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HEAT TRANSFER IMPROVEMENT USING VORTEX GENERATOR

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Abstract

Heat transfer performance of fin-tube heat exchanger can be augmented by the use of longitudinal vortex generators which generates longitudinal vortices. In the present work experimentations have been performed to investigate the heat transfer and flow resistance characteristics of rectangular winglet pair (RWP) type vortex generators (VGs) mounted on fin surface in a fin-tube heat exchanger. RWP have been placed in Common Flow Down (CFD) configuration in downstream location. Heat transfer and flow resistance characteristics have been compared with the baseline case using Colburn's factor(j), friction factor(f) and performance evaluation criterion (PEC) also known as area goodness factor = j / f. Investigations have been performed considering the Reynolds number in the range of 1000 to 10000 and angle of attack as 35°. The vortex generator considerably improves the thermos hydraulic performance and decreases the flow resistance due to a reduction in the face area. The result clearly indicates that the rectangular winglet pair gives the better thermos hydraulic performance.

Keywords: *Rectangular Winglet, Vortex generator, Fin-tube heat exchanger*

1. Introduction

Fin and tube heat exchangers have very wide applications in different types of equipment for example, refrigerators; thermal power plant; heating, ventilation, and air conditioning (HVAC) devices and radiators used in automobiles. Research are going on since last three decades to augment heat transfer between both the fluids flowing into and over the heat exchanger. There are numbers of active and passive methods to augment heat transfer in a heat exchanger. One of such passive methods is the use of vortex generators (VGs). VGs have been thoroughly investigated in order to improve the air side connective heat transfer coefficient of fin-tube type heat exchangers.

The primary function of Vortex Generator is to produce longitudinal vortices (LV) which disturbs the thermal boundary layer formed along the wall and hence transfers the heat from the wall by generating large-scale turbulence. Among the different kinds of VGs, winglets are of prime interest because these kind of VGs could be easily attached on fins. Winglets can effectively generate LV which in turn increases the convective heat transfer coefficient by creating turbulence and at the same time due to resistance offered to the flow there is an increase in the pressure drop..

There are several experimental and numerical studies which have been performed over the decades to examine the effects of winglet pair on thermohydraulic performance of fin-tube heat exchanger. Jacobi and Shah (1995) presented a comprehensive review of heat transfer augmentation and flow resistance characteristics by using longitudinal vortex generators. Biswas et al. (1994) performed numerical simulations and Valencia et al. (1996) investigated experimentally and found that the use of vortex generators on the surfaces of fin is useful in order to enhance the heat transfer. Tiggelbeck et al. (1994) and Biswas et al. (1994) concluded that winglets are better than wings for heat transfer enhancement.

Numerous investigations have been performed both experimentally and numerically to examine the effect of different shapes of winglets and their configurations. Most of the studies are focused on the winglets having rectangular and delta shapes as per literature. Fiebig Martin (1998) performed a comparison study for the thermohydraulic performance of the winglets in the channel flow. Pauley and Eaton (1988) made an experimental investigations and proposed two configurations for winglets which are known as common flow up (CFU) and common flow down (CFD). In CFD configuration leading edge of winglet are closer than trailing edge w.r.t. tube in a fin-tube heat exchanger. In contrast to CFD in CFU configuration trailing edge of the winglet are closer than leading edge w.r.t. tube in a fin-tube heat exchanger.
In the present investigations, we have examined the effects of rectangular winglets pair which are attached in CFD configuration in downstream location of flow in a fin -tube heat exchanger and compared it with baseline case.

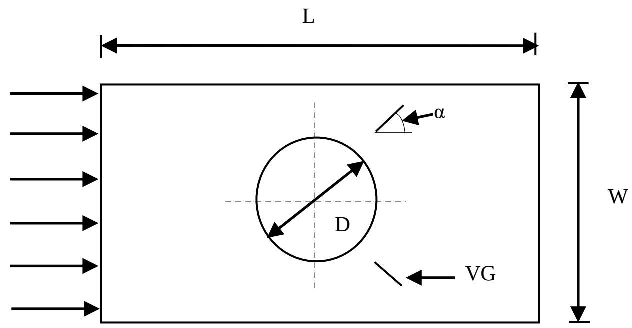

Figure 1. Common Flow Down (CFD), Downstream

2. Physical Model

In the present study, we have considered a fin-tube heat exchanger for the experimentation. Fin and tube are arranged in cross flow manner with twenty-five fin plates arranged parallel to one another and a tube is located centrally and vertically passing through all the fin plates. Fin plates are made up of aluminum and the tube is made up of copper. For the experimentation, fin plate located at the center has been considered and rest of the plates were arranged to maintain periodicity. Vortex generator under consideration was rectangular winglet as represented in figure

Table 1. The Parameters of fin-tube heat exchangers under consideration

Parameters	Without VG	With VG
Tube outside diameter(D)	42mm	42mm
Fin plate length(L)	400mm	400mm
Fin plate width(W)	200mm	200mm
Fin plate thickness(t)	1mm	1mm
Fin pitch(F_p)	24mm	24mm
Longitudinal vortex generator position(X)	-----	26mm(0.5D)

