Heat Transfer Enhancement Techniques in Plate Heat Exchangers: A Review

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***Abstract*- Mechanical requests for superior heat exchanger devices are expanding quickly step by step to get a generous decrease in vitality utilization. The plate heat exchangers (PHEs) are minimal and effective, generally utilized in numerous applications (heat recuperation, cooling, HVAC, bottling works, dairy, nourishment preparing, seaward oil, pharmaceuticals, substance, mash and paper creation, control age, refrigeration, and so on.) due to their high warm productivity, adaptability and simplicity of sanitation. Plate heat exchangers have been broadly connected in various modern applications since their first business misuse during the 1920s. The corrugated shape patterns examples of the individual plate geometries are one of the numerous appropriate methods to improve the heat transfer in heat exchangers. At the point when liquid streams in a creased channel, the stream progresses toward becoming irritated because of developing distribution locales close the ridged divider, which improves the disturbance coming about to accomplish the most astounding conceivable heat transfer coefficient with least pressure drop. These points of interest make the PHE progressively ecological amicable; notwithstanding, increments of outflow and running expense because of high spillage plausibility, pressure drop are some ecological drawbacks. Gigantic hypothetical and exploratory research takes a shot at warmth move, fouling and liquid stream parts of PHE with different geometries and warmth move liquids for different potential applications have been performed inside most recent couple of decades. This paper presents a review on performance characteristics of a corrugated plate heat exchanger.**

Index Terms- Plate Heat Exchanger, Corrugated Plate, Reynold's number, Nusselt number, Friction factor.

I. INTRODUCTION

Industrial demands for high performance heat exchanger devices are increasing rapidly day by day to get substantial reduction in energy consumption. The developments and the enhancements in all the heat transfer equipment's are mainly purposed for energy savings and savings in projects capital investment, through reducing the costs (energy or material). The better heat exchanger is one that transfer's high heat rate at low pumping power with a minimum cost.

Recently corrugated types of heat exchangers have come into picture. Their advantages include increased heat transfer, reduced servicing costs, compact design and minimal fouling. Because of these advantages, corrugated type heat exchangers are gaining popularity. A lot of research is being done in their design field.

The plate heat exchangers (PHEs) are compact and efficient, widely used in many applications (heat recovery, cooling, HVAC, breweries, dairy, food processing, offshore oil, pharmaceuticals, chemical, pulp and paper production, power generation, refrigeration, etc.) because of their high thermal efficiency, flexibility and ease of sanitation. The corrugated shaped patterns of the individual plate geometries are one of the many suitable techniques to enhance the heat transfer in heat exchangers. When fluid flows in a corrugated channel, the flow becomes disturbed due to growing recirculation regions near the corrugated wall, which enhances the turbulence resulting to achieve the highest possible heat transfer coefficient with minimum pressure drop. These advantages make the PHE more environmental friendly; however, increases of emission and running cost due to high leakage possibility, pressure drop are some environmental disadvantages.

1.1 Heat Exchanger

Heat exchangers are heat transfer devices that exchange thermal energy between two or more mediums. Heat exchangers play a significant role in the operation of many systems such as power plants, nuclear reactors, process industries and heat recovery units. The development of heat exchangers design, reliability and maintainability is always a required matter to enhance the overall systems performance. Broadly there are two types of heat exchangers: Direct contact type heat exchanger and indirect contact type heat exchanger.

The principal types of heat exchanger used in the chemical process and allied industries are listed below:

1. Double-Pipe Exchanger: used For Cooling and Heating.
2. Shell and tube exchangers: used for all applications.
3. Plate and frame exchangers (plate heat exchangers): used for heating and cooling.
4. Plate-fin exchangers.
5. Spiral heat exchangers.
6. Air cooled: coolers and condensers
7. Direct contact: cooling and quenching.
8. Agitated vessels.
9. Fired heaters.

1.2 Plate Heat Exchanger

Plate heat exchangers have been widely applied in numerous industrial applications since their first commercial exploitation in the 1920s.Plate-type heat exchangers are usually built of thin plates (all prime surface). The plates are either smooth or have some form of corrugation, and they are either flat or wound in an exchanger. Generally, these exchangers cannot accommodate very high pressures, temperatures, or pressure and temperature differences. Plate heat exchangers (PHEs) can be classified as gasketed, welded (one or both fluid passages), or brazed, depending on the leak tightness required. Other plate-type exchangers are spiral plate, lamella, and plate coil exchangers.

