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HEAT TRANSFER AUGMENTATION BY PLATE FIN HEAT EXCHANGER USING CFD TECHNIQUES "A REVIEW"

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ABSTRACT

Counter rotating longitudinal vortices produced by winglet in a triangular plate-fin heat exchanger. In the present investigation and heat transfer by a winglet of zero thickness has been studied. A Delta winglet type vortex generator I placed in a hydrodynamically and thermally developing laminar channel flow. In this analyzing of flow structure is used to investigate the heat transfer and pressure drop in laminar flow through a triangular plate-fin heat exchanger, with the intension of determining the effect of winglet location.

In this case temperature of the walls kept constant, air is used as the working fluid. In order to compensate for the poor heat transfer properties of gases, the surface area density of plate heat exchangers can be increased by making use of the secondary fins such as, off-set fins, triangular fins, wavy fins, louvered fins etc. 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. The plate fin heat exchangers are mostly used for the nitrogen liquefiers, so they need to be highly efficient because no liquid nitrogen is produced, if the effectiveness of heat exchanger is less than 87%.

A plate-fin heat exchanger with triangular fins is studied using FLUENT as the CFD tool.

Keywords: CFD, delta winglet, Heat transfer, Plate fin heat exchanger, Triangular fin

I. INTRODUCTION

A. Plate fin heat exchanger

Plate fin heat exchangers are widely used in automobile, aerospace, cryogenic and chemical industries. They are characterized by high effectiveness, compactness (high surface area density), low weight and moderate cost. Although these exchangers have been extensively used around the world for several decades, the technologies related to their design and manufacture remain confined to a few companies in developed countries. Recently efforts are being made in India towards the development of small plate fin heat exchangers for cryogenic and aerospace applications. This thesis constitutes a part of this overall effort. Its focus, however, is on the basic heat transfer and flow friction phenomena applicable to all plate fin heat Exchangers, and not confined to the Indian development programme.

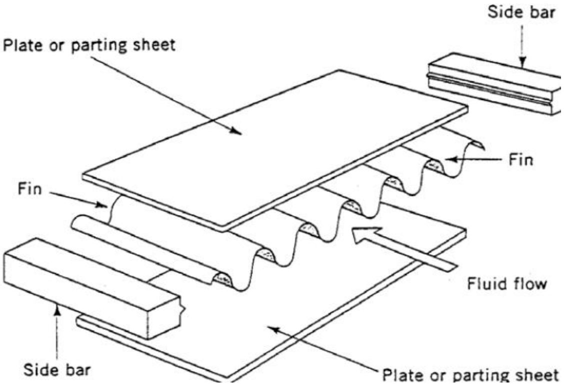

Fig. 1 Plate fin heat exchanger assembly and details Side

Plate fins are categorized as (1) plain (i.e., uncut) and straight fins, such as plain triangular and rectangular fins, (2) plain but wavy fins (wavy in the main fluid flow direction), and (3) interrupted fins, such as offset strip, louver, perforated, and pin fins.

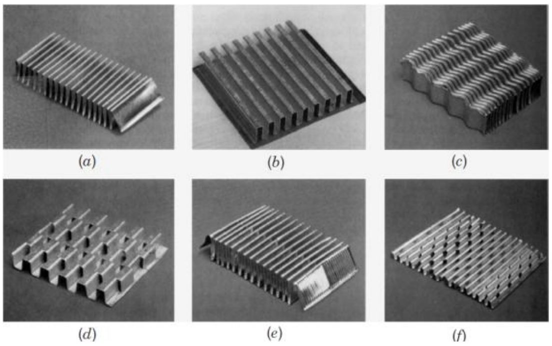

Fig. 2 Nine corrugated fin geometries for plate-fin heat exchangers: (a) plain triangular fin; (b) plain rectangular fin; (c) wavy fin; (d) offset strip fin; (e) multilouver fin; (f) perforated fin. Tubesheets. These are used to hold tubes at the ends. A tubesheet is generally a round metal plate with holes drilled through for the desired tube pattern, holes for the tie rods (which are used to space and hold plate baffles), grooves for the gaskets, and bolt holes for flanging to the shell and channel

B. Merits and Drawbacks

Plate fin heat exchangers offer several advantages over competing designs.

