Performance Analysis of Compact Heat Exchanger

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***Abstract* - Compact heat exchangers are one of the most critical components of many cryogenic components; they are characterized by a high heat transfer surface area per unit volume of the exchanger. The heat exchangers having surface area density (β) greater than 700 m2/m3 in either one or more sides of two-stream or multi stream heat exchanger is called as a compact heat exchanger. Plate fin heat exchanger is a type of compact heat exchanger which is widely used in automobiles, cryogenics, space applications and chemical industries. The plate fin heat exchangers are mostly used for the nitrogen liquefiers, so they need to be highly efficient because no liquid nitrogen is produced, if the effectiveness of heat exchanger is less than 87%. So it becomes necessary to test the effectiveness of these heat exchangers before putting them in to operation.**

The available plate fin heat exchanger has rectangular offset strip geometry and is tested in the laboratory using the heat exchanger test rig. The experiment is conducted under balanced condition i.e. the mass flow rate for both sides of fluid stream is same, and the experiment is carried out at different mass flow rates. The effectiveness of heat exchanger is found out for different mass flow rates. Various correlations are available in the literature for estimation of heat transfer and flow friction characteristics of the plate fin heat exchanger, so the various performance parameters like effectiveness, heat transfer coefficient and pressure drop obtained through experiments is compared with the values obtained from the different correlations. The longitudinal heat conduction through walls decreases the heat exchanger effectiveness, especially of cryogenic heat exchangers, so the effectiveness and overall heat transfer coefficient is found out by considering the effect of longitudinal heat conduction using the Krueger's equation.

Keywords: IJSPR, International Journal, Research, Technology.

I. INTRODUCTION

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.So the main requirement for any heat exchanger is that it should be able to transfer the required amount of heat with a very high effectiveness. In order to increase the heat transfer in a basic heat exchanger mechanism shown below in Figure 1.1, assuming that the heat transfer coefficient cannot be changed, the area or the temperature differences have to be increased. Usually, the best solution is that the heat transfer surface area is extended although increasing the temperature difference is logical, too.

In reality, it may not be much meaningful to increase the temperature difference because either a hotter fluid should be supplied to the heat exchanger or the heat should be transferred to a colder fluid where neither of them are usually available. For both cases either to supply the hot fluid at high temperature or cold fluid at lower temperature extra work has to be done. Furthermore increasing the temperature difference more than enough will cause unwanted thermal stresses on the metal surfaces between two fluids. This usually results in the deformation and also decreases the life span of those materials. As a result of these facts, increasing the heat transfer surface area generally is the best engineering approach.

The above requirements have been the motivation for the development of a separate class of heat exchangers known as Compact heat exchangers. These heat exchangers have a very high heat transfer surface area with respect to their volume and are associated with high heat transfer coefficients. Typically, the heat exchanger is called compact if the surface area density (β) i.e. heat transfer surface area per unit volume is greater than 700 m2/m3 in either one or more sides of two-stream or multi stream heat exchanger [R.K Shah, Heat Exchangers, Thermal Hydraulic 1980]. The compact heat exchangers are lightweight and also have much smaller footprint, so they are highly desirable in many applications.

Plate Fin Heat Exchanger

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 pressure. The side bars prevent the fluid to spill over and mix with the second fluid. The fins and side bars are brazed with the parting sheet to ensure good thermal link and to provide the mechanical stability.

II. METHODOLOGY

The main aim of present work is to calculate the performance parameters like, effectiveness, overall heat transfer coefficient of the plate fin heat exchanger. 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.

III. SYSTEM MODEL

Experimental Setup

Table-1 Shows the Experimentally Observed Data

Flow Rate (litr/min)	P1 (Kg/cm^2)	P2 (Kg/cm^2)	Δhc (mm of Hg)	Δhh (mm of Hg)	T1 (^{a})	T2 (^{a})	T3 (^{a})	T4 (^{a})
300	0.08	0.06	9	6	42.24	87.34	96.2	47.15
400	0.14	0.12	15	12	38.35	87.02	95.12	43.01
500	0.2	0.17	25	22	38.93	88.49	96.12	43.11
550	0.24	0.20	30	26	39.82	88..83	96.66	43.48
588	0.28	0.24	31	27	40.41	88.45	96.20	43.99
650	0.32	0.26	40	35	41.16	87.86	95.95	44.17
300	0.08	0.06	8	6	40.92	62.06	66.48	43.06
400	0.135	0.10	16	14	42.77	62.90	66.43	44.56
500	0.2	0.16	24	22	39.57	62.52	66.02	41.69
600	0.28	0.23	31	30	39.94	62.44	65.98	41.73
650	0.34	0.28	37	34	42.72	62.77	66.34	44.06