Plate heat exchangers are used wherever thermal energy (heat) has to be transferred from one fluid to another. The advantage is that they can maintain the fluid temperature at a very low and stable level – depending on the temperature of the coolant. Plate heat exchangers consist of a stack of stamped heat exchange plates which are either brazed together or bolted together in a frame with gaskets. Medium flows in the channels between the plates where hot medium (which will be cooled) alternates with cold medium (which will be heated). The design of the plates induces the turbulent flow required for efficient heat transfer.

PHE usually consists of a number of corrugated or embossed metal plates in mutual contact. Each plate has four apertures serving as inlet and outlet ports, and seals designed to direct the fluids in alternate flow passages. Adjacent plates form the flow passages so that the two streams exchange heat while passing through alternate channels.

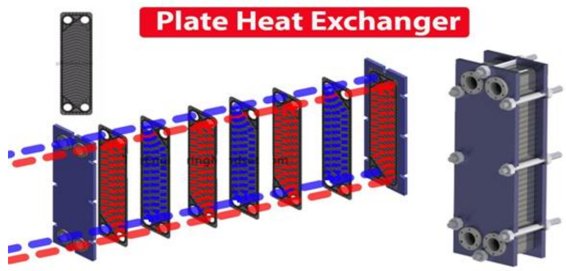

Figure 1: Plate and frame heat exchanger

The plates produce an extremely large surface area, which allows for the fastest possible transfer. Making each chamber thin ensures that the majority of the volume of the liquid contacts the plate, again aiding exchange. The troughs also create and maintain a turbulent flow in the liquid to maximize heat transfer in the exchanger. A high degree of turbulence can be obtained at low flow rates and high heat transfer coefficient can then be achieved.

As compared to shell and tube heat exchangers, the temperature approach in a plate heat exchangers may be as low as 1 °C whereas shell and tube heat exchangers require an approach of 5 °C or more. For the same amount of heat exchanged, the size of the plate heat exchanger is smaller, because of the large heat transfer area afforded by the plates (the large area through which heat can travel). Increase and reduction of the heat transfer area is simple in a plate heat-exchanger, through the addition or removal of plates from the stack.

To achieve improvement in PHE's, two important factors namely amount of heat transfer and pressure drop have to be considered such that amount of heat transfer needs to be increased and pressure drops need to be decreased. In plate heat exchangers due to presence of corrugated plate, there is a significant resistance to flow with high friction loss. Thus to design plate heat exchangers, one should consider both factors. For various range of Reynolds numbers, many correlations and chevron angles for plate heat exchangers exist. The plate geometry is one of the most important factor in heat transfer and pressure drop in plate heat exchangers, however such a feature is not accurately prescribed. In the corrugated plate heat exchangers, because of narrow path between the plates, there is a large pressure capacity and the flow becomes turbulent along the path. Therefore, it requires more pumping power than the other types of heat exchangers. Therefore, higher heat transfer and less pressure drop are targeted. The shape of plate heat exchanger is very important for industrial applications that are affected by pressure drop.

The total rate of heat transfer between the hot and cold fluids passing through a plate heat exchanger may be expressed as: $Q = UA\Delta Tm$ where U is the Overall heat transfer coefficient, A is the total plate area, and ΔTm is the Log mean temperature difference. U is dependent upon the heat transfer coefficients in the hot and cold streams

Enhancing the thermal-hydraulic performance of plate heat exchangers is of crucial importance for the energy conversion as well as for the improvement of the system economy, through savings in the capital investment. The efficiency of a plate heat exchanger can be improved either by optimizing its geometry or using heat transfer enhancement techniques.

The maximum cooling capacity of a plate heat exchanger depends on several factors:

- The inlet temperature of the hot and cold medium.
- The flow rate of the hot and cold medium.
- The media used.

1.3 Plate Fin Heat Exchanger

A plate-fin heat exchanger is a type of heat exchanger design that uses plates and finned chambers to transfer heat between fluids. It is often categorized as a compact heat exchanger to emphasise its relatively high heat transfer surface area to volume ratio. The plate-fin heat exchanger is widely used in many industries, including the aerospace industry for its compact size and lightweight properties, as well as in cryogenics where its ability to facilitate heat transfer with small temperature differences is utilized.

In a plate-fin heat exchanger, the fins are easily able to be rearranged. This allows for the two fluids to result in crossflow, counter flow, cross-counter flow or parallel flow. If the fins are designed well, the plate-fin heat exchanger can work in perfect counter current arrangement.

Plate-fin heat exchangers are generally applied in industries where the fluids have little chances of fouling. The delicate design as well as the thin channels in the plate-fin heat exchanger make cleaning difficult or impossible.

