Heat Transfer Augmentation Techniques in a Plate-Fin Heat Exchanger

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Abstract- After tubular heat exchangers, Plate-fin heat exchangers (PFHEs), are the most common types of heat exchangers in thermal engineering applications. Plate fin heat exchangers, because of their low weight, compactness and high effectiveness are widely used in cryogenic and aerospace applications. This paper focuses on the passive augmentation techniques in the recent past and will be helpful to designers implementing passive augmentation techniques in heat exchange instruments. For the compensation of the poor heat transfer properties, the surface area density of plate heat exchangers can be increased by making use of the secondary fins such as, triangular fins, off-set fins, wavy fins, louvered fins etc. In addition, for the enhancement of heat transfer a promising technique is the use of longitudinal vortex generators. Due to the pressure difference generated between the front and back surface of the vortex generator produces the longitudinal vortices. These longitudinal vortices facilitate the exchange of fluid near the walls with the fluid in the core and hence, the boundary layer get disturbed which causes the increase in temperature gradient at the surface which leads to the augmentation in heat transfer. An innovative design of triangular shaped secondary fins with rectangular or a delta wing vortex generator mounted on their slant surfaces for enhancing the heat transfer rate in plate-fin heat exchanger is proposed.

Keywords – Plate-fin Heat Exchangers, Longitudinal Vortex Generators, Delta Wing Vortex Generator.

I. Introduction

Energy and materials saving considerations, and economic incentives, have led to efforts to produce more efficient heat exchangers, common goals regarding this field are to reduce the size of a heat exchanger for a specified heat duty, to enhance the capacity of an existing heat exchanger, to reduce the approach temperature difference for the process streams, or to reduce the pumping power.

Augmentation techniques can be classified as passive methods and active methods, in passive methods there is no direct application of external power and in active methods external power is needed. The effectiveness of both passive and active types depends strongly on the mode of heat transfer, i.e. from single-phase free convection to dispersed-flow film boiling. Heat exchangers have several engineering and industrial applications. The design procedure of heat exchangers is complicated, as it needs exact analysis of heat transfer rate and pressure drop estimations apart from issues such as economic aspect of the equipment and the long term performance. The major challenge in designing a heat exchanger is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer enhancement are related to several engineering applications. In recent years, the increasing energy cost and material has resulted in an increased effort for producing more efficient heat exchanger. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years and are discussed in the following sections of this paper.

II. PRINCIPLE OF ENHANCEMENT IN HEAT EXCHANGERS

In the compact heat exchangers, the heat transfer rate can be increased by changing the surface geometry of the plates by employing a proper enhancement technique. The principle behind this is as follows. The basic equation for the heat transfer rate for a two fluid heat exchanger is given by

$$q = UA\Delta T_m.$$

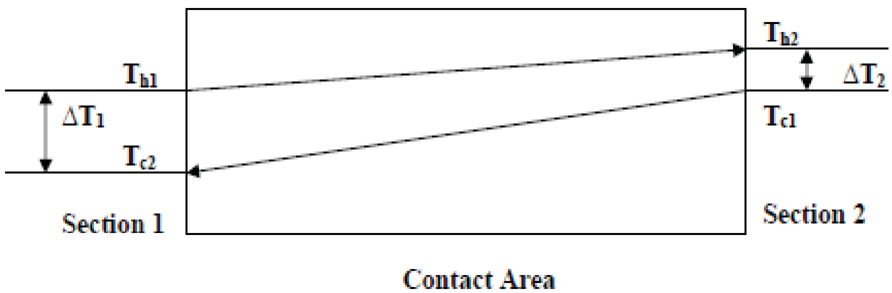

Fig.1: Single phase counter flow heat exchanger

Where U is the overall heat transfer coefficient based on area , q is the rate of heat transfer, A, which is either of the areas Ai or Ao, the tube side and shell side areas respectively and ΔTm is the logarithmic mean temperature difference defined as

$$\Delta T_m = \frac{(\Delta T_2 - \Delta T_1)}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

where ΔT1 = (Th1 – Tc2) and ΔT2 = (Th2 – Tc1) being the temperature differences between the hot and cold fluids at sections (1) and (2) respectively as shown in Fig.1. The overall thermal resistance is given by

