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An Optimized Plate Fin Type Heat Exchanger

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Abstract:- Heat exchangers are one of the vital components in diverse engineering plants and systems. So the design and construction of heat exchangers is often vital for the proper functioning of such systems. It has been shown in [Barron, 1985] that the low temperature plants based on Linde – Hampson cycle cease to produce liquid if the effectiveness of the heat exchanger is below 86.9%. On the other hand in aircrafts and automobiles, for a given heat duty, the volume and weight of the heat exchangers should be as minimum as possible.

I. INTRODUCTION

a. A heat exchanger is a device to transfer heat from a hot fluid to cold fluid across an impermeable wall. Fundamental of heat exchanger principle is to facilitate an efficient heat flow from hot fluid to cold fluid. This heat flow is a direct function of the temperature difference between the two fluids, the area where heat is transferred, and the conductive/convective properties of the fluid and the flow state. This relation was formulated by Newton and called Newton's law of cooling, which is given in Equation (1.1)

$$Q = h \times A\Delta T \qquad \text{……………………...................1.}$$

b. Where h is the heat transfer coefficient [W/m^{2}K], where fluid's conductive/convective properties and the flow state comes in the picture, A is the heat transfer area [m^2], and T is the temperature difference [K]. Figure. 1.1 shows the basic heat transfer mechanism.

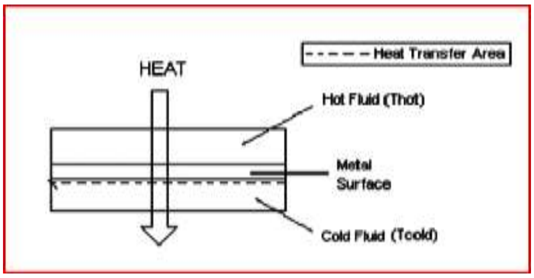


Fig. 1.1 Basic heat transfer mechanism

c. Heat exchangers are one of the vital components in diverse engineering plants and systems. So the design and construction of heat exchangers is often vital for the proper functioning of such systems. It has been shown in [Barron, 1985] that the low temperature plants based on Linde – Hampson cycle cease to produce liquid if the effectiveness of the heat exchanger is below 86.9%. On the other hand in aircrafts and automobiles, for a given heat duty, the volume and weight of the heat exchangers should be as minimum as possible.

PLATE FIN HEAT EXCHANGER

d. Plate fin exchanger is a type of compact heat exchanger where the heat transfer surface area is enhanced by providing the extended metal surface interface between the two fluids and is called as the fins. Out of the various compact heat exchangers, plate-fin heat exchangers are unique due to their construction and performance. They are characterized by high effectiveness, compactness, low weight and moderate cost. As the name suggests, a plate fin heat exchanger (PFHE) is a type of compact exchanger that consists of a stack of alternate flat plates called parting sheets and corrugated fins brazed together as a block. Streams exchange heat by flowing along the passages made by the fins between the parting sheets. Separating plate acts as the primary heat transfer surface and the appendages known as fins act as the secondary heat transfer surfaces intimately connected to the primary surface. Fins not only form the extended heat transfer surfaces, but also work as strength supporting member against the internal

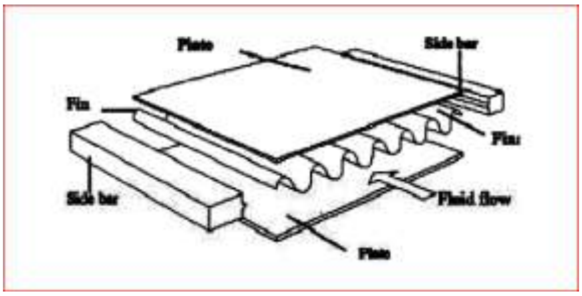


Fig. 1.2 Exploded view of a plate fin heat exchanger

e. **Advantages & Disadvantages**
[1]. **Affordability**
[2]. Plate fin heat exchangers offer several advantages over the other heat exchangers:
[3]. **Compactness**
[4]. **Effectiveness**
[5]. **Temperature control**
[6]. **Flexibility**
[7]. **Operation**
[8]. The main disadvantages of a plate fin heat exchanger are:
[9]. Limited range of temperature and pressure.
[10]. Difficulty in cleaning of passages, which limits its application to clean and relatively noncorrosive fluids, and
[11]. Difficulty of repair in case of failure or leakage between passages.