Applications of plate-fin heat exchangers include:

- Natural gas liquefaction
- Cryogenic air separation
- Ammonia production
- Offshore processing

Plate fin heat exchangers offer several advantages over the other types of heat exchanger:

1. Compactness: Large heat transfer surface area per unit volume (typically 1000 m2 /m3), is usually provided by plate fin heat exchangers. Small passage size produces a high overall heat transfer coefficient because of the heat transfer associated with the narrow passages and corrugated surfaces.
2. Effectiveness: Very high thermal effectiveness more than 95% can be obtained.
3. Temperature control: The plate fin heat exchanger can operate with small temperature differences. A close temperature approach (temperature approach as low as 3K) is obtained for a heat exchanger exchanging heat with single phase fluid streams. This is an advantage when high temperatures need be avoided. Local overheating and possibility of stagnant zones can also be reduced by the form of the flow passage.
4. Flexibility: Changes can be made to heat exchanger performance by utilizing a wide range of fluids and conditions that can be modified to adapt to various design specifications. Multi stream operation is possible up to 10 streams.
5. Counter flow: 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) is possible in a plate fin heat exchanger.

The main disadvantages of a plate fin heat exchanger are:

1. The rectangular geometry used puts a limit on operating range of pressure and temperatures

2. Difficulty in cleaning of passages, which limits its application to clean and relatively non-corrosive fluids, and
3. Difficulty of repair in case of failure or leakage between passages.
4. Relatively high pressure drop due to narrow and constricted passages.

1.3.1 Plate Fin Heat Transfer Surfaces

The plate fin exchangers are mainly employed for liquid-to-gas and gas-to-gas applications. Due to the low heat transfer coefficients in gas flows, extended surfaces are commonly employed in plate-fin heat exchangers. By using specially configured extended surfaces, heat transfer coefficients can also be enhanced.

While such special surface geometries provide much higher heat transfer coefficients than plain extended surfaces, but at the same time, the pressure drop penalties are also high, though they may not be severe enough to negate the thermal benefits. A variety of extended surfaces like the plain trapezoidal, plain rectangular shown in Figure 2 can perform such function.

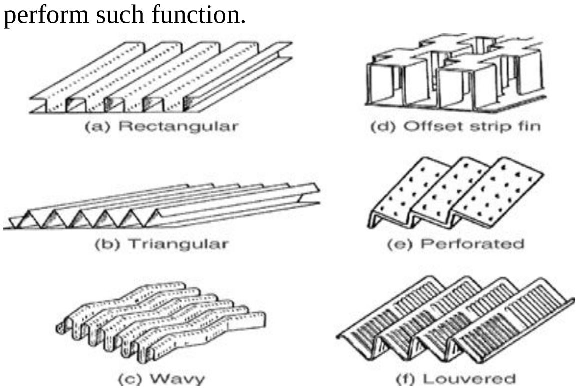

Figure 2 Types of plate fin surfaces.

In order to improve the gas side heat transfer coefficients, surface features are needed to be provided on the gas side. These features may be divided into two categories: the first, in which the surface remains continuous (wavy and herring-bone fins) and the second in which it is cut (offset, louvered). In a continuous type fin, the corrugations cause the gas to make sudden direction changes so that locally the velocity and temperature gradients are increased (Figure 1.4). This results in local enhancement of heat transfer coefficient. But an undesirable consequence of such enhancement in heat transfer coefficient is an increase in the friction factor and pressure drop whereas in a discontinuous type of fin geometry boundary layers are interrupted, otherwise this would have formed on a continuous plate. Adjacent to the leading edge of the fin, both heat transfer coefficient and friction factor are high due to generation of fresh boundary layers. But in addition to this friction drag, form drag is also formed due to the finite thickness of the fin. Although friction drag is associated with high heat transfer coefficient, form drag has no counterpart and represents one form of wasted energy. The form drag can be substantial depending on the quality of the cutting edge. However, machined-formed fins are generally free from this problem.

1.4 Heat Transfer and Flow Characteristics

The heat transfer and flow friction characteristics of a heat exchanger surfaces are commonly expressed in non-dimensional form and are simply referred to as the basic characteristic or basic data of the surface. Various correlations are available in literatures which express the Colburn factor, j and friction factor, f as functions of Reynolds number and other geometrical properties. The Colburn and friction factors are defined by the relations:

$$j = \frac{h(Pr)^{\frac{2}{3}}}{Gc_p}$$

$$\Delta p = \frac{4flG^2}{2D_h\rho}$$

Where, h =heat transfer coefficient (W/m^2-K)

G = Mass velocity (kg/s-m^2) [on the basis of minimum free flow area]

L = Length of flow passage (m)

D_h = Hydraulic diameter (m)

ρ = Mean density of fluid (kg/m^3)

Thermodynamically, the counter-flow arrangement provides the highest heat (or cold) recovery, while the parallel flow geometry gives the lowest. The cross flow arrangement, gives an intermediate thermodynamic performance, by offering superior heat transfer properties and easier mechanical layout. Under some circumstances, a hybrid cross – counter-flow geometry provides greater heat (or cold) recovery with superior heat transfer performance. Thus in general engineering practice, there are three main configurations for the plate fin heat exchangers: (a) cross flow, (b) counter-flow and (c) cross-counter flow.

