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A Critical Review on Enhancement of Heat Transfer in Compact Heat Exchangers

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Abstract: This paper features a broad discussion on the enhancement of heat transfer through heat exchangers. The use of Process Integration in heat transfer enhancement has many benefits. First, enhanced heat exchangers require less heat transfer area for a given heat duty because of higher heat transfer coefficients. Second, the heat transfer capacity for the given heat exchanger can be increased without changing physical size of the exchanger. This paper provides some methods for increasing shell and tube and compact exchanger's performance. The methods consider whether the exchanger is performing correctly to begin with, excess pressure drop capacity in existing exchangers, there-evaluation of fouling factors, and the use of augmented surfaces, and enhanced heat transfer. Also the Nano fluids possess immense potential to improve heat transfer and energy efficiency in heat exchangers. Finally, the following enhancements in geometries are discussed: tube inserts, tube deformation, baffles, finning.

Keywords: Compact heat exchanger, Enhancements in heat exchanger, Nano fluid, Shell and tube heat exchanger.

INTRODUCTION

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. In heat exchangers, there are usually no external heat and work interactions. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air conditioning system in household, to chemical processing and power production in large plants. Heat exchangers differ from mixing chambers in that they do not allow the two fluids involved to mix. Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. In the Analysis of a heat exchanger, it is convenient to work with an overall Heat transfer co-efficient U, that accounts for the contribution of all these effects on heat transfer [6].

Shell and Tube Heat Exchangers

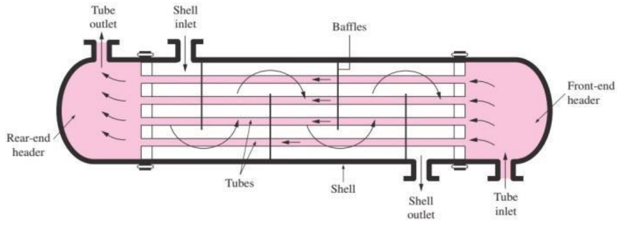

Fig.1: The schematic of a shell and tube heat exchanger[6]

Shell-and-tube heat exchangers contain a large number of tubes (sometimes several hundred) packed in a shell with their axes parallel to that of the shell. Increasing heat exchanger performance usually means transferring more duty or operating the exchanger at a closer temperature approach. This can be accomplished without a dramatic increase in surface area. This constraint directly translates to increasing the overall heat transfer coefficient, U. The overall heat transfer coefficient is related to the surface area, A, duty, and driving force, ΔT. This equation is found in nearly all heat exchanger design.

$$Q = UA\delta T$$

U is a function of the heat transfer film coefficients, h, the metal thermal conductivity, k, and any fouling considerations, f. Anex changer usually operates correctly if the value of U available exceeds the U required. The precise calculation of U from the transport relationships accounts for all of the resistances to heat transfer. These resistances include the film coefficients, the metal thermal conductivity, and fouling considerations. The calculation of U is based upon an area. For shell-and-tube exchangers, the area is usually the outside surface of the tubes [1].

$$U = f(h, k, f, A)$$

Compact Heat Exchanger

The ratio of the heat transfer surface area of a heat exchanger to its volume is called the area density β. A heat exchanger with $\beta = 700\ m^2/m^3$ (or 200 ft^2/ft^3) is classified as being compact. A compact heat exchanger is generally defined as one which incorporates a heat transfer surface having a high "area density". In other words, it possesses a high ratio of heat transfer surface area to volume. This does not necessarily mean that a compact heat exchanger is of small mass or volume. However, if compact heat exchangers did not incorporate a surface of such high area density, the resulting units would be much more bulky and massive than their compact counterparts [7].Compact surfaces are used to yield a specified heat exchanger performance q/ΔTmean, within acceptable mass and volume constraints, where

$$\frac{q}{\Delta T_{mean}} = U\beta V$$

TiO_2/water Nano-fluid

Nano fluids are a new class of fluids engineered by dispersing nanometer-sized materials (nanoparticles, Nano fibers, nanotubes, nanowires, Nano rods, Nano sheet, or droplets) in base fluids. Common base fluids include water, organic liquids (e.g. ethylene, tri-ethylene-glycols, refrigerants, etc.), oils and lubricants, bio-fluids, and other common liquids. Titanium dioxide (TiO_2) is one of promising materials for heat transfer enhancement purpose due to its excellent chemical and physical stability. In addition, TiO_2 particles are cheap and commercially available. TiO_2 nanoparticles suspended in conventional fluids were extensively utilized in various forms of heat exchangers, including circular tube, a double tube and a shell and tube [8].

