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A Review on Heat Transfer Improvent of Plate Heat Exchanger

Abhishek Nandan[1], Gurpreet Singh Sokhal[2], Sandeep Kumar[2] Amit Singla[2]
1. P.G. student, Mechanical Engineering Department, Chandigarh University, Gharuan, Punjab
2. Assistant professor, Mechanical Engineering Department, Chandigarh University, Gharuan, Punjab

Abstract
Plate heat exchanger has found a wide range of application in various industries like food industries, chemical industries, power plants etc. It reduces the wastage of energy and improves the overall efficiency of the system. Hence, it must be designed to obtain the maximum heat transfer possible. This paper is presented in order to study the various theories and results given over the improvement of heat transfer performance in a plate heat exchanger. However, there is still a lack in data and generalized equations for the calculation of different parameters in the heat exchanger. It requires more attention to find out various possible correlations and generalized solutions for the performance improvement of plate heat exchanger.

Nomenclature

D_p Port diameter (m)
β Chevron angle
L_w Plate width (m)
L_h Horizontal distance between centers of port (m)
L_v Vertical distance between centers of port (m)
ϕ Surface enlargement factor
P_c Corrugation pitch (m)
p Rib spacing (m)
e Rib height (m)
t Plate thickness (m)
b Corrugation depth (m)
D_h Channel hydraulic diameter (m)
ρ Density (kg/m^3)
Δp Pressure drop (kPa)
γ Aspect ratio
μ Dynamic viscosity (kg/m s)
h Convective heat transfer coefficient
k Thermal conductivity (W/mK)
Pr Prandtl Number
Nu Nusselt Number
Re Reynolds Number
f Friction factor
Δt_i Inlet primary and secondary fluid temperature difference (^{o}C)
Δt_o Outlet primary and secondary fluid temperature difference (^{o}C)

Subscript

h hot stream
c cold stream
w wall
i inlet fluid condition
o outlet fluid condition

I. Introduction

In most of the chemical processes, transfer of heat to and from the fluids is an essential part. Transfer of heat in any manufacturing industry takes place with the help of heat transfer equipment such as shell tube heat exchanger, double pipe heat exchanger, heat pipes etc.

In the chemical, power, and manufacturing industries, plate heat exchangers have came up with many applications. Due to ease production, compactness and ease maintenance they are widely used. The performance and efficiencies of plate heat exchanger is much more than double pipe heat exchanger or shell and tube heat exchanger.

Gasket type plate heat exchanger consists of series of plates between two covers called end covers. Depending on the applications, plates may be gasketed, welded or brazed. Performance of plate heat exchanger is depends upon the different parameters such as number of plates, configuration of plates, chevron angle, inlet and outlet temperatures of hot and cold fluid, maximum operating temperature and pressure, pressure drop and flow arrangement etc.

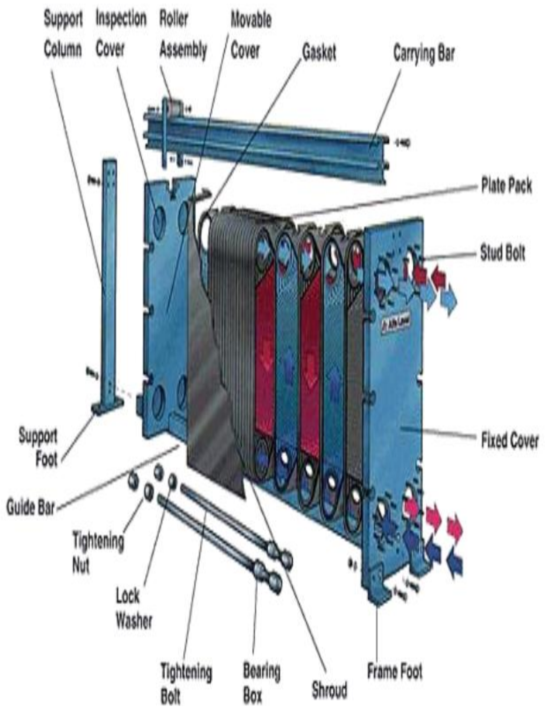

Fig.1 Plate heat exchanger

Stainless steel is a metal of choice for constructing flat plate heat exchange because it can bear high temperature without corrosion. Plate heat exchanger is suitable only for the temperature up to 200 ^{0}C and pressure up to 20 bars. Typically gasket materials for the plate heat exchanger are Styrene-butane rubber. Acrylonitrile-butane rubber, Fluorocarbon rubber, compressed asbestos etc.