II. LITERATURE REVIEW

The developments and the enhancements in all the heat transfer equipment's are mainly purposed for energy savings and savings in projects capital investment, through reducing the costs (energy or material). The better heat exchanger is one that transfer's high heat rate at low pumping power with a minimum cost. The spent of money for the research and development in corrugated plate heat exchangers, in last decades, from some companies, offered different and versatile types and models of that heat exchanger.

2.1. Previous work

Numerous works has been done on Plate Heat Exchangers (PHEs) and their data related to thermal and hydraulic characterization are available in open literature. But there is a widespread discrepancy in these reported correlations and before commencing the present study, it was necessary to analyse the experimental facilities and procedure, data reduction methods, results and conclusions of some of the important past works.

Sharif Asal et al. (2018) used Computational Fluid Dynamics approach with the Reynolds stress model to investigate the influence of the apex angle on the thermal and hydraulic features of triangular cross-corrugated heat exchangers. The Reynolds number was varied from 310 to 2064. The numerical results varied by 5% than experimental results. On increasing the apex angle, pressure forces increase which lead to pressure drop along with heat exchanger coefficient. It is concluded that on increasing apex angle from 45^0 to 150^0, vorticity magnitude & pressure forces along the direction of flow increase which lead to higher heat transfer.

Khavin G. (2018) studied about the different height of corrugation for heat exchangers with a circular plate. For designing of such heat exchanger, use of plates with different corrugation heights along hot and cold side can prove to be very helpful. Due to this design, resistance to contamination increases.

Johnson et.al (2017) studied the analytical design of the heat exchanger which has been also numerically analyzed. On the basis of standard k- ε modelling CFD analysis have been done. The solution of the problem yields when the optimum values of flow rate, outer diameter of pipe and inner diameter of pipe to be used at an effective length for a double pipe heat exchanger. When the stream processes for specified flow rates then it was treated for a given inlet to outlet temperature. From the result it has been found that the design and analysis of the double pipe heat exchanger would be a great success.

R K Ajeel et.al (2017) studied CFD study on turbulent forced convection flow of Al2O3-water nanofluid in semi-circular corrugated channel. Computational Fluid Dynamics (CFD) simulations of heat transfer and friction factor analysis in a turbulent flow regime in semi-circle corrugated channels with Al2O3-water nanofluid is presented. Simulations are carried out at Reynolds number range of 10000-30000, with nanoparticle volume fractions 0-6% and constant heat flux condition. The results for corrugated channels are examined and compared to those for straight channels. Results show that the Nusselt number increased with the increase of nanoparticle volume fraction and Reynolds number. The Nusselt number was found to increase as the nanoparticle diameter decreased. Maximum Nusselt number enhancement ratio 2.07 at Reynolds number 30,000 and volume fraction 6%.

Hasanpour et al. (2016) have experimentally studied a double pipe heat exchanger with inner tube corrugated filled with various categories of twisted tapes from conventional to modified types (perforated, V-cut and U-cut). The twist ratio, the hole diameter, the width and depth ratio of the cuts have been varied and the Reynolds number has been changed from 5000 to 15000. Overall more than 350 experiments were carried out. Nusselt number and friction factor for corrugated tube equipped with modified twist tapes are found out to be higher than typical tapes.

Elmaaty et al. (2015) developed a corrugated plate heat exchanger. The author has presented review related to plate heat exchanger and further on brazed corrugated plate heat exchanger the authors have been worked upon. The author have concluded that additional work & modelling are needed on visualization, calculation & measurements of pressure drop and heat transfer using nano-fluids.

Kabeel A.E et al. (2013) have experimentally tested loop to study the PHE thermal characteristics, heat transfer coefficient, pressure drops etc. at different concentrations of nanofluids. The measured heat transfer coefficient results have been compared with theoretical values. An increase in heat transfer coefficient up to 13%, for a nano-fluid concentration of 4% in laminar flow regime, at constant Re number with 9.8% uncertainty is observed. On using nano fluids, power being transmitted is enhanced. But effectiveness of plate heat exchanger decreases.