II. MATERIALS

a. Plate fin heat exchangers are generally, made from an alloy of aluminum or stainless steel. However, the process temperature and pressure dictates the choice of the material. Aluminum alloys are particularly suitable for low temperature applications because of their low weight and excellent ductility and increasing strength under such conditions. In general, the fins or secondary surfaces and the side bars are usually joined to the separating plate by using dip brazing technology or more recently vacuum brazing technique. The brazing material in case of aluminum exchangers is an aluminum alloy of lower melting point, while that used in stainless steel exchangers is a nickel based alloy with appropriate melting and welding characteristics.

2.1 Manufacture

b. The basic principles of plate fin heat exchanger manufacture are the same for all sizes and all materials. The heat exchanger is assembled from a series of flat sheets and corrugated fins in a sandwich construction. Separating plates (i.e. parting sheets) provide the primary heat transfer surface. Separating plates are positioned alternatively with the layers of fins in the stack to form the containment between individual layers. These elements i.e. the corrugations, sidebars, parting sheets and cap sheets are now held together in a jig under a predefined load, and placed in a furnace and brazed to form the plate fin heat exchanger block. After this the header tanks and nozzles are welded to the block, taking care that the brazed joints remain intact during the welding process. Differences arise in the manner in which the brazing process is carried out. The methods in common use are salt bath brazing and vacuum brazing. In the salt bath process, the stacked assembly is preheated in a furnace to about 5500^0C, and then dipped into a bath of fused salt composed mainly of fluorides or chlorides of alkali metals.

2.2 Applications

c. miscellaneous applications are:
1. Fuel cells
2. Process heat exchangers.
3. Heat recovery plants.
4. Pollution control systems
5. Fuel processing and conditioning plants.
6. Ethylene and propylene production plants.

2.3 Flow arrangement

d. A plate fin heat exchanger can have two or more than two streams, which may flow in directions parallel or perpendicular to one another. When the flow directions are parallel, the streams may flow in the same or in opposite sense. So there are three primary flow arrangements for a plate fin heat exchanger (i) parallel flow, (ii) counter-flow and (iii) cross flow. Thermodynamically, the counter-flow arrangement provides the highest heat (or cold) recovery, while the parallel flow geometry gives the lowest. While 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.

e.

(a) Cross flow:

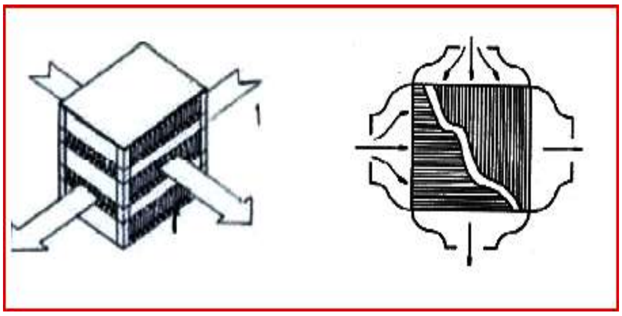


Fig.1.3 Cross flow arrangement

(b) Counter flow:

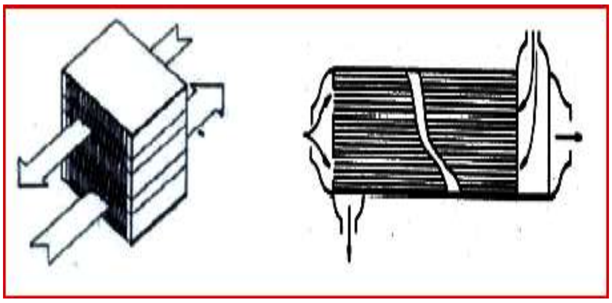


Fig.1.4 Counter flow arrangement

(c) Cross-Counter flow:

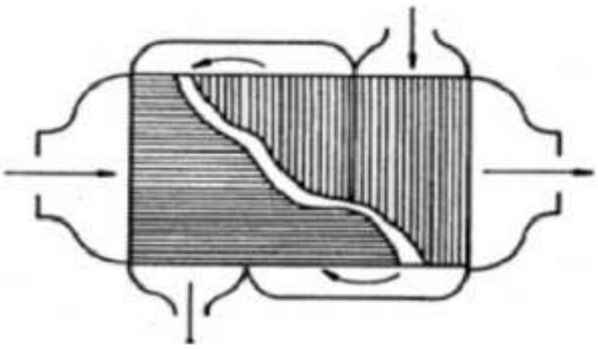


Fig.1.5 Cross-counter flow arrangement

III. DETAILED DESCRIPTION OF VARIOUS EQUIPMENT'S AND INSTRUMENTS USED

3.1 Plate fin heat exchanger

f. The test section consists of a counter flow plate fin heat exchanger with offset strip fin geometry. This Plate Fin Heat Exchanger was sent here for its performance analysis and to establish the correlation for j and f factors, which is manufactured by Laxmi industries pvt. Ltd. Bhopal, for BARC Mumbai. Figure 3.3 shows the plate fin heat exchanger with all its dimensions and arrangements of inlet and outlet ports. This plate fin heat exchanger consists of offset strip fins. And table 3.1 and 3.2 provides the details of core dimensions and thermal data respectively. This Project is basically an experimental set-up, which is build up for the thermal performance testing of the plate fin heat exchanger for studying its performance. The procured heat exchanger is an