II. Geometric and Physical Parameters Affecting The Heat Exchangers

Chevron Angle (β) ranges from 20^0 to 65^0. It is the measure of softness (small β, low thermal energy and pressure drop) and hardness (large β, high thermal energy and pressure drop) of the thermal and hydraulic characteristics of plates. Some researcher defines "$\pi/2 - \beta$" as the chevron angle.

Surface Enlargement Factor (ϕ) the ratio of the developed area (based on corrugation pitch, Pc, and plate pitch, p) to the projected area (viz. $L_w * L_p$, $L_w = L_h + D_p$ and $L_p = L_v - D_p$).

Corrugation Depth or Mean Channel Spacing, b: It is the difference between plate pitch, p and the plate thickness, t.

Channel Flow Area (A_{ch}) is the minimum flow area between the plates and is estimated to the product of plate corrugation depth and width of plate (i.e. $A_{ch} = b * L_w$).

Channel Hydraulic Diameter, D_h: It is defined as four times the ratio of minimum flow area to wetted perimeter, (i.e. $D_h = 2b/ \phi$; Since $b << L_w$).

Physical Parameters Affecting Plate Heat Exchangers Followings are the six major parameters:

i. Amount of heat to be transferred (heat Load)
ii. Inlet and outlet temperatures on the primary and secondary sides.
iii. Maximum allowable pressure drops on the primary and secondary sides.
iv. Maximum operating temperature.
v. Maximum operating pressures.
vi. Flow rate on the primary and secondary sides.

Temperature Program means the inlet and outlet temperature of both media in heat exchangers.

Heat Load (Q) is heat lost (heat load) by one side of a plate heat exchanger is equal to the heat gained by the other side, disregarding the heat losses to the atmosphere which is negligible. The heat load is expressed in kW or kcal/h.

Logarithmic Mean Temperature Difference (LMTD) is the effective driving force in heat exchanger and is given by

$$LMTD = (\Delta t_o - \Delta t_i) / \ln(\Delta t_o / \Delta t_i)$$

Density (ρ): The mass per unit volume and is expressed in kg/m^3.

Flow Rate is expressed in two different ways, either by weight or by volume. The unit of flow by weight is kg/s or kg/h while that of by volume are m^3/h.

Pressure drop (Δp) is in the direct relationship to the size of the plate heat exchanger. If it is possible to increase the allowable pressure drop, and incidentally accept higher pumping costs, then the heat exchanger will be smaller and less expensive. As a guide, allowable pressure drops between 20 and 100 N/m^2 are accepted as normal for oil/water duties.

Specific Heat (c_p) is the amount of energy required to raise 1kg of a substance by one degree centigrade. The specific heat of oil at 70 ^{0}C is 2.05 kJ/kg ^{0}C and for water at 32 ^{0}C is 4.18 kJ/kg ^{0}C.

Viscosity is a measure of the ease of flow of a liquid. The lower the viscosity, the more easily it flows. Viscosity is expressed in $kg \cdot m^{-1} \cdot s^{-1}$. For hot side is 0.00462 $kg \cdot m^{-1} \cdot s^{-1}$ and for cold side 0.000767 $kg \cdot m^{-1} \cdot s^{-1}$.

III. Literature Survey

Focke. W.W. et. al [1] concluded that inclination angle between plate corrugations and overall flow directions are the major parameter in thermodynamic performance of any heat exchanger. Maximum heat transfer is observed at an angle of 80^0 from the experimental data. At an angle above that, heat transfer decreases as the flow pattern becomes less effective due to its separation.