- (High thermal effectiveness and close temperature approach. (Temperature approach as low as 3K between single phase fluid streams and 1K between boiling and condensing fluids is fairly common.),
- (Large heat transfer surface area per unit volume (Typically 1000 m^2/m^3),
- (Low weight,
- (Multi-stream operation (Up to ten process streams can exchange heat in a single heat exchanger.), and
- (True counter-flow operation (Unlike the shell and tube heat exchanger, where the shell side flow is usually a mixture of cross and counter flow.).

The principal disadvantages of the plate fin geometry are:

- (Limited range of temperature and pressure
- (Difficulty in cleaning of passages, which limits its application to clean and relatively non-corrosive fluids, and
- Difficulty of repair in case of failure or leakage between passages.

C. Materials

Plate fin heat exchangers can be made in a variety of materials. Aluminum is preferred in cryogenic and aerospace applications because of its low density, high thermal conductivity and high strength at low temperature. The maximum design pressure for brazed aluminium plate fin heat exchangers is around 90 bar. At temperatures above ambient, most aluminium alloys lose mechanical strength. Stainless steels, nickel and copper alloys have been used at temperatures up to 500 ^{0}C

D. Manufacture

The basic principles of plate fin heat exchanger manufacture are the same for all sizes and all materials. The corrugations, side-bars, parting sheets and cap sheets are held together in a jig under a predefined load, placed in a furnace and brazed to form the plate fin heat exchanger block. The header tanks and nozzles are then welded to the block, taking care that the brazed joints remain intact during the welding process. Differences arise in the manner in which the brazing process is carried out. The methods in common use are salt bath brazing and vacuum brazing. In the salt bath process, the stacked assembly is preheated in a furnace to about 550 ^{0}C, and then dipped into a bath of fused salt composed mainly of fluorides or chlorides of alkali metals. Brazing takes place in the bath when the temperature is raised above the melting point of the brazing alloy.

E. Applications

Plate-fin exchangers have found application in a wide variety of industries. Among them are air separation (production of oxygen, nitrogen and argon by low temperature distillation of air), petro-chemical and syn-gas production, helium and hydrogen liquefiers, oil and gas processing, automobile radiators and air conditioners, and environment control and secondary power systems of aircrafts. These applications cover a wide variety of heat exchange scenarios, such as:

1) Exchange of heat between gases, liquids or both,

2) Condensation, including partial and reflux condensation,

3) Boiling,

4) Sublimation, and

5) heat or cold store.

F. Mechanisms of Augmentation of Heat Transfer.

To the best knowledge of the authors, the mechanisms of heat transfer enhancement can be at least one of the following.

1) Use of a secondary heat transfer surface.

2) Disruption of the unenhanced fluid velocity.

3) Disruption of the laminar sublayer in the turbulent boundary layer.

4) Introducing secondary flows.

5) Promoting boundary-layer separation.

6) Promoting flow attachment/reattachment.

7) Enhancing effective thermal conductivity of the fluid under static conditions.

8) Enhancing effective thermal conductivity of the fluid under dynamic conditions.

9) Delaying the boundary layer development.

10) Thermal dispersion.

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11) Increasing the order of the fluid molecules.

12) Redistribution of the flow.

13) Modification of radiative property of the convective medium.

14) Increasing the difference between the surface and fluid temperatures.

15) Increasing fluid flow rate passively.

16) Increasing the thermal conductivity of the solid phase using special nanotechnology fabrications.

II. PROBLEM FORMULATION

The velocity at constant Reynolds number inside the domain of interest needs to be computed first. From this, the analysis in heat transfer with the vortex generator and winglet position are to be studied. The heat transfer rate in computation is performed on a three-dimensional channel which is formed by a fin of a plate-fin compact heat exchanger. A portion of a compact cross-flow heat exchanger having plain triangular fins is shown in fig. 1. The passage formed by the surfaces of the triangular fin and that of the plate of the plate-fin heat exchanger can be considered as a triangular channel. The primary objective is to compute the flow structure and temperature distribution of the fluid flowing in this channel in the presence of a vortex generator

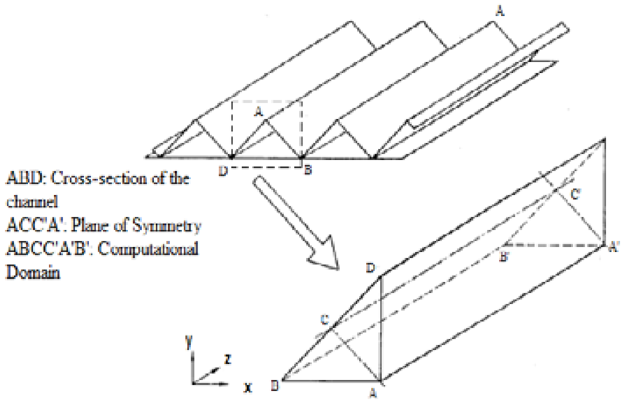


Fig. 3 (a): Triangular Channel (After Rotation),

(b). Triangular Channel With a Mounted Delta Winglet

III. GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

Continuity equation

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \qquad \text{....(1)}$$

Momentum equation

$$\frac{\partial(\rho u_i T_k)}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\mu \frac{\rho u_k}{p x_i}\right) - \frac{\rho p}{\rho x_k} \qquad \text{....(2)}$$

