

Heat Transfer Enhancement and Fluid Flow across Tube Banks Heat Exchanger with Passive Control Technique by Using Vortex Generator (A Review)

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Abstract: This paper describes the heat transfer enhancement and fluid flow across tube banks heat exchanger by means of vortex generator. One of the most important passive techniques to augment the heat transfer is the use of vortex generators. The vortex generator can be embedded in the plane fin and that too in a low cost with effect the original design and setup of the commonly used heat exchangers. Heat transfer and pressure drop depend on complex flow pattern of fluid in tube banks, whereas pressure drop linked directly with the fluid pumping capacity. Paper focuses to review a various design modifications which are implemented and studied experimentally and numerically by effect the shape of vortex generator, angles of attack, position and Reynolds number on wake size and vortex shedding.

Keywords: tube bank, vortex generator, heat exchanger, passive techniques, heat transfer.

1. Introduction

Heat exchangers have been widely used in many applications such as the fields of refrigeration, air conditioning, space heating, power system and chemical engineering, etc. The main subject to design the compact heat exchanger is how to enhance the heat transfer so that its integral performance may be improved to meet the demand of high efficiency (energy saving) and low cost with the volume as small as possible and the weight as light as possible. Many studies have been carried out and many methods have been applied to the heat transfer enhancement in the compact heat exchanger since 1960s. In compact heat exchanger, when exchanging heat with air, the main thermal resistance is located on the air side of the heat exchanger (can contribute up to 85% of the total heat transfer resistance) [1]. As we know, how to reduce the thermal resistance is the key for the heat transfer enhancement. One frequently used method for heat transfer enhancement employs surfaces that are interrupted periodically along the stream wise direction. Typically, these surfaces are in the form of wavy, louver, slit, or offset strip fins. Despite the fact that interrupted surfaces can significantly improve the heat transfer performance, the associated penalty of pressure drop is also tremendous [2]. Tube bank is the cross flow tubular heat exchanger consists of multiple rows of tubes. One fluid passing through the tubes and other is passing across the tubes as shown in **Figure 1**. Heat Exchanger involve several important design consideration which include thermal performance, pressure drops across the exchanger, fluid flow capacity, physical size and heat transfer requirement. Out of this following consideration, determination of pressure drop in a heat exchanger is essential for many applications because the fluid needs to be pumped through the heat exchanger. The fluid pumping power is proportional to the exchanger pressure drop. In tube banks, the heat transfer and pressure drop characteristic depend upon the flow pattern of fluid. The fluid flow converges as the minimum area occurs between the tubes in transverse row or in a diagonal row

which makes the flow pattern very complex [3].

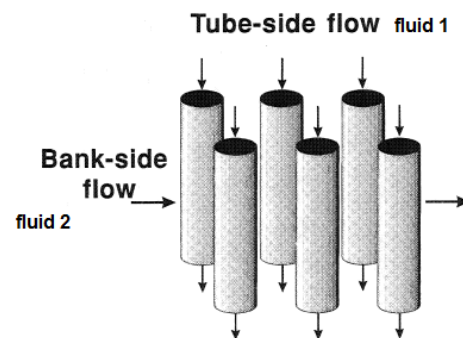


Figure 1: Tube bank heat exchanger

Passive control is one of the flow control techniques to augment the heat transfer is the use of vortex generators. Transverse vortex generators produce vortices, whose axis is transverse to the main flow direction, whereas, the longitudinal vortex generators generate vortices whose axis is parallel to the main flow direction. It has been found that longitudinal vortex generators are more suitable than the transverse vortex generators when the heat transfer augmentation with pressure drop is an important consideration. The longitudinal vortices behind a slender aerodynamic object have been investigated for many years. Longitudinal vortices are found to persist for more than 100 protrusion heights downstream [4].

2. Heat Transfer Enhancement Techniques

There are about 14 enhancement techniques used for the heat exchangers identified by Bergles et al. 1983 [5]. These enhancement techniques can be classified into active and passive techniques. Passive techniques do not require any type of external power for the heat transfer augmentation, whereas, the active techniques need some power externally, such as electric or acoustic fields and surface vibration.