Mehrabian M.A. and Pouter R. [2] studied the effect of change of corrugation angle on local hydrodynamic and thermal characteristics between two identical APV SR3 keepings the plate spacing fixed.

Metwally H.M. and Mbanglik R.M. [3] observed the corrugated plate channels with uniform wall temperature and found that flow field is greatly influenced by aspect ratio (γ) and Reynolds Number (Re). The observations gave two different regimes that is one having low Reynolds Number or γ- undistributed laminar flow regime and the other one having a high Reynolds Number or γ- swirl flow regime.

Gradeck M. et. al [4] experimentally observed, the effect of hydrodynamic conditions on the enhancement of heat transfer for the single phase flow with varying range of Reynolds Number (0<Re<7500). The analysis showed a strong relation between wall velocity gradient and Nusselt relation.

Bobbili Prabhakar Rao et. al [5] experimentally studied the effect of flow and pressure difference across the port of channel in plate heat exchanger with varying Reynolds Number (1000<Re<17000). The experiments were carried out for low corrugation angle with water as hot and cold fluid.

$f = 1.059\ Re^{-0.145}$ for 900<Re<10000 [5]

Longo and Gasparella [6] reported different Nusselt Number correlations for the herringbone type plate heat exchanger with water as working fluid having chevron angle around 65^0.

Garaci Caseales J.R et. al [7], studied the effect of heat transfer in plate heat exchanger while working with R-22 and R-290 refrigerants as the working fluid and compared the different correlation for the evaluation of the heat transfer coefficient.

Naphon Paisarn [8] studied the heat transfer characteristics and the pressure drop on the corrugated plate with different corrugated angles of 20^0, 40^0 and 60^0 with the height of 12.5 mm. The heat flux and the Reynolds Number were taken in the range of 0.5 to 1.2 $KW/m^2$and between 500 to 1400 respectively for the experimental purpose. The corrugation surface showed a significant enhancement of heat transfer and pressure drop due to the presence of recirculation zone.

Lin J. H. et. al [9], with the help of Buckingham Pi theorem, reported the correlation for characterizing the heat transfer performance of corrugated channels in the plate heat exchanger. It was verified with experiments and the effect of different parameters on the heat transfer performance was studied.

Zhi-jian Luan et. al [10], experimentally studied the heat transfer performance and effect of flow resistance of the working fluid over the new-type of corrugation plate heat exchanger and the numerical solution for the same has been given.

Warnakulasuriya and Worek [11] experimentally studied the effect of heat transfer and pressure drop of viscous absorbent salt solution in a commercial plate heat exchanger and observed that there is increase in heat transfer coefficient and Nusselt Number with the increase in Reynolds Number. The correlations for the Nusselt Number and friction factor were concluded through the experiments.

Tsai Ying Chi et. al [12] through experimentally observed the two corrugated channels of plate heat exchangers and studied the hydrodynamic characteristics and distribution of flow. The important results were proposed for the local flow characteristics around the contact point and the effect of velocity pressure and flow distribution of the fluid among the two channels of the plate heat exchanger for the same has been studied.

Dovie D. et. al [13] proposed the mathematical model for the study of the characteristics of flow in plate heat exchanger with chevron angle (β) to be 28^0 and 61^0. He reported the relation for finding out the friction factor (f) and the Nusselt Number (Nu) for the flow channels of arbitrary geometry.