Transverse vortex generator position(Y)	-----	26mm(0.5D)
Vortex generator attack angle(α)	-----	35°
Vortex generator length (L_g)	-----	18mm
Vortex generator height (H_g)	-----	15mm
Vortex generator thickness (t_g)	-----	1mm

3. Performance Parameters

To determine heat transfer performance and resistance characteristics the following equations have been used:

$$Q = \dot{m}.c_p.(T_{m,out} - T_{m,in})$$

and the temperature difference has been defined according to the equation

$$\Delta T_M = \frac{(T_{m,wall} - T_{m,in}) - (T_{m,wall} - T_{m,out})}{\ln\frac{(T_{m,wall} - T_{m,in})}{(T_{m,wall} - T_{m,out})}}$$

So, convective heat transfer coefficient

$$h = \frac{Q}{A_S.\Delta T_M}$$

where Q is the total rate of heat transfer, m is mass flow rate of working fluid, $T_{,m,out}$ is the temperature of the fluid at the outlet, $T_{,m,in}$ is the temperature of the fluid at the inlet, T_{wall} is the temperature of the wall, C_p is specific heat capacity of working fluid and A_s is the total surface area of heat transfer. Now

The hydraulic diameter is given by

$$D_h = 4.A_c/P_w$$

The kinematic viscosity is given by

$$\nu = \mu/\rho$$

and Reynolds number based on hydraulic diameter is given by

$$Re = uD_h/\nu$$

Where u represents the inlet velocity of air, ν represents kinematic viscosity of air, A_c represents the cross-sectional area for fluid flow and P_w represents wetted surface perimeter, μ and ρ were dynamic viscosity and density of air respectively.

The Nusselt number has been defined as follows:

$$Nu = \frac{h.D_h}{k}$$

The Prandtl number has been defined as follows:

$$Pr = \mu.C_p/k$$

Darcy Friction factor 'f' represents the friction characteristics, has been defined as follows:

$$f = \Delta P_m.D_e/(2L.\rho.u^2)$$

Besides, Colburn's factor 'j' represented the heat transfer capacity, has been defined as follows:

$$j = \frac{Nu}{Re.Pr^{1/3}}$$

where ΔP_m is the pressure drop between inlet and outlet section of the test prototype, L represents the length of flow direction.

Finally, in order to estimate the heat transfer performance and flow resistance characteristics of the tube-and-fin heat exchanger, performance evaluation criteria (PEC) has been used to

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evaluate the overall thermal performance, defined in terms of Colburn's factor and friction factor. PEC has been used to compare the performance of modified fin-tube heat exchanger having vortex generator with the conventional fin-tube heat exchanger having no vortex generator.

$$PEC = \{(j / j_o) / (f / f_o)^{(1/3)}\}$$

Where j_o and f_o are the Colburn's factor and Friction factor for fin-tube heat exchanger having no vortex generator

4. Results and discussion

It can be noticed from the figure 2 that by attaching winglet on the fin surface has considerable benefit over the baseline case with no winglet i.e. no vortex generator. The main reasons for using winglet is that it delays the formation of wake region by delaying boundary layer separation. It generates longitudinal vortices due to a sudden drop in pressure which helps in delaying boundary layer separation and thereby increases heat transfer.

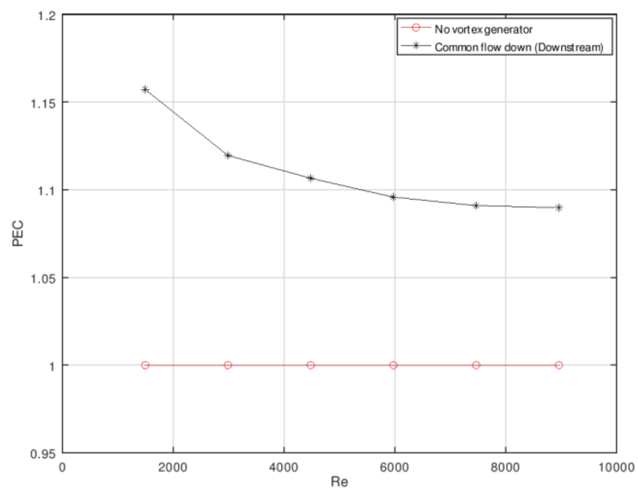

Figure 2 Variation of Performance Evaluation Criterion with Reynolds no.

In a similar kind of heat exchanger with no winglets, air streams come across the bulge of the tube which gives rise to the formation of a wake region immediately after the tube. When a winglet is attached over the plate, either in upstream or downstream of the tube, it generates longitudinal vortices due to a sudden drop in pressure which helps in delaying boundary layer separation and thereby increases heat transfer. It is essential to delay the formation of wake region as much as possible because heat transfer in the wake region is minimum. This could be due to the negative high-pressure zone being formed with the minimum velocity of air streams.

5. Conclusion

The present work concentrates on heat transfer augmentation assisted by the addition of winglets having punched holes as the vortex generators. Although there is some pressure drop in using vortex generators, there is an overall improvement in thermal performance as shown by PEC study.

6. References

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