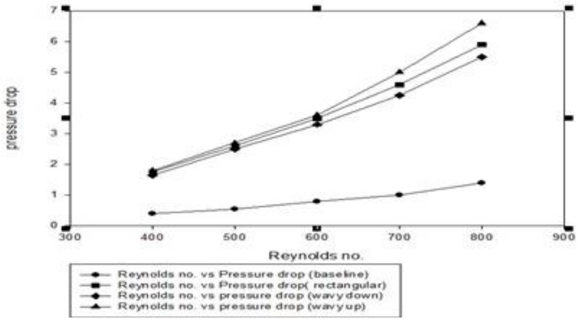

**Fig. 8: Pressure drop vs. Re for the existing structures**

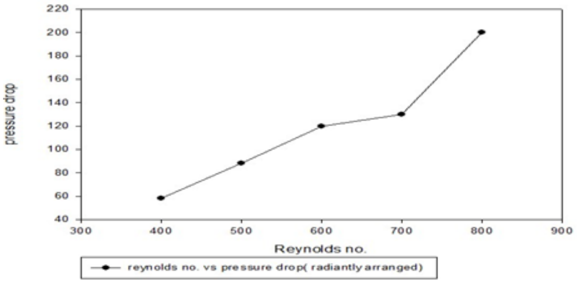

**Fig. 9: Pressure drop vs. Re for the proposed structure**

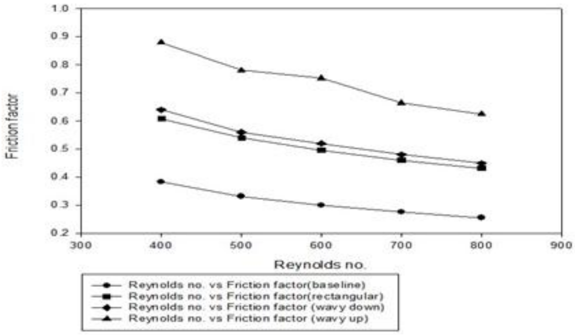

**Fig. 10: Friction factor vs. Re for the existing structures**

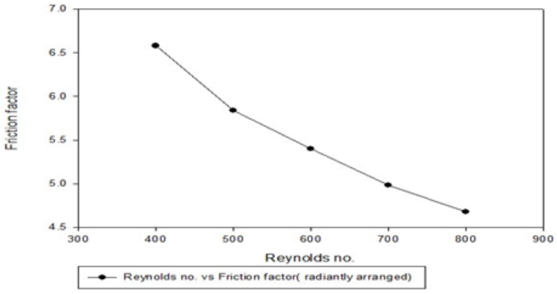

**Fig. 11: Friction factor vs. Re for the proposed structure**

## 4. Conclusions

According to the existing research and validations, the heat transfer coefficient of the fin and tube compact heat exchanger is improved when compared with the baseline case and conventional form of winglets. The rectangular winglet vortex generator with wavy up and wavy down significantly enhance the heat transfer performance of fin and tube compact heat exchangers. Radiantly arranged rectangular winglet construction constitute multiple paths with convergence. The converging passage guides the fluid entering and further increases the mixing to create turbulence. It also leads to reduction of wake region behind the tube walls. When the fluid passes through the tube walls some of the fluid impinges the wall leading to heat transfer enhancement. The proposed structure with radiantly arranged rectangular winglets possesses the best heat transfer enhancement as compared to the existing structures.

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