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INVESTIGATION OF HEAT TRANSFER AND PRESSURE DROP IN PLATE HEAT EXCHANGER WITH VARIOUS PATTERNS

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Abstract - This study was conducted with an objective to investigate the heat transferring ability of plate heat exchangers with various patterns and to compare the same with traditional plate heat exchanger with herring-bone pattern. Heat transfer rate can be increased by using passive methods and improvement can be had without giving any extra energy. The wicked and baffled pattern is used in this investigation to increase the heat transfer rate instead of herring-bone pattern by changing the surface of plate. The rate of heat transfer is more than 15% high in wicked and baffled pattern. Hence the study concluded that, rate of heat transfer is high in wicked and baffled pattern when compared to herringbone pattern.

Key Words: wicked and baffled pattern, plate heat exchanger, more heat transfer

1. INTRODUCTION

Heat exchanger is a device designed for the effective transfer of heat energy between two fluids. Heat can flow only from hotter to cooler fluids as per the second law of thermodynamics. Heat exchanger has variety of application. It include chemical, petrochemical, oil & gas, power generation, refrigeration, pharmaceutical, HVAC, food & beverage processing and pulp & paper industries.

When fluid is used to transfer heat the fluid could be a liquid such as water, oil or could be moving air. The most well know type of heat exchanger is a car radiator. In a radiator mixture of water and ethylene glycol are used as refrigerant transfers the heat from the engine to the radiator and then from radiator to the ambient air flowing through it. This process keeps a car engine from overheating.

When selecting a heat exchanger it is important to know depending upon the application and fluid available for removal of heat and number considerations including flow rate, pressure drop, materials compatibility and more. Different types of heat exchangers works in different ways use different flow arrangements, equipments and design features.

2. PLATE HEAT EXCHANGER

The plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids. The plate heat exchanger is formed by series of corrugated metal plates. The corrugated plates are fixed in the frame with the help of fixed plate on one side and a movable pressure plate on opposite side of fixed plate and are pressed together with the help of tightening bolts. Corrugated plates with special pattern not only raise the level of turbulence but also provide pressure difference between media.

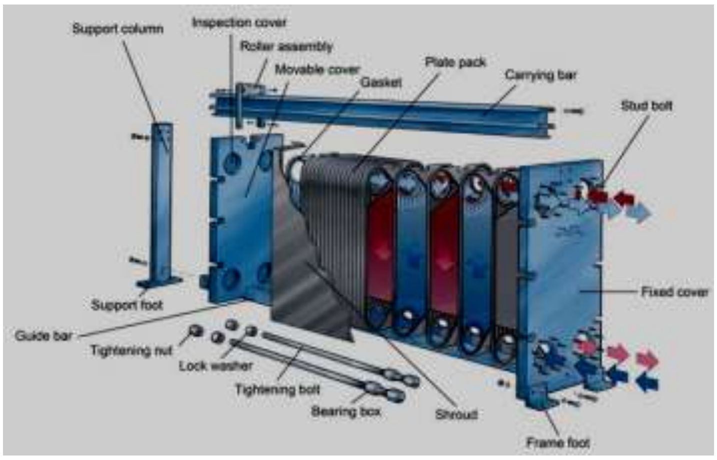

Figure -1: Schematic diagram of Plate heat exchanger

The 1st patent for a plate heat exchanger was granted in 1878 to Albretch Dracke a German inventor. It was commercially available in the market in 1923. However, the plate heat exchanger development race began in the 1930's and the gasket plate and frame type heat exchangers are mainly used as pasteurizers (e.g. for milk and beer). Industrial plate heat exchangers were introduced in the year 1950's and initially they were converted dairy models. Brazed plate heat exchangers were developed in the late 1970's. However, copper brazed units did not start selling until the early 80's. Nickel brazing came to market around ten years later, since copper presents compatibility problems with some streams (e.g. ammonia). All-welded and semi-welded (laser weld) plate heat exchangers were developed during the 1980's and early 90's. Shell and plate heat exchangers were recently introduced in the market and can withstand relatively high pressures and temperatures, as the shell and tube does. The fusion bonded plate heat exchangers (100% stainless steel) are a technology from the 21st century, these equipments being more durable than brazed plate heat exchangers. This has a major advantage over a conventional heat exchanger in that the fluids are exposed to a much larger surface area because the fluids are spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of the temperature change.

