Numerical Investigation of Turbulence Effects of Delta Wing Vortex Generators on Thermal Performance of Plate-Fin-And-Oval-Tube Heat Exchanger

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Abstract— The vortex generators are useful devices to enhance the heat transfer and thermal performance of fin-and-tube heat exchanger. Turbulators or vortex generators will produce a change in structure of fluid flow which will helps in augmenting the heat transfer rate and also the thermal enhancement factor. Numerical investigation method is adopted to study the effects of wings on the heat exchanger performance in order to reduce the cost. The results are shown that the use of the punched delta wings in the parallel plate-and-oval-tube heat exchanger leads to an enhancement in heat transfer and friction loss as compared to the plain-fin for all cases (Nu/Nu0 higher than 1). The punched delta wings create the vortex flows between parallel plates that helps enhance the strength of the impinging flow on the tube walls. To enhance the thermal performance of the heat exchanger, impingement of the flowing fluid is an important factor.

Key words: Turbulators, Numerical Investigation

I. INTRODUCTION

A device that transfers the thermal (heat) energy from one fluid to other fluid is known as heat exchanger. Heat exchange takes place due to the thermal contact between the two fluids provided by the heat exchanger equipment. Different types of heat exchangers of different sizes are developed for various applications like steam power plants, room heating, chemical processing, automobile radiators, and refrigerators and air-conditioning etc. In heat exchangers and radiators, heat transfer process takes place primarily by conduction and then by convection between two fluids and a metal wall separating them. In cooling towers, heat exchange process takes place by direct mixing of the hot fluid with a spray of cold fluid by both convection and vaporization. Many other types of heat exchangers are present which involves all the three modes of heat transfer.

Designing a heat exchanger involves many parameters. During the process, it is necessary to analyse rate of heat transfer in the equipment, size of the equipment is also important in terms of effective area available for the heat transfer process which is decided by the compactness of the equipment. Pressure drop also plays an important role which is to be analysed. Overall performance and cost estimation is very important before finalizing the design. In large installations like in power plants and chemical processing installation cost is considered before the design, but in aerospace applications size and weight is given more importance.

II. EQUESTIONS AND VARIABLES

A. *Active Techniques for Heat Transfer Augmentation*

1) *Surface vibration:*

In single phase heat transfer, surface vibration can be used as a mean to augment the heat transfer rate. Surface vibrations can be created by piezoelectric device. A piezoelectric transducer is used by Heffington et al. [2001] to create vibrations in a plate at 2.5 kHz.

2) *Mechanical aids:*

Mechanical aid is a device used to stir the air entering the exchanger or it may rotate the heat exchanger surface itself. Heat transfer is augmented by inserting mechanical surface scrappers. Rotating ducts can also be employed to augment the heat transfer rate.

3) *Fluid vibration:*

It is most suited to single phase fluids, fluid vibrations may involve pulsations ranging from 1Hz to ultrasound, and this is the most realistic type of vibration augmentation due to the heat exchanger mass.

4) *Electrostatic fields:*

When dielectric fluids are used as a working medium, by applying an electrostatic field it is possible to properly mix the fluids near the heat transfer surface. By applying electric field, it is possible to impose a body force on the fluid, and this body force influences the fluid motion.

5) *Injection:*

This technique involves injection of gas to the flow field of the liquid which improves the single phase flow. The fluid flow improvement can also be achieved by injecting the same fluid upstream.

6) *Suction:*

This process involves the removal of vapour, in nucleate boiling or film boiling process. This process is also used during the withdrawal of the fluid from a heated porous surface. Suction is used only for single phase fluids..

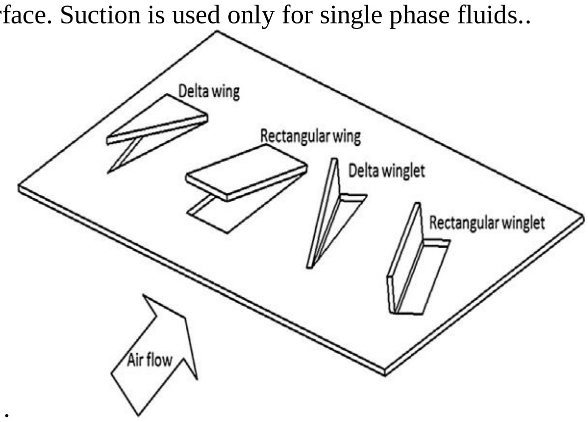

Fig. 1.3: Four basic vortex generator forms [4]

B. *Governing equations:*

Equation of continuity,

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0$$

Equation for momentum,

$$\frac{\partial}{\partial x_i}(\rho u_i u_k) = -\frac{\partial P}{\partial x_k} + \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_k}{\partial x_i}\right)\right]$$

Equation for energy,

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial T}{\partial x_j}\right)$$

In the present study, the parameters considered are, Reynolds number (Re), Nusselt number (Nu), friction factor (f) and thermal enhancement factor (TEF). They are expressed as follows,

Equation for Reynolds number,

$$Re = (\rho U_c D_h)/\mu$$

Equation for Friction factor,

$$f = ((2\Delta p))/(\rho U_c^2)(D_h/L)$$

Equation for Nusselt number,

$$Nu = (hD_h)/k$$

Thermal enhancement factor,

$$TEF = (Nu/Nu_o)/(f/f_o)^{(1/3)}$$

Where, Uc is average velocity in the cross section for minimum flow in the flow channel, μ is viscosity, k is thermal conductivity, Dh is hydraulic diameter, Δp is pressure drop in the computation domain, L is length of fin in the flow direction, H is channel height, Nu is the area-average Nusselt number, Nuo is average Nusselt number of plain fin.