LITERATURE REVIEW

A logical analysis to increase the heat exchanger performance is given by the series of steps namely, the first step considers if the exchanger is initially operating correctly. The second step considers increasing pressure drop if available in exchangers with single-phase heat transfer. Increased velocity results in higher heat transfer coefficients, which may be sufficient to improve performance. Next, a critical evaluation of the estimated fouling factors should be considered. Heat exchanger performance can be increased with periodic cleaning and less conservative fouling factors. Finally, for certain conditions, it may be feasible to consider enhanced heat transfer through the use of finned tubes, inserts, twisted tubes, or modified baffles.

Enhanced surfaces

Heat exchanger enhancement can be divided into both passive and active methods. Passive methods include extended surfaces, inserts, coiled or twisted tubes, surface treatments, and additives. Active techniques include surface vibration, electrostatic fields, injection, and suction. Figure 2 shows several different schematics of enhancements to heat exchanger tubes including finning, inserts, and twisting [1].

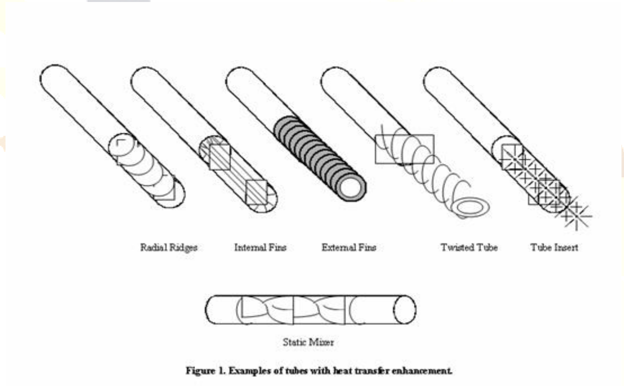

Fig.2: Examples of tubes with heat transfer enhancement [1]

Finning

Tubes can be finned on both the interior and exterior. This is probably the oldest form of heat transfer enhancement. Finning is usually desirable when the fluid has a relatively low heat transfer film coefficient as does a gas. The fin not only increases the film coefficient with added turbulence but also increases the heat transfer surface area. This added performance results in higher pressure drop. However, as with any additional surface area, the fin area must be adjusted by efficiency. This fin efficiency leads to an optimum fin height with respect to heat transfer [10].

Tube Inserts

Inserts, tabulators, or static mixers are inserted into the tube to promote turbulence. These devices are most effective with high viscosity fluids in a laminar flow regime. Increases in the heat transfer film coefficients can be as high as five times. Inserts are used most often with liquid heat transfer and to promote boiling. Inserts are not usually effective for condensing in the tube and almost always increase pressure drop. Because of the complex relationships between the geometry of the insert and the resulting increase in heat transfer and pressure drop, there are no general correlations to predict enhancements. However, through the modification of the number of passes, a resulting heat transfer coefficient gain can be achieved at lower pressure drop in some situations [3].

Tube Deformation

Many vendors have developed proprietary surface configures by deforming the tubes. The resulting deformation appears corrugated, twisted, or spirally fluted. The surface condenses steam on the outside and heats water on the inside. There is a 400 % increase in the inside heat transfer film coefficient; however, pressure drops were 20 times higher relative to the unaltered tube at the same maximum inside diameter.

Recently, researchers describe some of the benefits of a new twisted tube technology including the fact that tube vibration can be minimized. Furthermore the researcher describes how baffles may be eliminated completely. Similar to the tube inserts, these twisted tubes promote turbulence and enhance boiling. Unfortunately, no quantitative results are provided to show the increase in film coefficients for both the shell and tube fluids [5].

Baffles

Baffles are designed to direct the shell side fluid across the tube bundle as efficiently as possible. Forcing the fluid across the tube bundle ultimately results in a pressure loss. The most common type of baffle is the single segmental or cut segmental baffle shown in figure 3 which changes the direction of the shell side fluid to achieve cross flow. Deficiencies of the segmented baffle include the potential for dead spots in the exchanger and excessive tube vibration.

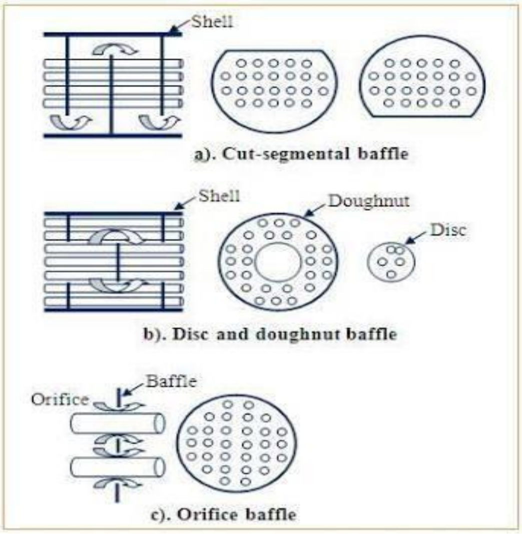

Fig.3: Baffles

Baffle enhancements have attempted to alleviate the problems associated with leakage and dead areas in the conventional segmental baffles. The most notable improvement has resulted in a helical baffle as shown in Figure 4. The researcher further describes how the baffles promote nearly plug flow across the tube bundle.