H. Dardour [1] had done numerical analysis of the thermal performance of a plate type heat exchanger with co-current flow configuration. The numerical results illustrate the evolution of the most important parameters of the plate heat exchanger.

3. EXPERIMENTAL SETUP

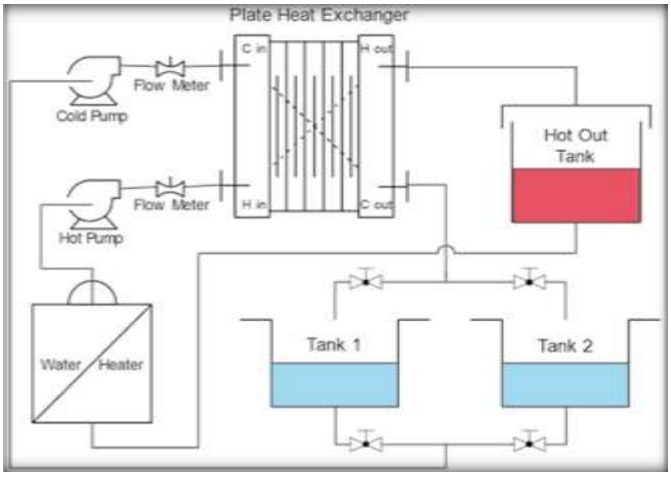

Figure -2: Experimental setup

The experimental set up consisted of plate heat exchanger, thermocouple, Rota-meter, U tube manometer, stop watch, flow rate measuring flask. The heat exchanger has 7 plates and it is constructed using stainless steel. Each plate is flat and has a wicked and baffled pattern. External pipes were used to carry hot and cold fluid. Inlet pipes are connected to top side while outlet pipes are connected to bottom side of heat exchanger. Cold fluid is supplied to exchanger at room temperature. Fluid flow varies by gate valves. Rota-meter are used to measure flow rate in liter/hour. U tube manometer was placed to measure the pressure difference. Thermocouple was used to measure the temperature of hot and cold fluid. Measuring flask used to measure flow rate of outlet fluid.

4. INVESTIGATION PROCEDURE

Initial investigation was conducted on plate heat exchanger with herringbone pattern. Hot water at temperature of 80°C and cold water temperature of around 30°C was employed to determine heat transfer rate in the plate heat exchanger. The cold water flow in one channel was heated up by the flow of hot water in the other channel.

The heat transfer rate was calculated by measuring the temperature difference and mass flow rate. The primary measurement consisted of the mass flow rate, the inlet and outlet temperature and the pressure drop between the inlet and outlet of two fluid streams.

The total heat transfer rate in the plate heat exchanger was determined from the macroscopic energy balance. The heat transfer coefficient for the plate heat exchanger was correlated in terms of Nusselt number, Prandtl number and Reynolds number.

The non-dimensional number like Reynolds number was based on the Equivalent diameter (D_e) as the characteristic dimension. The average fluid properties were calculated according to the inlet and outlet bulk fluid temperature. Procedure was repeated for getting more accurate results and plotted.

A similar investigation was followed for the wicked and baffled pattern plate heat exchange. The non-dimensional Reynolds and Prandtl numbers flow properties were also determined in similar manner. The heat transfer co-efficient of the wicked and baffled pattern in plate was also correlated in terms of Nusselt number. The performance of these two plate heat exchangers had been compared and the heat transfer rate was pointed out.

