Enhancement of Heat Transfer In Crossed Flow Heat Exchangers With Aid of Oval Tubes And Multiple Delta Winglets

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Abstract- *A three-dimensional study of laminar flow and heat transfer in a channel with built-in oval tube and delta winglets is carried out through the solution of the complete Nervier–Stokes and energy equations using a body-fitted grid and a finite-volume method. The geometrical configuration represents an element of a gas–liquid fin–tube cross-flow heat exchanger. The size of such heat exchangers can be reduced through enhancement of transport coefficients on the air (gas) side, which are usually small compared to the liquid side. In a suggested strategy, oval tubes are used in place of circular tubes, and delta-winglet type vortex generators in various configurations are mounted on the fin-surface. Delta winglets were provided inside the oval tubes to create turbulence in the fluid which is flowing inside the tubes. These winglets acts like obstruction for the fluid and makes the fluid to change its direction and suddenly reduces the velocity over the place. Then a turbulence is created at the place and there will be an improvement in time required for the flow due to this the fluid will have enough time to touch the surface of the winglets. Due to which the fluid will transfer more heat to the winglets enhancing heat transfer.*

By changing the angles of the winglets various results can be obtained. An Evaluation of the strategy is attempted in this investigation. The investigation is carried out for different angles of attack of the winglets to the incoming flow for the case of two winglet pairs. The variation of axial location of the winglets is also considered for one pair of winglets mounted in common-flow-down configuration. The structures of the velocity field and the heat transfer characteristics have been presented. The results indicate that vortex generators in conjunction with the oval tube show definite promise for the improvement of fin–tube heat exchangers.

Keywords: Heat transfer enhancement, oval-tubes, Delta winglets, cross flow heat exchangers.

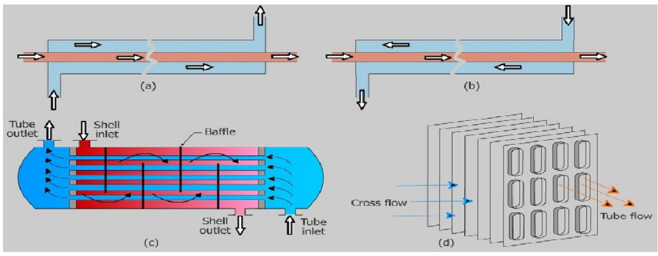
I. INTRODUCTION TO HEAT EXCHANGERS

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multicomponent fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperates. In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids—via thermal energy storage and release through the exchanger surface or matrix are referred to as indirect transfer type, or simply regenerators. Such exchangers usually have fluid leakage from one fluid stream to the other, due to pressure differences and matrix rotation/valve switching. Common examples of heat exchangers are shell-and tube exchangers, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers. If no phase change occurs in any of the fluids in the exchanger, it is sometimes referred to as a sensible heat exchanger. There could be internal thermal energy sources in the exchangers, such as in electric heaters and nuclear fuel elements. Combustion and chemical reaction may take place within the exchanger, such as in boilers, fired heaters, and fluidized-bed exchangers. Mechanical devices may be used in some exchangers such as in scraped surface exchangers, agitated vessels, and stirred tank reactors. Heat transfer in the separating wall of a recuperate generally takes place by conduction. However, in a heat pipe heat exchanger, the heat pipe not only acts as a separating wall, but also facilitates the transfer of heat by condensation, evaporation, and conduction of the working fluid inside the heat pipe. In general, if the fluids are immiscible, the separating wall may be eliminated, and the interface between the fluids replaces a heat transfer surface, as in a direct-contact heat exchanger.

A heat exchanger consists of heat transfer elements such as a core or matrix containing the heat transfer surface, and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals. Usually, there are no moving parts in a heat exchanger; however, there are exceptions, such as a rotary regenerative exchanger (in which the matrix is mechanically driven to rotate at some design speed) or a scraped surface heat exchanger. The heat transfer surface is a surface of the exchanger core that is in direct contact with fluids and through which heat is transferred by conduction. That portion of the surface that is in direct contact with both the hot and cold fluids and transfers heat between them is referred to as the primary or direct surface. To increase the heat transfer area, appendages may be intimately connected to the primary surface to provide an extended, secondary, or indirect surface. These extended surface elements are referred to as fins. Thus, heat is conducted through the fin and convicted (and/or radiated) from the fin (through the surface area) to the surrounding fluid, or vice versa, depending on whether the fin is being cooled or heated. As a result, the addition of fins to the primary surface reduces the thermal resistance on that side and thereby increases the total heat transfer from the surface for the same temperature difference. Fins may form flow passages for the individual fluids but do not separate the two (or more) fluids of the exchanger. These secondary surfaces or fins may also be introduced primarily for structural strength purposes or to provide thorough mixing of a highly viscous liquid. Not only are heat exchangers often used in the process, power, petroleum, transportation, air-conditioning, refrigeration, cryogenic, heat recovery, alternative fuel, and manufacturing industries, they also serve as key components of many industrial products available in the marketplace. These exchangers can be classified in many different ways. They are classified according to transfer processes, number of fluids, and heat transfer mechanisms. Conventional heat exchangers are further classified according to construction type and flow arrangements. Another arbitrary classification can be made, based on the heat transfer surface area/volume ratio, into compact and non-compact heat exchangers. This classification is made because the type of equipment, fields of applications, and design techniques generally differ.