2.1. Active Heat Transfer Enhancement Techniques

In these techniques, external power is used to facilitate the desired flow modification and the concomitant improvement in the rate of heat transfer. Augmentation of heat transfer by this method can be achieved by:

- a) Mechanical Aids
- b) Surface Vibration
- c) Fluid Vibration
- d) Electrostatic Fields
- e) Injection
- f) Jet impingement
- g) Suction

2.2. Passive Heat Transfer Enhancement Techniques

These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. Heat transfer augmentation by these techniques can be achieved by using:

- a) Coating of the Surfaces
- b) Rough surfaces
- c) Extended Surfaces
- d) Displaced inserts
- e) Swirl flow devices
- f) Surface tension devices
- g) Additives for liquids
- h) Additives for gases

3. Vortex Generator and their Applications

Vortex generators are small plates placed in the stream flow of mixed flow, disturbing flow and controlling the growth of boundary layer [6]. The common shapes of vortex generator (winglets) are circular and square. The vortex generator winglets affect both tube and fin, all previous studies were studied the effect of wing and winglet on heat transfer from the fin by generating a vortex due to pressure difference between front surface and back surface, this vortex will mix the hot fluid near the surfaces with cold main flow, this process enhances heat transition from the surfaces [7]. The effect of winglet on tube guides the flow at high momentum in to low heat transfer region [6]. The size, shape and angle of attack of winglet determine the specific characteristics of the Vortices generated in the flow [8]. The advantages of these vortex generators or tabulators (turbulence promoters) are to:

- 1) Improve heat exchange in compact heat exchangers and electronic equipment packages or microelectronic devices in industrial application [9] like the wide use of plate-fin and fin-tube heat exchangers, for example, in dry cooling towers, in chemical industry and in automotive applications [10].
- 2) Enhance heat transfer in channels e.g. parallel plate channel, rectangular, triangular, square ducts, U-Bend of strong curvature applications, and grooved channel [11].
- 3) Increase heat transfer rate inside or outside tubes, for example, gas flow outside the tube and liquid flow inside the tube and the finned tubes situated in vertical channel.

- 4) Enhance the cooling capability of gas-cooled nuclear reactor, for example, finned nuclear fuel.
- 5) Increase internal cooling in the passages of modern gas turbine blades and vanes that must be protected from hot gas streams.
- 6) Improve the aerodynamic performance by using various types of vortex generators, for example, to improve the performance of conical diffusers, or by using thin slender wings to make modern combat airplanes fly at high angles of attack.
- 7) Decrease vortex losses in channels, for example, in channels of power plants, ventilation systems, and in various pipes, owing to the influence of the positive pressure gradient associated with variation in cross section or bending of the channel intense formation of vortices which takes place as a rule due to flow separation. These formations of vortices cause an increase in hydraulic losses and in degree of non uniformity. A new method of decreasing losses is based on division of vortices by transverse baffles or fins positioned on one side [12].
- 8) In aerodynamics, in spite of longitudinal (stream wise) vortices, which lead to an improvement of 80%, also a reduction of 5% behind the investigated grids depends on the wavelength and the intensity of the disturbance [13].

4. Effect of Vortex Generator On Flow and Heat Transfer Behavior a Cross Tube Bank Heat Exchanger

In recent years, the use of vortex generators in channel flow applications has received considerable attention. A lot of experimental as well as theoretical and numerical research has been carried out on the enhancement of heat transfer by using vortex generator were presented. A. Joardarl and A. M. Jacobi [14] experimentally investigated the winglet type vortex generator arrays for air side heat transfer in a full scale wind tunnel. In this study the effect of the 3 vortex generator tube inline array was compared to a single row vortex generator design and the base line configuration. Particular vortex generator configuration called common up flow has been shown effective in delaying the boundary layer separation from the tube. Common up flow configuration for tube wake management is implemented and the use of winglet arrays is explored and compared to leading edge vortex generator with experimental setup as show in Figure 2.