4.1. Flow distribution and heat transfer equation

Design calculations of a plate heat exchanger include flow distribution and pressure drop and heat transfer. The former is an issue of Flow distribution in manifold [2] a layout configuration of plate heat exchanger can be usually simplified into a manifold system with two manifold headers for dividing and combining fluids, which can be categorized into U-type and Z-type arrangement according to flow direction in the headers, as shown in manifold arrangement. Bassiouny and Martin developed the previous theory of design [3] [4]. In recent years Wang [5] [6] unified all the main existing models and developed a most completed theory and design tool.

The total rate of heat transfer between the hot and cold fluids passing through a plate heat exchanger may be expressed as: $Q = U\ A\ \Delta_{Tm}$ 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 [7].

5. CALCULATION

5.1. After pattern change on SS 316 plates

Table -1: Observation Table

Observation	Flow rate (LPS)	Hot fluid temperature °C		Cold fluid temperature °C	
		Inlet T_1	Outlet T_2	Inlet t_1	Outlet t_2
1	0.3	80	70	30	50
2	0.4	80	71	30	51
3	0.5	80	72	30	52

Properties of hot fluid at temperature 80°C

$\rho = 974$ kg/m^3

$C_p = 4195$ j/kg k

K = 0.6687 w/m k

$\mu = 0.000355$ kg/ms

1. Heat rejected by hot fluid

$Q = m_h C_{ph} \Delta T_h$

= 0.3*4195*(80-70)

= 12585 W

2. Hot fluid mean temperature

$T_{avg} = (T_{hi}+T_{ho})/2$

= (80+70)/2

= 75°c

3. Hydraulic diameter

$D_e = 2b$

=2*0.007

= 0.014 m

4. Flow area of hot water

$A_h = N_h * W * b$

= 7*0.13*0.007

= 0.00637 m^2

5. Velocity of hot water

$$V_h = \frac{m}{A_h \rho_h}$$

= 0.3/ (0.00637*974)

= 0.048 m/s

6. Reynolds number for hot fluid

$$Re_h = \frac{\rho_h V_h D_e}{\mu_h}$$

= (974*0.048*0.014)/ (0.000355)

= 1843.74

7. Prandtl number for hot fluid

$$Pr_h = \frac{\mu_h C_{ph}}{k_h}$$

= (0.000355*4195)