II. HEAT EXCHANGER TYPES

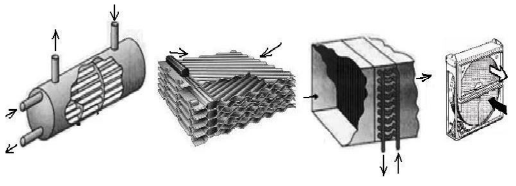
Heat exchangers are typically classified according to flow arrangement and type of construction. In this introductory treatment, we will consider three types that are representative of a wide variety of exchangers used in industrial practice. The simplest heat exchanger is one for which the hot and cold fluids flow in the same or opposite directions in a concentric-tube(or double-pipe) construction. In the parallel-flow arrangement of Figure 1.2a, the hot and cold fluids enter at the same end, flow in the same direction, and leave at the same end. In the counter flow arrangement, Figure 1.2b, the fluids enter at opposite ends, flow in opposite directions, and leave at opposite ends. A common configuration for power plant and large industrial applications is the shell-and-tube heat exchanger, shown in Figure 1.2c. This exchanger has one shell with multiple tubes, but the flow makes one pass through the shell. Baffles are usually installed to increase the convection coefficient of the shell side by inducing turbulence and a cross-flow velocity component. The cross-flow heat exchanger, Figure 1.2d, is constructed with a stack of thin plates bonded to a series of parallel tubes. The plates function as fins to enhance convection heat transfer and to ensure cross-flow over the tubes. Usually it is a gas that flows over the fin surfaces and the tubes, while a liquid flows in the tube. Such exchangers are used for air-conditioner and refrigeration heat rejection applications.



A cross-flow heat exchanger exchanges thermal energy from one airstream to another in an air handling unit (AHU). Unlike a rotary heat exchanger, a cross-flow heat exchanger does not exchange humidity and there is no risk of short-circuiting the airstreams. A cross-flow heat exchanger is used in a cooling and ventilation system that requires heat to be transferred from one airstream to another. A cross-flow heat exchanger is made of thin metal panels, normally aluminum. The thermal energy is exchanged via the panels. A traditional cross-flow heat exchanger has a square cross-section. It has a thermal efficiency of 40–65%. A counter-flow or dual cross-flow heat exchanger can be used if greater thermal efficiencies are required – typically upto75–85%.

In some types of exchanger, humid air may cool down to freezing point, forming ice. A cross-flow is typically less expensive than other types of heat exchanger. It is normally used where hygienic standards require that both airstreams are kept completely separate from one another. It is often used in heat recovery installations in large canteens, hospitals and in the food industry. Unlike a rotary heat exchanger, a cross-flow heat exchanger does not exchange humidity.The basic designs for heat exchangers are the shell-and-tube heat exchanger and the plate heat exchanger, although many other configurations have been developed. According to flow layout, heat exchangers are grouped in:

- Shell-and-tube heat exchanger (STHE), where one flow goes along a bunch of tubes and the other within an outer shell, parallel to the tubes, or in cross-flow (Fig. 1.3a shows a typical example of STHE; details presented below).
- Plate heat exchanger (PHE), where corrugated plates are held in contact and the two fluids flow separately along adjacent channels in the corrugation (Fig. 1.3 b shows details of the interior of a PHE; more details are presented below).
- Open-flow heat exchanger, where one of the flows is not confined within the equipment (or at least, like in Fig. 1.3 c, not specifically piped). They originate from air-cooled tube-banks, and are mainly used for final heat release from a liquid to ambient air, as in the car radiator, but also used in vaporizers and condensers in air-conditioning and refrigeration applications, and in directly-fired home water heaters. When gases flow along both sides, the overall heat-transfer coefficient is very poor, and the best solution is to make use of heat-pipes as intermediate heat-transfer devices between the gas streams; otherwise, finned separating surfaces, or, better, direct contact through a solid recuperator, are used.
- Contact heat exchanger, where the two fluids enter into direct contact (simultaneous heat and mass transfer takes place). Furthermore, the contact can be continuous, i.e. when the two fluids mix together and then separate by gravity forces, as in a cooling tower, or the contact can be alternatively with a third medium, usually solid, as in regenerative heat exchangers (RHE), like the rotating wheel shown in Fig. 1.3 d (the hot gas heats the wheel whereas the cold gas retrieves that energy). When the heat-exchange process between the hot and the cold fluids is delayed significantly, the term 'thermal energy storage' is used instead of RGE. There is always some contamination by entrainment of one fluid by the other, although many times it is irrelevant (as in air-conditioning heat-recuperators), or even intended (as in cooling towers). Notice also that, if the mixed-up fluids do not separate, as in open feed-water heaters or in evaporative coolers, the device is not named heat exchanger but just heater or cooler.



Additionally, heat exchangers may be classified according to the type of fluid used (liquid-to-liquid, liquid-to-gas, gas-to-liquid, gas-to-gas), according to phase changes (vaporizers, condensers), according to relative flow direction (counter-flow, co-flow, cross-flow), according to area density (transfer area per unit volume) or channel size, etc. in terms of the smallest hydraulic diameter of the two flows.

Heat exchangers are used to promote thermal energy flows at intermediate stages in process engineering, or as a final heat release to the environment, ambient air in most cases, which renders non-contact devices as STHE and PHE) rather inefficient and recourse is to be made of contact heat exchangers as the wet cooling towers treated aside. A special case is that of marine engineering, where seawater is plenty available in the environment, greatly alleviating the thermal problem for heat-exchangers, but at a cost in materials compatibility (cupro-nickel or titanium must be used instead of copper or aluminium), since seawater is very corrosive and plenty of microorganisms. In order to mitigate the effects of seawater on heat exchangers, and to minimize hull-pass-troughs, only one central heat exchanger is cooled by seawater (a PHE usually), and all other required heat exchangers use clean fresh-water as an intermediate fluid loop to finally discharge the energy at the seawater exchanger (centralized cooling system); different fluid loop layouts can be used, normally grouping several thermal loads by proximity of location and by temperature level. For the latter, two levels are considered: high-temperature level (HT-circuit), say at >50 ºC like for engine cooling circuits (main engine and auxiliaries), and low-temperature level (LT-circuit), say at <50 ºC like for engine-oil-lubrication cooling, air-conditioners and refrigerators, electronic equipment, and so on; instead connecting the HT-circuit to the LT-circuit by means of a heat exchanger, it is better to use a partial mixing of the streams (regulated by a thermostatic valve).

III. LITERATURE REVIEW

For well over a century, efforts have been made to produce more efficient heat exchangers by employing various methods of heat transfer enhancement. The study of enhanced heat transfer has gained serious momentum during recent years, however, due to increased demands by industry for heat exchange equipment that is less expensive to build and operate than standard heat exchange devices. Savings in materials and energy use also provide strong motivation for the development of improved methods of enhancement. When designing cooling systems for automobiles and spacecraft, it is imperative that the heat exchangers are especially compact and lightweight. Also, enhancement devices are necessary for the high heat duty exchangers found in power plants (i.e. air-cooled condensers, nuclear fuel rods). These applications, as well as numerous others, have led to the development of various enhanced heat transfer surfaces. In general, enhanced heat transfer surfaces can be used for three purposes:

1) To make heat exchangers more compact in order to reduce their overall volume, and possibly their cost
2) To reduce the pumping power required for a given heat transfer process
3) To increase the overall UA value of the heat exchanger.

A higher UA value can be exploited in either of two ways:
1) To obtain an increased heat exchange rate for fixed fluid inlet temperatures, or
2) To reduce the mean temperature difference for the heat exchange; this increases the thermodynamic process efficiency, which can result in a saving of operating costs.

Enhancement techniques can be separated into two categories: passive and active. Passive methods require no direct application of external power. Instead, passive techniques employ special surface geometries or fluid additives which cause heat transfer enhancement. On the other hand, active schemes such as electromagnetic fields and surface vibration do require external power for operation.