$$\frac{1}{UA} = \frac{1}{h_i A_i} + \frac{1}{h_o A_o} + \frac{t}{kA}$$

Where hi and ho are the tube side and shell side convective heat transfer coefficients, Ai and Ao are the corresponding heat transfer areas respectively, k is the thermal conductivity of the wall material, t is the wall thickness, and A is the average of the inner and outer areas of the tube. When the surfaces are enhanced the thermal resistance of the enhanced system is given by

$$\frac{1}{UA} = \frac{1}{(\eta_1 h_i A_i)} + \frac{1}{(\eta_2 h_o A_o)} + \frac{1}{(kA)}$$

where η is the extended surface efficiency. The values of both η1 and η2 are greater than 1.0 leading to a reduction in the overall thermal resistance.

III. AUGMENTATION TECHNIQUES IN A PLATE-FIN HEAT EXCHANGER

Heat transfer augmentation techniques can be classified as passive methods and active methods, passive method is one which require no direct application of external power and active method is one which require the external power. The effectiveness of both types strongly depends on the mode of heat transfer, which might range from single-phase free convection to dispersed-flow film boiling. Some of the passive techniques are:

3.1 Passive Techniques

This method does not need any external power input and the additional power needed to enhance the heat transfer is taken from the available power in the system, which ultimately leads to a fluid pressure drop. Some of the techniques are as follows.

a) *Coated surfaces:* In this method the surface is coated with metallic and non-metallic coating. These are used to enhance the heat transfer in single phase convection or boiling and condensation. Non wetting coating such as Teflon is used to promote drop wise condensation.

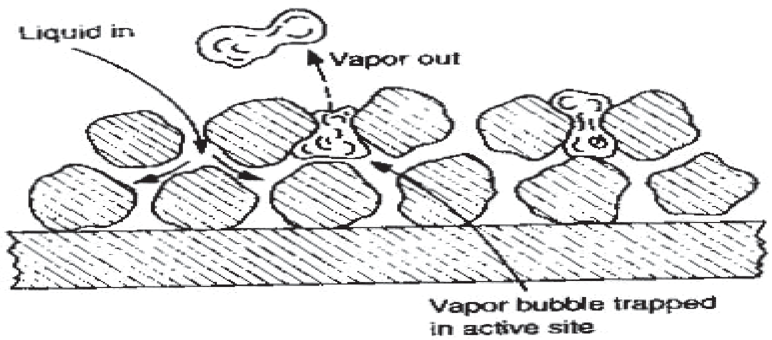

Fig.2: Porous metal coating

b) *Rough Surfaces:* These are either integral surface formed by machining to the base surfaces or these are made by placing a rough surface. The roughness of sand grain type to discrete protuberance configuration is chosen such that it promotes the mixing in boundary layer near the surface rather than to increase the heat surface area.

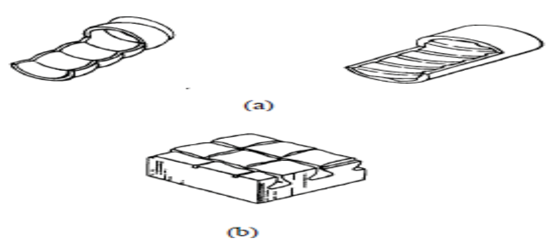

Fig.3: (a) Tube side roughness (b) Rough surface for nucleate boiling

c) **Extended Surfaces:** The extended surfaces i.e. fins are employed in many heat exchangers. The extended surfaces employed on the gas side produces a higher heat transfer coefficients than a plane fin.
d) **Displaced Enhancement Devices:** These devices or some geometries are inserted into the flow channel which alters the flow or create turbulence and indirectly improve the energy transport at the heated surface..
e) **Swirl Flow Devices:** These devices are inserted into the forced flow that creates rotary flow or secondary flow. The swirl flow devices are tube inserts for forced flow, inlet vortex generators, coiled tubes, twisted tape insert, and axial-core inserts with a screw type winding.
f) **Surface Tension Devices:** These consist of grooved or wicking surfaces to direct the flow of liquid in boiling or condensing.
g) **Additives for Liquids:** These are solid particles and gas bubbles in single-phase flows and liquid trace additives for boiling systems used for heat transfer enhancement.