=2.227

8. Nusselt number for hot fluid

Here Re < 2000 so taking relation for turbulent flow

$$Nu_h = 0.662\, Re_h{}^{0.5} Pr_h{}^{0.33}$$

Nu_h =37

9. Heat transfer coefficient for hot fluid:

$$Nu_h = 0.662\, Re_h{}^{0.5} Pr_h{}^{0.33}$$

$$h_h = (0.662)\left(\frac{k_h}{D_e}\right) Re_h{}^{0.5} Pr_h{}^{0.33}$$

= 0.662 * 47.76 * 42.93 * 1.302

= 1768.31 W/ m²K

Properties of cold fluid at temperature 30°C

ρ= 997.5 kg/m^3

Cp = 4178 j/kg k

K = 0.6129 w/m k

μ = 0.000826 kg/ms

10. Heat gained by cold water

$$Q = m_c C_{pc} \Delta T_c$$

Q= 0.3 * 4178 * 20
Q = 25068 W

11. Cold water mean temperature

$T_{avg} = (T_{CI}+T_{CO})/2$
= (30 +50)/2
= $40^{\circ}{}_{C}$

12. Hydraulic diameter

D_e = 2b
=2*0.007
= 0.014 m

13. Flow area of cold water

$A_C = N_C * W * b$
= 7*0.13*0.007
= 0.00637 m^2

14. Velocity of cold water

$$V_c = \frac{m_c}{A_c \rho_c}$$

= 0.3 / (0.00637 * 997.5)
= 0.0472 m/s

15. Reynolds number for cold fluid

$$Re_c = \frac{\rho_c V_c D_c}{\mu_c}$$

= (997.5 * 0.0472 * 0.014)/ 0.000826
=798

16. Prandtl number for cold fluid

$$Pr_c = \frac{\mu_c C_{pc}}{k_c}$$

= 0.000826 * 4178 / 0.6129
= 5.63

17. Nusselt number for cold fluid

- = 0.662 $Re^{0.5} Pr^{0.33}$
- = 0.662 * 28.24 * 1.76
- =1.768

18. Heat transfer coefficient for cold fluid

$$h_c = (0.662)\left(\frac{k_c}{D_e}\right) Re_c^{\ 0.5} Pr_c^{\ 0.33}$$

= 1.768 * 43.77

= 1448. 06 W/ m²K

19. Overall heat transfer coefficient

$$\frac{1}{U} = \frac{1}{h_h} + \frac{t}{k_p} + \frac{1}{h_c}$$

= 1/1448.06 + 0.001/14+ 1/1768.31

= 753.28 w/ m²K

20. LMTD

$$\Theta_m = \left[\frac{[(T_{h1} - T_{c2}) - (T_{h2} - T_{c2})]}{ln \left[\frac{(T_{h1} - T_{c2})}{(T_{h2} - T_{c2})} \right]} \right]$$

= (-10)/ (-0.287)

= 34.76°C

21. Heat transfer

Q = UA ΔT

= 753.28 X 0.2 X 34.76

=5236.89W

5.2. Before pattern change on SS 316 plates

Heat transfer

Q = 4451.36 W

6. RESULT AND DISCUSSION

Chart -1: shows the variation of convective heat transfer coefficient with Reynolds number. From chart-1 it observed that heat transfer coefficient increase with Reynolds number. Increase in Reynolds number is an inclination that flow is becoming more turbulent and results into higher heat transfer

Chart -2: shows variation of convective heat transfer coefficient with respect to mass flow rate of cold fluid. Increase in mass flow rate results into increase in flow velocity of fluid, it leads to increase in Reynolds number which considerably increases heat transfer rate.

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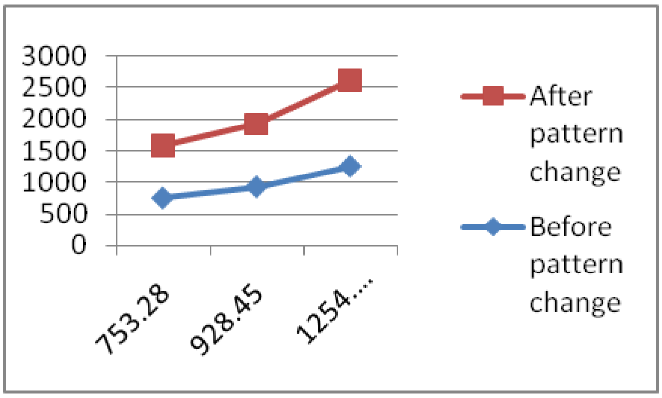

Chart-1: Reynolds number Vs overall heat transfer coefficient

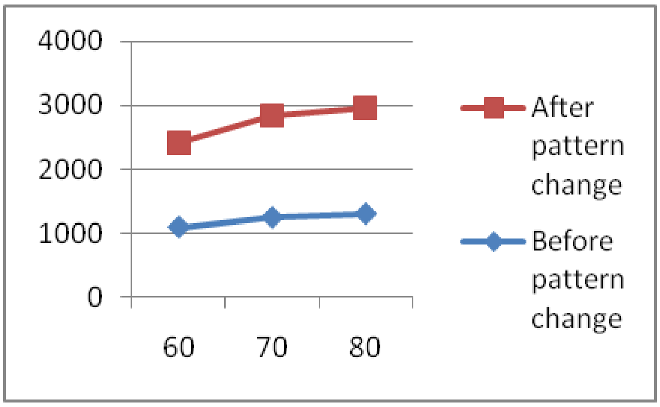

Chart -2: Mass flow rate Vs overall heat transfer coefficient

7. CONCLUSION

From above investigation we can conclude that Wicked and baffled pattern heat transfer plate have more heat transfer rate than heat transfer plate with herringbone pattern is increased up to 15%. Also plate heat exchanger having 3 or more times more heat transfer coefficient than shell and tube heat exchanger. The above procedure is suitable and simple tool for use in the determination of overall heat transfer coefficient and heat transfer rate.

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