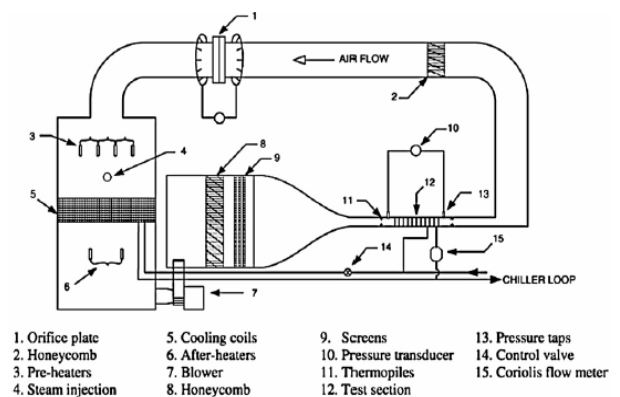


Figure 2: Experimental setup for Joardarl

Y. Chen et al. [15] investigated the effect of punched longitudinal vortex generator in form of winglets staggered

arrangements to enhance the heat transfer in high performance finned oval tube heat exchanger. Winglets in staggered arrangement bring larger heat transfer enhancement than in inline arrangement. K. Torii et al. [16] proposes a novel technique that can augment heat transfer but nevertheless can reduce pressure-loss in a fin-tube heat exchanger with circular tubes in a relatively low Reynolds number flow, by deploying delta winglet-type vortex generators. Following the same arrangement as discussed in many papers above, “common flow up” configuration as well as the “common flow down” configuration is shown with the diagram as shown in Figure 3 (a), (b).

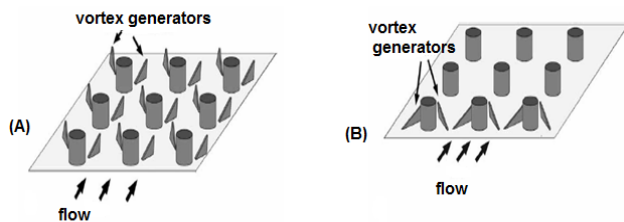


Figure 2: (A), (B) Delta winglet-type

Abdulmajeed A. Ramadhan [2] presented a numerical study of fluid flow and heat transfer over a bank of oval-tubes heat exchanger with vortex generators, his study represented a two-dimensional numerical investigation of forced laminar flow heat transfer over a 3-rows oval-tube bank in staggered arrangement with rectangular longitudinal vortex generators placed behind each tube. The effects of Reynolds number (from 250 to 1500), the positions (3 in x-axis and 2 in y-axis) and angles of attack (30° and 45°) of rectangular vortex generator are examined. His results showed increasing in the heat transfer and skin friction coefficient with the increasing of Re number and decreasing the relative distance of positions of longitudinal vortex generators. It has been observed that the overall Nu average number of three oval-tubes increases by 10–20.4% and by 10.4–27.7% with angles of 30° and 45° respectively, with increasing in the overall average of skin friction coefficient of three oval-tubes reached to 53% and 72% with two angles used respectively, in comparison with the case without vortex generator.

K.Thirumalai kannan, et al [17] studied the numerical study of heat transfer and fluid flow analysis in plate-fin and tube heat exchangers with different shaped vortex generators mounted behind the tubes. The effects of different span angles α ($\alpha = 30^\circ, 45^\circ$ and 60°) are investigated in detail for the Reynolds number ranging from 500 to 2500. His results indicated that the triangle shaped winglet is able to generate longitudinal vortices and improve the heat transfer performance in the wake regions. The case of $\alpha = 45^\circ$ provides the best heat transfer augmentation than rectangle shape winglet generator in case of inline tubes. Common flow up configuration causes significant separation delay, reduces form drag, and removes the zone of poor heat transfer from the near wake of the tubes.