III. FIGURES

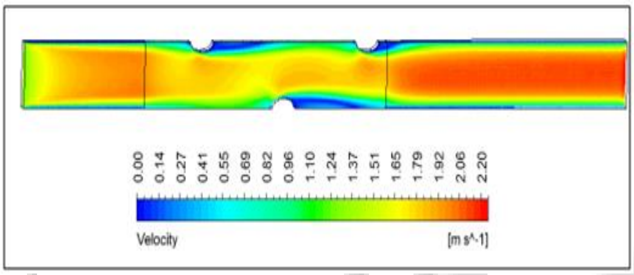

Fig. 3.1: Velocity distribution in flow direction

Figure 3.1 shows velocity distribution along flow direction and shows that velocity is increased continuously from inlet to outlet due to boundary layer formation. At inlet, velocity is increased continuously till the flow interacts with oval tubes. Towards outlet of the flow, boundary is thickened and it is caused for further increase at outlet. On rear side of oval tubes velocity is almost zero due to flow separation and it is formed as wake and flow becomes circulated and it is continued to certain distance .This phenomena can be seen on all oval tubes.

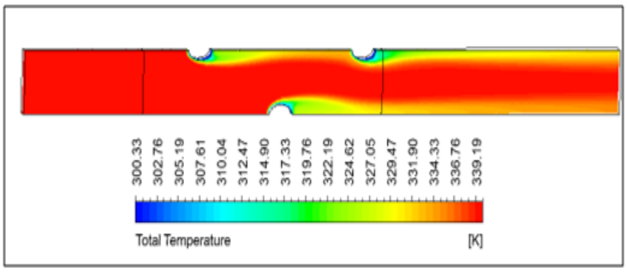

Fig. 3.2: Total temperature distribution in flow direction

In Figure 3.2 it is observed that the total temperature of flow remains constant except at oval tubes as wall temperature of the oval tubes is less than the inlet total temperature of flow. Due to heat exchange between the oval tubes and flow, temperature drop taking place in flow and the total temperature towards outlet is decreased continuously. The total temperature at rear side of the oval tubes is less compared to main flow due to continuous interaction of wake flow or stagnation flow with wall of oval tube.

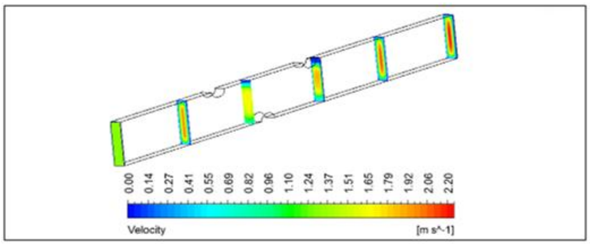

Fig. 5.3: Velocity distribution in transverse plane

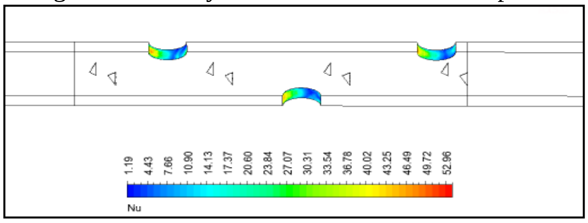

Fig. 3.4: Nusselt Number variation on oval tube

Nusselt number is maximum at leading side of the oval tubes as seen from Figure 5.88, this is due to velocity of flow is high at leading face. Nusselt number towards rear side is less due to low velocity of flow caused by separation of the flow, wake formation and flow gets circulated. Due to turbulence effects, effect of wake is less and Nusselt number is more in this case compared without wing for same Reynolds number. Maximum Nusselt number is approximately 52.96 on leading edge side and minimum Nusselt number is approximately 1.19 on rear side.

IV. CONCLUSION

Analysis is carried out without wings and with wings for pitch ratios 2, 4 and 6. Various charts are drawn to compare Nusselt number, Friction factor, Nusselt number ratio, Friction factor ratio and thermal enhancement factor with Reynolds number to find out the effect of wings on the thermal performance of plate-fin-and-oval-tube heat exchanger**.**

Nusselt number is higher for a configuration with wing pitch ratio 2 and lower for base line case as seen in Figure. Nusselt number is inversely proportional to pitch ratio. Higher the pitch ratio, turbulence mixing is less and lowers the pitch ratio higher the turbulent mixing i.e. higher turbulence mixing causes for increase Nusselt number and heat transfer coefficient.

Friction factor is high for a configuration with wing pitch ratio 2 and lower for base line case. Friction factor is inversely proportional to pitch ratio as shown in Figure. Higher the pitch ratio, turbulence effect is less and lowers the pitch ratio higher the turbulent effect i.e higher turbulence effect causes for increase in friction factor.

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