Aluminum Plate Fin Heat Exchanger and which was manufactured at Laxmi industries pvt. Ltd. Bhopal for BARC Mumbai. As per the information gathered from the BARC Mumbai this heat exchanger is designed for operating at high pressure and is to be used for low temperature applications. The properties such as effectiveness, NTU, overall heat transfer coefficient, colburn factor j and skin friction coefficient f etc are calculated in order to measure its performance.

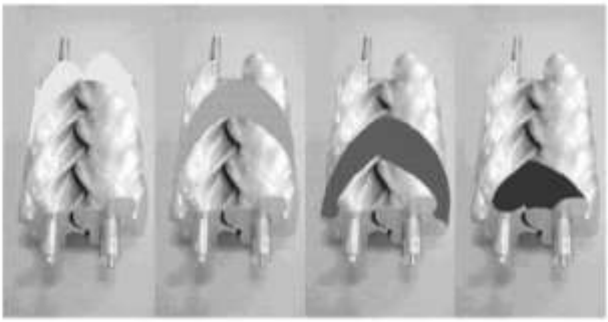
CORE DATA

	INTERNAL (HOT SIDE)	EXTERNAL (COLD SIDE)
FIN	OSF	OSF
NO. OF PASSAGE	4	5
NO. OF PASS	1	1
FLOW RATE	COUNTER FLOW	COUNTER FLOW

Table 3.1(a) Dimensions of procured plate fin heat exchanger. (Provided by company)

3.2 Twin – Screw Compressor

g. Our air supply system consists of a Twin screw rotary compressor which is a positive displacement machine that uses two helical screws known as rotors to compress the gas. The rotors comprise of helical lobes affixed to a front and rear shaft. One rotor is called the male rotor and it will typically have three bulbous lobes. The other rotor is the female rotor and this has valleys machined into it that matches the curvature of the male lobes. Typically the female rotor has five valleys. In a dry running rotary screw compressor, timing gears ensure that the male and female rotors maintain precise alignment. In oil flooded rotary compressor lubricating oils bridges the space between the rotors, both providing a hydraulic seal and transferring mechanical energy between the driving and driven rotors. Gas enters at the suction side and moves through the threads as the screws rotate. The meshing rotors force the gas through the compressor and the gas exits at the end of the screw. A 3-5 rotor combination is provided in the compressor so that, the male rotor turns 1.66 times to every one time of the female rotor. Screw compressors have relatively high rotational speed compared to other types of positive displacement machines which make them compact. They have the ability to maintain high efficiencies over a wide range of operating pressure and flow rates and have long service life and high reliability. All these things make them widely acceptable by various industries of the world.



Suction Entrapment Compression Discharge

Fig. 3.2 working mechanism of Twin Screw Compressor

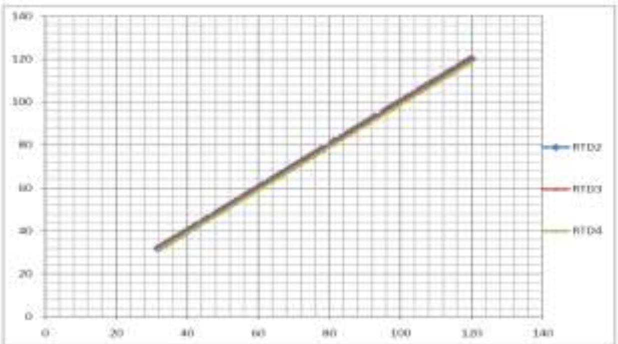


Fig.3.3 RTD Calibration graph

IV. RESULT & DISCUSSION

h. The main aim of present work is to calculate the performance parameters like, effectiveness, overall heat transfer coefficient of the plate fin heat exchanger using air as working fluid . In order to find the performance of present heat exchanger a number of experiments were carried out at different mass flow rates and at different hot fluid inlet temperature under balanced flow.

4.1 Calculations

i. The temperature values which are obtained experimentally are fit for all corrected values using the calibration chart, and also the pressure values are converted in units of Pa or bar, and then used for further calculations.