Han, Xiao-Hong et al. (2010) have used chevron corrugated plate heat exchanger to obtain three dimensional parameters- temperature, pressure and velocity fields. It was seen that in the first zone, the temperature gradient increases gradually and got the maximum in the central of the flow, the temperature gradient became smaller again. The highest temperature appeared around the upper port, while the lowest temperature appeared in the cold fluid inflow around the lower port. From the flow field, a dead zone where the fluid flow rate is very low departed from corrugated side. The simulated results have been compared with the experimental values and it was found that results were consistent with those of pressure drop.

Min & et al. (2009) reviewed use of heat exchanger into gas turbines. The authors discussed the work of other researches about the design of a heat exchanger matrix, material selection, manufacturing technology and optimization. A potential heat exchanger designs for an aero gas turbine recuperator, intercooler and cooling air cooler has been suggested based on previous research. It is included that primary surface heat exchanger have relatively larger effectiveness.

Islamoglu Y. & A. Kurt (2004) used artificial neural networks (ANNs) for heat transfer analysis in corrugated channel. Experiments were conducted for processing with the use of neural networks. Back propagation algorithm was used in training and testing the network and an algorithm using C++ has been developed to solve it. The results of ANN approach & experimental varied by about 4%.

J.A. Stasiek (1998) developed liquid crystal technique and applied it to study six element shapes of rotary air heat preheaters. A complete mapping of temperature, heat transfer coefficient and pressure drop has been obtained at every angle and Reynolds number. It is concluded that the presented corrugated-undulated geometry (CU) can be considered as a generalized of the crossed-corrugated geometry.

Vicente & et al. (2004) studied corrugated tubes using experimental techniques to obtain their heat transfer and isothermal friction characteristics. Water and ethylene glycol were used as working fluids. 10 corrugated tube with rib height ranging from 0.02 to 0.06 & spiral pitch from 0.6 to 1.2 were manufactured using cold rolling. It is concluded that heat transfer increases with increase in Prandtl number. Also at low Reynolds number, tubes with height severity index are most advantageous ones.

Kondepudi & O'Neal (1991) experimentally investigated fin tube heat exchanger for studying the effects of frost growth on thermal performance of fin tube heat exchangers with wavy and corrugated fins. More frost growth and higher pressure drops were found for higher air humidity & fin density. It was concluded that frost growth was a function of spacing as well as air humidity. The pressure drop was found to be function of frost growth & heat exchanger geometry. Heat exchangers with smaller fins due to reduction free flow area have higher pressure drop.

Webb R.L. (1981) has extended previous work of Bergles and Webb to establish a broad range of Performance Evaluation Criteria (PEC) applicable to single phase flow in tubes. Detailed procedure have been outlined to calculate the performance improvement and to select the 'optimum' surface geometry. PEC are presented for four design cases: (1) Reduced heat exchanger material; (2) increased heat duty; (3) reduced long mean temperature difference; and (4) reduced pumping power. The cases discussed included fixed flow area and flow area. Appropriate PEC for two phase exchanger's area have been also discussed. It is concluded that modified PEC is applicable to heat exchangers having two-phase flow.

III. CONCLUSIONS

From the study on various literature reviews it can be observed that the heat transfer is the most important parameter to be measured as the thermal performance and heat transfer efficiency of the plate heat exchanger. Among all types of heat exchangers corrugated heat exchangers are found to have highest rate of heat transfer.

Corrugated plate heat exchangers are used to transfer heat but its manufacturing is very typical as compared to the plate heat exchangers. A lot of research work has been done in the field of heat exchangers. Among all types of heat exchangers corrugated heat exchangers are found to have highest rate of heat transfer. Corrugated plate heat exchangers are used to transfer heat but its manufacturing is very typical as compared to the plate heat exchangers. Corrugate plates contain sinusoidal shape plates which contain crest and trough which are typical to manufacture. Any fault in design will reduce the rate of heat transfer. Besides that, many studies have been done using both experimental and numerical analysis based on working fluid. In order to investigate more, fluid with higher viscosity should be used to observe the outcome of heat transfer performance. By using CFD simulation, the performance of plate heat exchanger can be optimized and at the same time, it can reduce the operation cost and time when using experimental analysis.

- The factors which are affecting the heat transfer rate are Area contact, Pressure drop, and turbulence creating on fluid flow and thermo physical properties of fluid.
- Decreasing the heat transfer rate due to the low value of overall heat transfer coefficient which is depending on the factors discussed above.
- Creating turbulence on the fluid flow decreases the thermal resistance which may results in higher heat transfer rate.

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