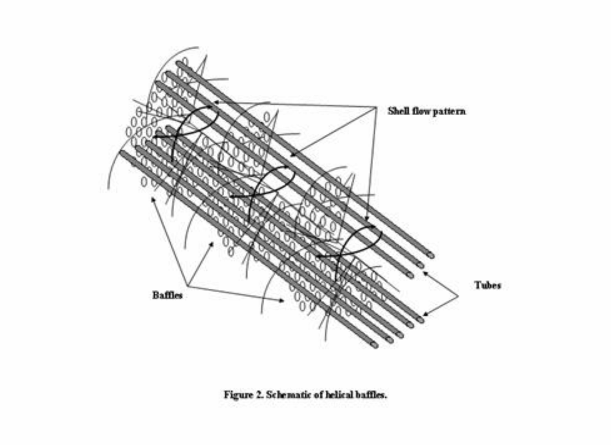

Fig.4: Schematic of helical baffles [11]

The baffles may result in shell reductions of approximately 10-20%.Comparison of exchanger, with and without baffles, shows that baffles have the vital role in heat transfer rate. The results also show that the effect of changing the number of baffles is more important than varying the height of baffles for heat transfer rate inside the shell. Increasing Reynolds number in shell-side causes the increase of heat transfer rate. Reynolds number can be increased by adding the number of baffles more easily and with less cost as compared to increasing the inlet velocity of the fluid [11].

Enhancement of fouling

The performance of heat exchanger usually deteriorates with time as a result of accumulation of deposits on heat transfer surface. The layer of deposits represents additional resistance to heat transfer and causes the rate of a heat transfer in a heat exchanger to decrease. The net effect of this accumulation on a heat transfer by a fouling factor R_f, which is a measure of the thermal resistance introduced by fouling. The most common type of a fouling is precipitation of solid deposits in a liquid on the heat transfer surface. The scale of such deposits comes off by scratching and the surfaces can be cleaned of such deposits by chemical treatment [2].

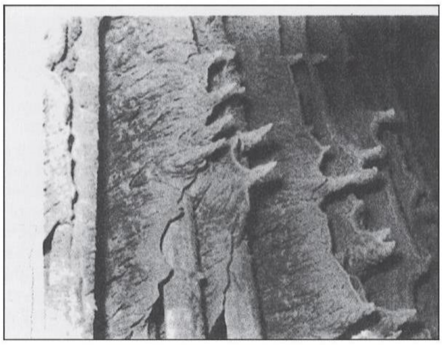

Fig.5: Precipitation fouling of ash particles on. super heater tubes [6]

Augmentation

Whenever inserts technologies are used for the heat transfer enhancement, along with the improvement in the heat transfer rate, the pressure drop also increases, which induces the higher pumping cost. Therefore any augmentation device or methods utilized into the heat exchanger should be optimized between the benefits of heat transfer coefficient and the higher pumping cost owing to the increased frictional losses. The objective of the heat transfer augmentation can be achieved by increasing the surface heat surface coefficient through improving the thermal contact of the heat exchanger fluid with the wall. In general, heat transfer augmentation methods are classified into three broad categories:

(1) Passive method: These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop. These techniques do not require any direct input of external power; rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop.

(2) Active method: These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications.

(3) Compound method: A compound augmentation technique is the one where more than one of the above mentioned techniques is used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger. When any two or more of these techniques are employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by either of them when used individually, is termed as compound enhancement. This technique involves complex design and hence has limited applications [9].

Enhancement using Nano-fluids

Nusselt number increases with increasing TiO2 concentration and all TiO2/water Nano fluids gave higher Nusselt number than water as the based fluid. The higher heat transfer by Nano fluids arises from: (i) the ability of suspended nanoparticles enhancing thermal conductivity; (ii) movement of Nanoparticles delivering energy exchange. The higher volume concentration of nanoparticles would increase thermal conductivity and contact surface, thus increasing heat transfer rate [4].

CONCLUSION

The first step considers if the exchanger is initially operating correctly. The second step considers increasing pressure drop if available in exchangers with single-phase heat transfer. Increased velocity results in higher heat transfer coefficients, which may be sufficient to improve performance. Next, a critical evaluation of the estimated fouling factors should be considered. Heat exchanger performance can be increased with periodic cleaning and less conservative fouling factors. Nano fluids, i.e., well-dispersed metallic nanoparticles at low volume fractions in liquids, enhance the mixture's thermal conductivity over the base-fluid values. Finally, for certain conditions, it may be feasible to consider enhanced heat transfer through the use of finned tubes, inserts, baffles and inculcation of Nano-fluids.

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