The majority of commercially interesting enhancement techniques are passive ones. Active techniques have attracted little commercial interest because of the costs involved, and the problems that are associated with vibration or acoustic noise. This paper deals only with gas-side heat transfer enhancement using special surface geometries. Special surface geometries provide enhancement by establishing a higher hA per unit base surface area. Clearly, there are three basic ways of accomplishing this:

1. Increase the effective heat transfer surface area (A) per unit volume without appreciably changing the heat transfer coefficient (h). Plain fin surfaces enhance heat transfer in this manner.
2. Increase h without appreciably changing A. This is accomplished by using a special channel shape, such as a wavy or corrugated channel, which provides mixing due to secondary flows and boundary-layer separation within the channel. Vortex generators also increase h without a significant area increase by creating longitudinally spiraling vortices exchange fluid between the wall and core regions of the flow, resulting in increased heat transfer.
3. Increase both h and A. Interrupted fins (i. e. offset strip and louvered fins) actin this way. These surfaces increase the effective surface area, and enhance heat transfer through repeated growth and destruction of the boundary layers.

The performance of fin-and-tube heat exchangers are related to geometric parameters. Early experiment results achieved by Rich (1973). Lu et al. (2011) illustrated the effects of geometric parameters such as fin pitch, tube pitch, fin thickness and tube diameter in detail. The optimum value for Q/ΔP was found by numerical simulation. Tang et al. (2009) analysed the air-side heat transfer and friction characteristics of 5 types of fins. Besides, in order to enhance performance, different kinds of methods are used in finned tube heat exchangers. The effects of the attack angle of delta winglet pair were achieved by Wu et al. (2012) with numerical and experimental methods. It was turned out that the average Nusselt Number of winglets with attack angle of 60° was higher than that of winglets with attack angle of 45° by experiment and computational method. He et al. (2012) used winglet type of vortex generators to enhance air-side heat transfer performance. Another method was carried out by Tao et al. (2007) who used triangular wavy fins to make the performance better. It can be seen that vortex generators and wave fins are always made to enhance the heat transfer on the air-side. The hydrophobic prosperities are very important for chemistry applications. Wang et.al (2002) describes the air-side heat transfer performance of a hydrophilic coating on plain-fin surface. To enhance performance, different kinds of methods are used in finned tube heat exchangers.

As is known to all, oval tubes have better performance than that of cylinder ones (Schulenb,1966). An experiment study was performed to compare the performance between cylinder tube and oval tube by James E.O (2004). The heat transfer and pressure drop characteristics of plate fin-and-oval-tube heat exchanger were analyzed numerically by Erek et al (2005). A three-dimensional numerical study of oval tube and the winglet pairs which can improve the heat transfer significantly was analyzed by Tiwalri et al (2003). The results indicated that the contribution of winglets pairs in heat transfer was more than 43.86 %, undoubtedly. The cooling delta angle on power plant natural draught dry cooling towers was analysed with porous media approach by Wang et al (2011).In general, heat exchangers are not placed horizontally butarranged with an angle to the ground in industrial application. In this paper, the inlet angle characteristics of a fin-and-oval-tube heat exchanger have been studied numerically. Because of the non-orthogonal layout of heat exchanger, we much concern about the thermal characteristics of fin-and-oval-tube heat exchanger with different inlet angles. So, 5 different inlet angles of fin-and-oval-tube heat exchanger unite are analysed by FLUENT in the present study.

The first literature reporting the enhancement of heat transfer of using surface protrusion vortex generators is by Edwards and Alker [1]. They noted a maximum increase in the local Nusselt number of 40%. Russell et al. [2] presented the first study on the air-side heat transfer enhancement using vortex generators for the heat exchanger. The numerical studies by Biswas et al. [3] and Jahromi et al. [4] showed that the heat transfer in the wake region can be enhanced significantly in the presence of winglet type longitudinal vortex generators behind the tubes. Extensive studies have been done on heat transfer characteristics and flow structure for heat exchangers with longitudinal vortex generators (LVGs). In recent years, the application of vortex generators in compact heat exchangers has received more and more attention.

An experimental study was conducted by Torii et al. [5] to obtain heat transfer and pressure loss in a fin-and-tube heat exchanger with in-line or staggered tube banks with delta winglet vort exgenerators of various configurations. The winglets were placed in a special orientation to augment heat transfer and reduce form drag. They showed that in case of staggered tube banks, the heat transfer was augmented by 30–10%, and the corresponding pressure loss was reduced by 55–34% for the Reynolds number ranging from 350 to 2100. Gentry and Jacobi [6] experimentally explored the heat transfer enhancement by delta-wing-generated tip vortices in flat-plate and developing channel flows. They reported that on the complete channel surface the largest spatially averaged heat transfer enhancement was 55% accompanied by a 100% increase in the pressure drop relative to the same channel flow with no delta-wing vortex generator. Leu et al. [7] numerically and experimentallystudied the heat transfer and flow in the plate-fin and tubeheat exchangers with inclined block shape vortex generators mounted behind the tubes. They pointed out that the proposed heat transfer enhancement technique is able to generate longitudinal vortices and to improve the heat transfer performance in the wake regions.