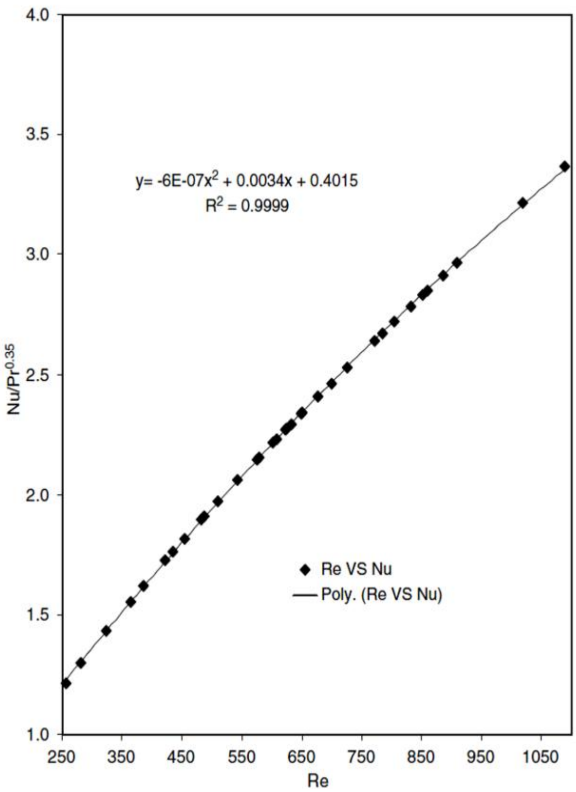

Fig.2 Effect between Reynolds Number and Prandtl Number over Nusselt Number. [11]

Durmus Aydin et. al [14] observed the effect of different parameters like heat transfer, friction factor and exergy loss due to surface geometries of three different types of heat exchangers that is flat plate heat exchangers (FPHE), corrugated plate heat exchangers (CPHE) and asterisk plate heat exchanger (APHE). The experiments were performed for single pass in parallel and counter flow direction for laminar condition (Reynolds Number ranging from 50 to 1000 and Prandtl Number from 3 to 7).

Khan T.S. et. al [15] proposed the correlation to determine the Nusselt Number as a function of Reynolds Number, Prandtl Number and chevron angle through the number of experiments over the

commercial plate heat exchanger. The experiments were done for single phase flow with chevron angle configuration $30^0/30^0$, $60^0/60^0$ and mixed $30^0/60^0$ with Reynolds Number ranging from 500 to 2500 and Prandtl Number ranging from 3.5 to 7.5. The relation for the Nusselt Number was given as:
$Nu = 0.1449\ Re^{0.8414}\ Pr^{0.35}\ (\mu/\mu_w)^{0.14}$ for $\beta = 60^0/60^0$
$Nu = 0.1437\ Re^{0.7810}\ Pr^{0.35}\ (\mu/\mu_w)^{0.14}$ for $\beta = 30^0/60^0$
$Nu = 0.1368\ Re^{0.7424}\ Pr^{0.35}\ (\mu/\mu_w)^{0.14}$ for $\beta = 30^0/30^0$
[15]

Gherasim Iulian et. al [16] suggested the friction factor for Reynolds Number up to 850 and Nusselt Number for hot chemicals for Reynolds Number up to 1500. The hydrodynamic and thermal fields in two channel chevron type plate heat exchanger for laminar and turbulent conditions was studied.

Tauscher R. et. al [17] reported the methods for the enhancement of heat transfer in plate heat exchanger by inducing turbulence in the path of fluid flow. It has been observed that the heat transfer can be doubled with the same pumping power if circular ribs with spacing of p/e =10 is used for turbulent flow (Re>2000). Numerical solution was also proposed for the same.

Saravanan K. and Rajavel Rangasamy [18] studied the different parameters in the spiral plate heat exchanger with mixture of water and electrolyte. Through experiments, different correlations for the heat transfer rate, Reynolds Number and Nusselt Number was suggested. There was found an increase in heat transfer and Nusselt Number with the increasing Reynolds Number. A correlation for the Nusselt Number has been suggested that is:
$Nu = 0.0476\ Re^{0.832}\ Pr^{0.149}$, for $3800>Re<8500$. [18]

Heggs et. al [19] suggested the electrochemical mass transfer techniques for determining the local heat transfer coefficients within the corrugated plate heat exchangers. The experiments were performed on 30^0, 45^0, 60^0 and 90^0 corrugation angles and it was observed that for low corrugation angle, pure laminar flow was not observed for Reynolds Number ranging from 150 to 11500.