IV. CALCULATIONS

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

T_i =38.93 a, T2= 87.23 a , t3 =95.96 a T4 =48.10a P1=1.1

Flow rate = 500litr/min

1. Mass Flow Rate = $Volume\ Flow\ Rate \times \frac{p_4}{RT_4}$

$$= \frac{500 \times 10^{-3}}{60} \times \frac{1.01325 \times 10^5}{287 \times 316.98} = \frac{0.01kg}{s}$$

2. Heat capacity of hot and cold fluids,

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

For hot fluid, $C_h = m_h * C_{ph} = 0.010093\ KW/K$

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

4. Effectiveness, $S_h = \frac{C_h(T_{hinlet} - T_{hexit})}{C_{nin}(T_{hinlet} - T_{cinlet})} = 91.134$

$$S_C = \frac{hinlet - T}{C_c(Tcinlet)} = 86.920$$

Number of transfer units, NTU = 15.009

5. 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 Kroger's equation matches with the experimental value of effectiveness.

6. Overall Heat transfer conductance, UA_0

$UA_0 = NTU \times C_{min} = 15.009 \times 0.010087$

$= 160.898$ W/K

Table 2 shows the performance parameters of heat exchanger obtained after calculation.

Table -2 Performance of Heat Exchanger

Flow Rate (lit/min)	Mass flow rate (kg/s)	sh	sc	NTU	UA_0 W/K	Reh	Rec	ΔT_{K0TEND}	$\Delta T_{C0LDEND}$
300	0.0057	89.902	83.749	13.64	80.95	298.67	199.72	8.73	5.87
400	0.0074	90.236	85.90	15.24	117.37	416.04	278.22	7.97	5.53
500	0.0103	91.134	86.920	15.00	160.89	542.44	362.75	7.44	5.05
550	0.0116	92.08	86.365	16.24	196.09	610.9	406.46	7.72	4.53
588	0.0127	92.001	86.247	15.70	207.64	668.83	445	7.64	4.45
650	0.0142	92.786	85.371	17.49	258.57	747.83	497.56	7.98	3.94
300	0.0057	88.108	83.064	11.76	69.74	280.24	186.48	4.3	3.02
400	0.0078	89.937	85.480	13.25	107.60	419.28	277.56	3.36	2.33
500	0.0101	88.48	86.814	9.79	102.89	491.54	399.77	3.48	3.04
600	0.011	90.004	86.597	11.28	135.41	702.63	465.13	3.46	2.58
650	0.014	90.572	85.114	12.00	174.87	789.66	525.48	3.49	2.21

In order to compare our experimental results with the values that are obtained from theoretical correlations, some graphs are plotted for which the experiment is conducted at mass flow rates and at two different hot inlet temperatures of 66 and 96ª. Some of the graphs are shown below:

Variation of Effectiveness with Mass Flow Rate

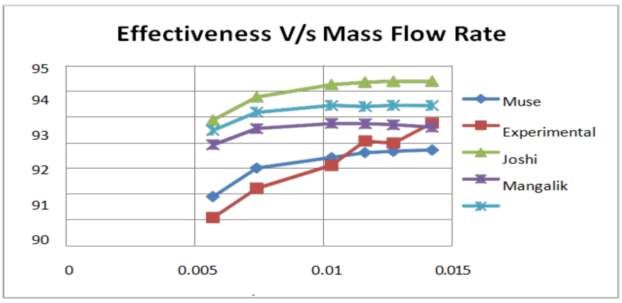
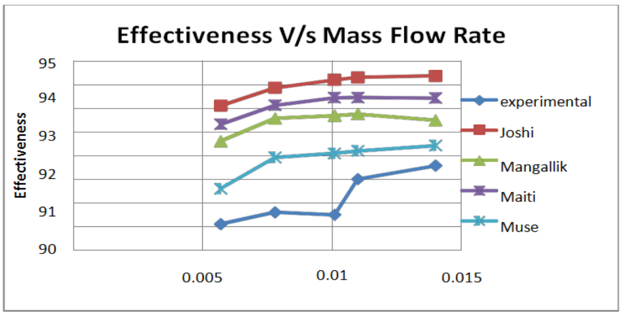


Fig. 5.1 Variation of effectiveness with mass flow rate (hot inlet temperature=96ª)



V. CONCLUSION

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 and 66ª. An average effectiveness of 91% is obtained. It is found in both the cases that the effectiveness and overall thermal conductance 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 and that obtained by using the simulation software, Aspen. 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.