$T_1 = 38.93^0 C$, $T_2 = 88.49^0 C$, $T_3 = 96.12^0 C$, $T_4 = 43.11^0 C$, $P_1 = 1.21 bar$, $P_2 = 1.18 bar$

Flow rate=500 lt./min

1. $\text{Mass flow rate} = \text{Volume flow rate} \times \frac{p_4}{RT_4}$ $= \frac{500\times10^{-3}}{60} \times \frac{1.01325\times10^5}{287\times316.98} = 0.01 kg/s$

2. Heat capacity of hot and cold fluids,

$$C_c = m_c \times C_{pc} = 0.010087 KW/K$$

j. For hot fluid $C_h = m_h \times C_{ph} = 0.010093 KW/K$

3. Capacity Rate ratio, $C_r = C_{\min} / C_{\max} = 0.9994$

4. Effectiveness,

$$\varepsilon_h = \frac{c_h (T_{hinlet} - T_{hexit})}{c_{\min} (T_{hinlet} - T_{cinlet})} = 91.134$$

(a)

$$\varepsilon_c = \frac{c_c (T_{cexit} - T_{cinlet})}{c_c (T_{hinlet} - T_{cinlet})} = 86.920$$

5. Number of transfer units, NTU = 15.009

k. After considering the effect of longitudinal heat conduction, Same steps as described in Chapter 4 are followed, but here the NTU value is assumed in such a way that the effectiveness obtained from Kroeger's equation matches with the experimental value of effectiveness.

6. Overall Heat transfer conductance, UA_0

l. UA_0 = NTU x C_{min} = 15.009x 0.010087

1. = 160.898 W/K

m. Here also the surface geometrical properties are calculated by following the procedure as mentioned in Chapter 4. Table 5.2 shows the performance parameters of heat exchanger obtained after calculation.

n. Variation of Effectiveness with Mass Flow Rate

We compare experimental values at hot fluid inlet tempt. 96^0C & 66^0C obtained by using aspen software with the results of work of various investigators like joshi [2], mangalik [5], maiti [19], Muse [12].

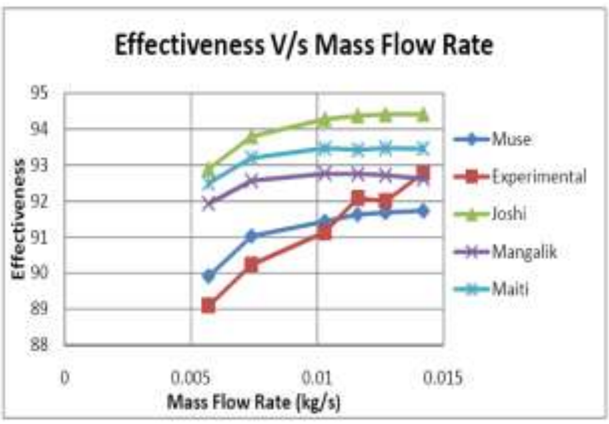


Fig. 5.1 Variation of effectiveness with mass flow rate (hot inlet temperature=96^0C) by using [2], [5], [19]

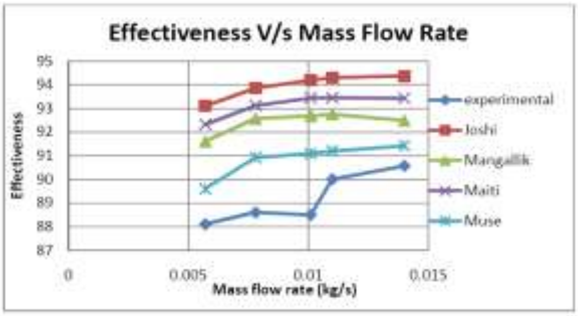


Fig. 5.2 Variation of effectiveness with

(a) mass flow rate

o. (hot inlet temperature=66^{0}C) by using

(a) [2], [5], [19]

V. CONCLUSION

p. The hot test is conducted to determine the thermal performance parameters of the available plate fin heat exchanger at different mass flow rates and two different hot inlet temperatures of 96^{0}C and 66^{0}C. An effectiveness of 88-92.78% is obtained during varying conditions. It is found in both the cases that the effectiveness and overall thermal conductance increases with increasing mass flow rate so overall heat transfer coefficient will also increases with increasing mass flow rate. It is also found that hot fluid effectiveness increases with flow rate of the fluid and agrees within 4% with the effectiveness value calculated by different correlations. Also the pressure drop increases with increasing mass flow rate and experimental values are more as compared to theoretical results because the losses in pipes and manufacturing irregularities have not been taken in to account.

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