Wisam Abed Kattaa [18] conducted an experimental study on the effect of vortex generators (Circular and square) on the flow and heat transfer at variable locations at ($X = 0.5, 1.5, 2.5$ cm) ahead of a heat exchanger with Reynolds number ranging from $62000 < Re < 125000$ and heat flux from $3000 \leq q \leq 8000$ W/m². His results show that there is an

effect for using vortex generators on heat transfer. Also, heat transfer depends on the shape and location. The circular is found to be the best shape for enhancing heat transfer at location [$X_m=0.5$ cm] distance before heat exchanger is the best location for enhancing heat transfer. The square is the best shape for enhancing heat transfer at location [$X_m=2.5$ cm] distance before heat exchanger is the best location for enhancing heat transfer. The results of flow over heat exchanger with vortex generators are compared with the flow over heat exchanger without vortex generators. Heat transfer around heat exchanger is enhanced (56%, 50%, 36%) at location ($X=0.5, 1.5, 2.5$ cm) respectively by using circular vortex generators without turbulator and heat transfer around heat exchanger is enhanced (39%, 42%, 51%) at location ($X=0.5, 1.5, 2.5$ cm) respectively by using square shape vortex generators without turbulator.

Ahmed Khafeef Obaid Albdoor [19] studied numerically the effect of vortex generator over tube bank heat exchanger with different shapes on heat transfer and fluid flow characteristics. The study was with three different shaped of vortex generators mounted behind the tubes with Reynolds number ranging ($7000 \leq Re \leq 11000$). The effects of three shapes of winglets is looked at (airfoil, rectangle and triangle) with different angles of attack (30° and 45°) has been investigated on average heat transfer (Nu), friction coefficient and pressure drop. His results showed that there is an effect for using winglet pairs on heat transfer, friction coefficient and pressure drop, also, heat transfer depends on the shape, angle of attack of winglet. The triangle is the best shape for enhancing heat transfer and ($\alpha = 45^\circ$) is the best angle of attack for enhancing heat transfer.

Fiebig et al [20] experimentally compared the effect of vortex generators on the heat transfer and flow losses in fin-flat/round tube heat exchangers for the Reynolds number between 600 and 3000. For the staggered fin-tube arrangement, their results showed that the heat exchanger element with round tubes and vortex generators increase heat transfer only 10%, but about 100% for flat tube. They also showed that pressure drop in flat tube bank with vortex generator is nearly half that for the round tube bank with vortex generator.

M. mirzaei el al. [21] numerically studied the augmentation of heat transfer by using vortex generator on flat/round tube heat exchangers. The simulations are performed with the steady three-dimensional incompressible conditions and a RNG K- ϵ turbulence model is used. The Reynolds numbers based on the bulk velocity and the height of channel are selected from 600 to 4050. To compare the effectiveness of vortex generator on the round and flat tubes for tube-fin heat exchangers, two different configurations are investigated with two and four delta winglet vortex generators for each tube. The streamlines, vorticity, the averaged Nusselt number, the friction factor and the performance factor (JF) are provided to evaluate the effectiveness of vortex generator for the heat exchangers employed. It is found that the flat tube with vortex generator provides better thermal performance than the round one, especially at the lower Reynolds numbers.

An analogous numerical study was performed by Brockmeier et al. [22] to evaluate the impact of vortex generation in forced convection between parallel plates. Delta wings and winglets were considered, and the impact of the hole under the wing was included. A delta wing with an aspect ratio of one was considered for attack angles varying from (10° to 50°), while the Reynolds number varied from 1000 to 4000. The computations predicted maximum cross flow velocities in the vortex on the same order as the mean axial velocity. The cross-section of the vortex produced by the delta wing was reported to be elliptical because the turning of the vortex by the wall distorted its cross-section. With the delta winglets at a 30° angle of attack and a Reynolds number of 4000, an average increase in the Nusselt number of 84 percent was predicted.

5. Conclusion

In this paper the effect of vortex generator on heat transfer enhancement in heat exchanger is described and reviewed. A various type of possible and cost effective technique of the heat transfer enhancement by using vortex generator were presented in this review. In this paper it is clear the vortex generator technique is one of the promising approaches of heat transfer enhancement. A Lot of work been carried out on various designs of vortex generator and the effect of shapes, position with tubes, angles of attack and Reynolds number also reviewed.

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