Energy equation:

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{\lambda}{C_p}\frac{\partial T}{\partial x_i}\right) \qquad \text{.... (3)}$$

Because the governing equation are elliptic in special coordinates the boundary condition are required for all boundaries of the computational domain.

Boundary Conditions at inlet:-

There is direction of the flow at the inlet is axial. Therefore, the components of velocity at inlet are given as:

U=0.176, V=0, W=0, P=0 and T_{in} =300k

The wall of the channel has no slip surfaces, hence

U=0, V=0, W=0, P=0 and T= =400k

Boundary Condition at the channel outlet:-

The Pressure at the channel outlet is assumed to be atmospheric,

Hence

$P_{outlet} = P_{atm.} = 0$

Boundary Condition at the extended surface

The extended surface is also treated as a wall, hence no slip Surface

$$\frac{\partial u}{\partial y} = \frac{\partial w}{\partial y} = \frac{\partial T}{\partial y} = 0 \quad \text{.... (4)}$$

v = 0

Parametric study

In order to present the analyzing the results, the following parameters are defined:

$$R_e = \frac{\rho V D}{\mu} \quad \text{.... (5)}$$

Where Re is the Reynolds number, ρ is the density, v is the mean velocity of the channel, D is the hydrodynamic diameter and μ is the viscosity.

$$N_u = \frac{q_w \cdot d_n}{k(T_w - T_b)} \quad \text{.... (6)}$$

Where Nu is the Nusselt number, q_w is the total heat flux, dh is the hydrodynamic diameter (16.57mm) and k is the thermal conductivity, t_w is the wall temperature and tb is the bulk temperature.

IV. GEOMETRY

Computational Fluid Dynamics (CFD) is the systematic application of computing systems and computational solution techniques to mathematical models formulated to describe and simulate fluid dynamic phenomena. For geometry creation and mesh generation and FLUENT 5/6 as the solver and GAMBIT as the Preprocessor. The analysis predicted the heat transfer coefficient and pressure drop along with the velocity and temperature distribution in the channel.