IV. HEAT TRANSFER ENHANCEMENT USING VORTEX GENERATOR

A different method of enhancing the heat transfer rate is by using a longitudinal vortex generator. These vortex generators are in the form of wings or winglets. These vortex generators are of triangular or rectangular shapes which can be welded or punched and bend out of the plate so that they project into the flow with an angle of attack to the main flow direction. If the chord length is attached to the plate then it is called a winglet and if the trailing edge is attached to the plate it is termed as a wing.

The different geometries of the vortex generators are shown in Fig.4 These vortex generators induce longitudinal stream wise vortices in the flow field create disturbance. The vortices developed along the edge of the vortex generator due to the pressure difference between the front surface facing the flow and the back surface. These vortices are called longitudinal vortices because their axes of rotation are aligned to the direction of main flow.

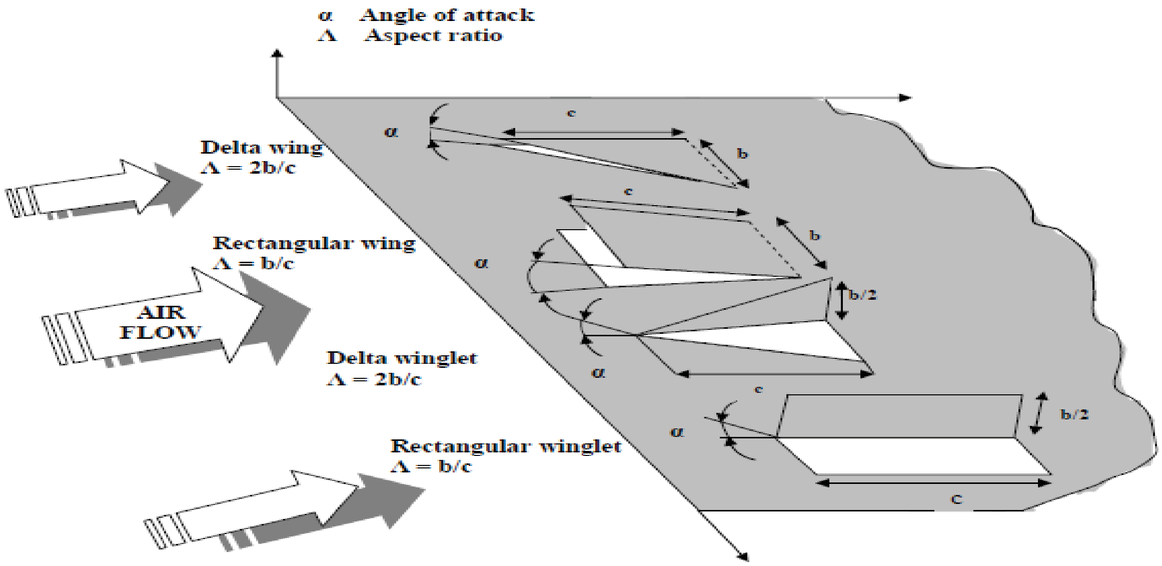

Fig.4. Longitudinal Vortex generators

These stream wise vortices interact with an otherwise two-dimensional boundary layer and produce a three dimensional swirling flow that mixes near-wall fluid with the free stream. This mechanism strongly enhances the exchange of fluid between the wall and the core region of the flow field, which causes high heat transfer augmentation.

V. CONCLUSION

This paper has considered different methods which can be used to enhance the heat transfer in a Plate fin heat exchanger specially the rectangular winglet pairs (RWPs) is one promising heat transfer enhancement technique

- The RWPs generated vortices can enhance the thermal mixing of the fluid, which delay the boundary layer separation, and hence reduce the size of tube wake.
- The longitudinal vortices generated by RWPs rearrange the temperature distribution and the flow field, and as a result significantly enhance the heat transfer performance of the plate-fin heat exchanger.
- Due to the “common-flow-up” orientation of the RWPs, a constricted nozzle-like passage is created between the RWPs and the region of the plate and hence the fluid is accelerated in that region.
- The accelerated flow cannot only further delay the boundary layer separation and reduce the tube wake, but also impinge directly on the downstream tube, which resulting insignificant augmentation of local heat transfer.

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