Pandey and Nema [20] experimentally determined the heat transfer characteristics for fully developed flow field of water and air in alternate corrugated duct and suggested various correlations for the Nusselt Number as

$$Nu = 68.686\ Re^{0.18} \quad [20]$$

The correlation for the friction factor was given as

$$f = 0.644 / Re^{0.18} \quad [20]$$

Sastry R.C. et. al [21] studied the effect of corrugation angle in corrugation plate heat exchanger with water as working fluid. The heat transfer coefficient and Nusselt Number for a given Reynolds Number was observed higher on 50^0 as compared to 30^0 and 40^0. The Nusselt Number was calculated using the equation is $Nu = hD_h / k$

F. Akturk [22] analyzed the chevron type gasket plate heat exchanger to find out the temperature, volumetric flow rates at all ports and pressure drop at inlet and outlet ports at different channels with Reynolds Number ranging from 450 to 5250. The results have been compared with the theoretical results. The correlation for the friction factor and Reynolds number was also proposed (fig. 3).
A new method of designing a plate heat exchanger was proposed by L. Wang and B. Sudan [23]. Proposed design method was with and without pressure drop specification. Proposed method was an easy approach to find out the different parameters like plate size, number of passes, fluid velocity etc. without iteration method.

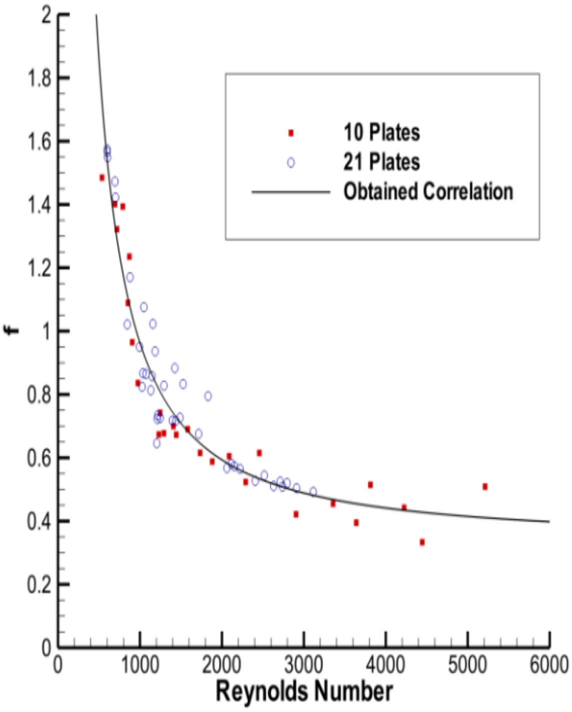

Fig.3 Relation between friction factor and Reynolds Number [22]

Mohammad S. Khan [24] studied the heat transfer characteristics and pressure drop condition for a ammonia with 30^0 chevron angle in chevron type plate heat exchanger and the correlations for the Nusselt Number and friction factor for the two phase flow was suggested.

J. M. Pinto and Jorge A. W. Gut [25] proposed the optimization method for the determining the best configuration of gasket plate heat exchanger by the method of minimizing the area of heat exchanger without affecting the rate of heat transfer, exchanger thermal effectiveness, pressure drop etc.

IV. Conclusions

Several experiments have been performed to study the effect of different parameters on the various types of plate heat exchangers. It has been observed that even at moderate velocities plate heat exchanger can achieve high heat transfer coefficient, low fouling factor etc. Nusselt Number is found to be greatly depending upon the Reynolds Number and it increases with the increase in Reynolds Number. At the different possible conditions various correlations have been proposed for Nusselt Number, Reynolds Number, Prandtl Number, heat transfer coefficient, friction factors etc. Dimensionless correlations have also been proposed for the plate heat exchanger. Models have been developed for the study of compact heat exchanger with multiple passes and multiple rows for the development of better generalized equations.

V. Future Scopes

On the basis of various studies made till today, we can further go for the studies on other types of plates. We can also study for the two phase flow and boiling flow over the plate heat exchanger.

Improvements can also be done by varying the rib angle3 of attack. Investigations can be made for the effect varying geometries on heat transfer of the plate heat exchanger. There can be enhancement of heat transfer by providing turbulence in fluid motion.

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