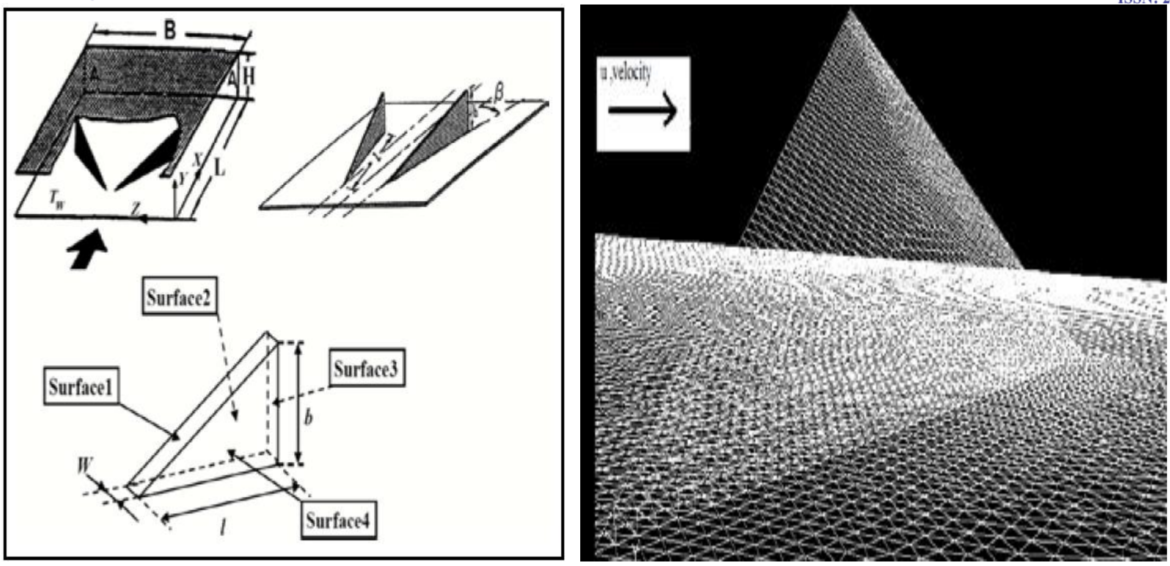
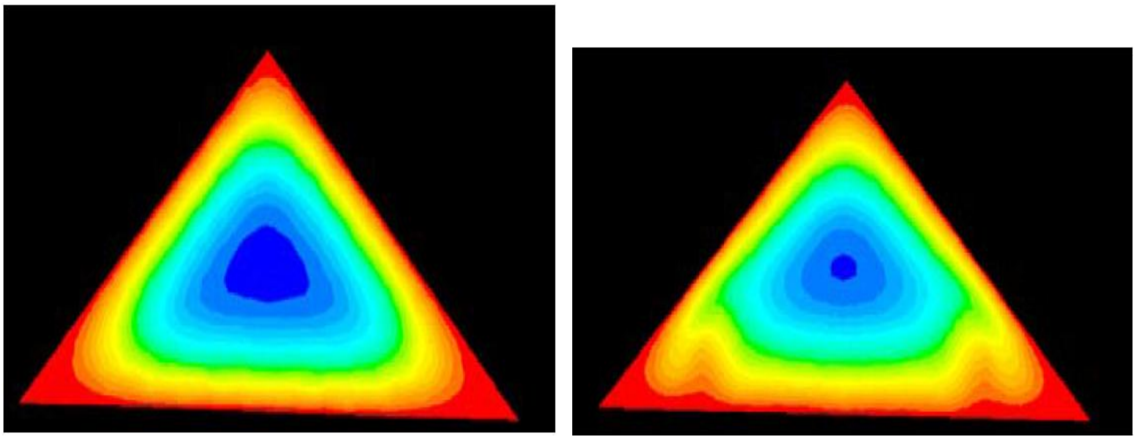


Fig. 4 Common-Flow-Up

V. HEAT TRANSFER CHARACTERISTICS

This section deals with the heat transfer characteristics for the flow through a triangular channel with built-in delta winglet. Subsequently the conclusions are drawn about the effect of winglet on heat transfer. The result and graphs are computed at Re =200, Pr =0.7. Temperature contours at various cross-sections along the main flow direction for the different plane on the channel at Re = 200 are shown in Fig.3.4. It can be seen that the mean temperature of the working fluid increases with the distance from the entrance as expected, as shown in Fig. 3.4. Also expected, the increase is rapid nearer the entrance because of high heat transfer rates in this region due to higher temperature differences between the wall surface and the fluid.



(a) (b)

Fig. 5 Temperature Contours at Different Cross Planes in the Presence of Built-in Winglet at Non-Dimensional Length (a) X/H=1.75 (b) X/H=2.6 Along the Main Flow Direction for Re = 200

Variation in Nusselt number at various cross-sections along the main flow direction for the different angle of attack at Re = 200 are shown in fig. 8. It is evident that the Nusselt number is maximum for an angle of attack of 45º. Apparently the Nusselt number may be interpreted as

$$N_u = q_w * {}^{dh}/_{k}(t_w - t_b) \quad \ldots.(8)$$

VI. CONCLUSION

In plate-triangular fin heat exchanger the use of delta winglet provide additional heat transfer enhancement on the extended surface. The potential of heat transfer and fluid flow characteristics at different location of the winglet at fixed angle of attack i.e.45º is also evaluated. The Nusselt number becomes higher at a non-dimensional length X/H=1.9 from inlet.

• The triangular winglet mounted on the triangular fins of plate fin heat exchanger disturbs the flow structure and creates longitudinal vortices. Due to the existence of complex stream wise vortices system in the flow passage, the heat transfer between the fluid and its neighboring surfaces enhanced with a moderate pressure drop.

CFD simulated temperature result of two different cross-sectional shapes (triangular & rectangular) with different working fluids at different flow rates. Present Study has been accomplished at an angle of attack of 45º for the delta winglet. The common-flow-up configuration arranged for a delta winglet with using of symmetry.

Scope for future work

- How to Heat transfer augment can be carried out.
- The present work can be further extended for plate fin geometries of the inserts (fins) being used between the plates of the heat exchanger.
- Variation of the fins can be increase and study the effect of temperature with help of CFD technologies.

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