Sommers and Jacobi[8] experimentally investigated the air-side heat transfer enhancement of a refrigerator evaporator using vortex generation. They noted that for air-side Reynolds numbers between 500 and 1300,the air-side thermal resistance was reduced by 35–42% when vortex generation was used.

Pesteeiet al. [9] experimentally studied the effect of winglet location on heat transfer enhancement and pressure drop in fin-tube heat exchangers. They found that the winglet pairs were most effective to enhance the heat transfer coefficients when these were placed in the downstream side.

IV. RESULTS AND DISCUSSIONS

The streamlines in the mid-plane of the channel of the study area for different inlet angle at Re = 7,000. The flow with inlet angle past the oval tube and it can be clearly found out that the wall in the direction of tube arrangement has periodic boundary condition which is plotted in Figure 5. It can be seen that the flow is separated by the oval tubes and clearly exhibits the phenomenon of vortex near the rear of the tube. Meanwhile, the location of stationary point is shifted upward as well as the inlet angle decreases, and the velocity gradient is also hanged in the channel. Such behavior can be attributed to the periodical flow condition in vertical direction which results that the downstream flow is affected by upstream flow. Furthermore, it can be seen that the region of vortex enlarges obviously with the decrease of inlet angle. Besides, the sequence of pictures illustrates that the average flow velocity has been increased because of the enhancement of vortex.

V. CONCLUSIONS

In this paper, a two-row heat exchanger unit model has been established and the inlet angle effects of plain fin-and-oval-tube heat exchanger have been investigated by FLUENT software. Some major conclusions are drawn as follows:

1. With the variation of inlet angle, the streamline has being changed remarkably. The layout of Vortex effected by inlet angle obviously and the hydrodynamics determine the distribution of the local Nusselt number.
2. The Nusselt number increases 16.7 % averagely at most for large Re comparing $\theta=30°$ with $\theta=90°$. Meanwhile, the pressure drop increases about 57.8 % at the same time. Because of the excellent capability of heat transfer, the arrangement of $\theta=30°$ is frequently used for industrial applications as the pressure loss is acceptable.
3. The Nusselt number increases 18.5 % averagely at most for large Re comparing $\theta=25°$ with $\theta=90°$. Meanwhile, the pressure drop increases about 62.9 % at the same time. Because of the excellent capability of heat transfer, the arrangement of $\theta=25°$ is frequently used for industrial applications as the pressure loss is acceptable.
4. Comparing the overall performance of different θ reflected by the ratio of j factor and f factor, the trend shows that 45° have an excellent performance. Meanwhile, the advantages are more obvious with the increase of Re.

A three-dimensional computational study of forced convection heat transfer has been accomplished to determine the flow structure and heat transfer in a rectangular channel with a built-in oval tube and delta winglet type vortex generators in various configurations. The duct was designed to simulate a passage, formed by two neighbouring fins in a fin–tube heat exchanger. The present study reveals that combinations of oval tube and the winglet pairs improve the heat transfer significantly, especially in the dead water zone. The mean span-averaged Nusselt number for the case of four winglet pairs, each two in sequence having a staggered configuration (Inner pair in common-flow-down and outer pair in common-flow-up arrangement) is about 100% higher as compared to no-winglet case at a Reynolds number of 1000. The enhancement in heat transfer, on the basis of finned oval tube as the base line case, is 43.86% for the case of two winglet pairs in staggered mode. A comparison of heat transfer for the cases of one, two and three winglet pairs (all in common-flow-down configuration) Confirms that the addition of each extra winglet pair causes further enhancement of heat transfer. The enhancement of heat transfer is marked even at far downstream locations. The winglets, at their moderate angle of attack, have quite streamlined like behaviour and so, are not expected to contribute much towards pressure losses. On the other hand, the contribution towards enhancement in heat transfer due to the winglet pairs is undoubtedly significant.

SCOPE FOR THE FUTURE

With the growing technology and demand for the heat transfer equipments this would be a fortune effect for the enhancement of heat transfer in the field of thermodynamics. This will be a beginning for the development of new materials for obtaining higher efficiencies in all the fields of science which are related to the transfer of energy. It is proved from the above project that the heat transfer enhancement is not only specified for some fields it also differentiates so many problems in the field of heat transfer

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