For a particular hot inlet temperature there is an optimum mass flow rate at which the difference between the hot and cold effectiveness of the heat exchanger is minimum and at this point the imbalance is also minimum. We found that the insulation which is provided in the heat exchanger has a significant effect on its performance. It is expected that the imbalance i.e. difference between the hot and cold end temperature can be brought to a minimum level if a perfect insulation like vacuum is provided.

Scope for Future Work

Present tests are conducted at room temperatures and in future we can perform the experiment at low temperatures in order to check the performance of the present heat exchanger for Cryogenic applications. In cold testing air at about 100K will be used as the cold fluid. In cold test in place of heater a cold box will be used.

REFERENCES

[1]. Patankar S. V. and Prakash C. 1981 An Analysis of Plate Thickness on Laminar Flow and Heat transfer in Interrupted Plate passages. International Journal of Heat and Mass Transfer 24: 1801-1810.

[2]. Joshi H. M. and Webb R. L. 1987. Heat Transfer and Friction in Offset Strip Fin Heat Exchanger, International Journal of Heat and Mass Transfer. 30(1): 69-80

[3]. Suzuki, K., Hiral, E., Miyake, T., Numerical and Experimental studies on a two Dimensional Model of an Offset-Strip-Fin type Compact Heat Exchanger used at low Reynolds Number. International Journal of Heat and Mass Transfer 1985 28(4) 823-836.

[4]. Tinaut F. V., Melgar A. and Rehman Ali A. A. 1992 Correlations for Heat Transfer and Flow Friction Characteristics of Compact Plate Type Heat Exchangers. International Journal of Heat and Mass Transfer. 35(7):1659:1665

[5]. Manglik and Bergles A. E. 1995 Heat Transfer and Pressure drop Correlations for Rectangular Offset Strip Finn Compact Heat Exchangers. Experimental Fluid Science 10:171- 180.

[6]. Hu S and Herold K. E. 1995a Prandtl Number Effect on Offset Strip Fin Heat Exchanger Performance: Predictive Model for Heat Transfer and Pressure Drop. International Journal of Heat and Mass Transfer 38(6) 1043-1051

[7]. Hu S and Herold K. E. 1995b Prandtl number Effect on Offset Strip Fin Heat Exchanger Performance: Experimental Results. International Journal of Heat and Mass Transfer 38(6) 1053-1061.

[8]. Zhang L. W., Balachandar S., Tafti D. K. and Najjar F. M. 1997. Heat Transfer Enhancement Mechanisms in Inline and Staggered Parallel Plate Fin Heat Exchanger. International Journal of Heat and Mass Transfer 40(10):2307-2325

[9]. Dejong N. C., Zhang L. W., Jacobi A. M., Balchandar S. and Tafti D. K. 1998. A Complementary Experimental and Numerical Study of Flow and Heat Transfer in Offset Strip Fin Heat Exchangers. Journal of Heat Transfer 12:690:702

[10]. Bhowmik H., Kwan- Soo Lee 2009. Analysis of Heat Transfer and Pressure Drop Characteristics in an Offset Strip Fin Heat Exchanger. International Journal of Heat and Mass Transfer 259-263

[11]. Saidi A. and Sudden B. 2001. A Numerical Investigation of Heat Transfer Enhancement in Offset Strip Fin Heat Exchangers in Self Sustained Oscillatory Flow. International Journal of Numerical Methods for Heat and Fluid Flow. 11(7): 699-716

[12]. Dong J., Chen J., Chen Z. and Zhou Y. 2007. Air Side Thermal hydraulic Performance of Offset Strip Fin Heat Exchangers Fin Aluminum Heat Exchangers. Applied Thermal Engineering 27:306-313

[13]. Michna J. G., Jacobi A. M. and Burton L. R. 2005. Air Side Thermal- Hydraulic Performance of an Offset Strip Fin Array at Reynolds Number up to 12, 0000. Fifth International Conference on Enhanced Compact and Ultra Compact Heat Exchangers. Science, Engineering and Technology 8-14.

[14]. Prabhat Gupta, Atrey M. D. Performance Evaluation Of Counter Flow Heat Exchangers Considering the Heat In Leak and Longitudinal Conduction for Low Temperature applications. Cryogenics Volume 40, issue 7, Pages 469-474.

[15]. Barron R. F., Cryogenic Heat Transfer, Taylor and Francis (1999) 311-318. Shah R. K. and Sekulic D. P.