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 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.

Key Words: Heating element, Orifice mass flow meter, Plate fin H.E., T- screw compressor, Test Rig.

I INTRODUCTION

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 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)

Q = hxAx T…………(1)
Where h is the heat transfer coefficient in W/m^2K A is the heat transfer area in m^2, and T is the temperature difference in K. Figure. 1 shows the basic heat transfer mechanism.

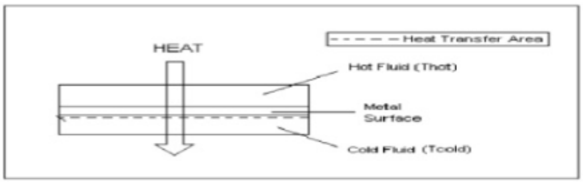


Fig. 1 Basic heat transfer mechanism

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. 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 min. 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, assuming that the heat transfer coefficient cannot be changed, the area or the temperature differences have to be increased By 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.

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 m^2/m^3 in either one or more sides of two-stream or multi stream heat exchange. The compact heat exchangers are lightweight and also have much smaller footprint, so they are highly desirable in many applications.

II PROBLEM FORMULATION NEED AND SIGNIFICATION OF PROPOSED RESEARCH WORK

Compact heat exchangers are one of the most critical components of many cryogenic components. 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%.

Plate fin heat exchangers offer several advantages over the other heat exchangers:

(a) Compactness: Large heat transfer surface area per unit volume (Typically 1000 m^2/m^3), is usually provided by the plate fin heat exchanger. This in turn produces a high overall heat transfer coefficient due to the heat transfer associated with the narrow passages and corrugated surfaces.

(b) Effectiveness: very high thermal effectiveness more than 95% can be obtained.

(c)Temperature control: The plate heat small temperature differences. A close temperature approach (Temperature approach as low as 3K between single phase fluid streams and 1K between boiling and condensing fluids is fairly common.),This is an advantage when high temperatures must be avoided.

(d) 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 the various design specifications. Multi steam operation is possible up to 10 streams.
The main disadvantages of a plate fin heat exchanger are:

(i) Limited range of temperature and pressure.
(ii) Difficulty in cleaning of passages, which limits its application to clean and relatively non-corrosive fluids, and
(iii) Difficulty of repair in case of failure or leakage between passages.

III THEORY

Accurate and reliable dimensionless heat transfer and pressure drop characteristics are a key input for designing or analyzing a plate fin heat exchanger. For single-phase flow, the heat transfer coefficient is generally expressed in terms of the Colburn correlation.

H=jCpG(Pr)…………………(2)

Where **j** called as Coburn factor separates the effects of the fluid properties on the heat transfer coefficient and permits correlations as a function of the Reynolds number (Re). While the j data are expressed as functions of Prandtl number (Pr) and Re, temperature does not appear directly in the expression. Temperature has the only role in determining the thermo-physical properties such as density, viscosity, specific heat and thermal conductivity. Therefore, it is generally recognized that **j** data determined at one temperature / pressure level and expressed in dimensionless form are directly usable at another temperature / pressure level.

Since the plate fin heat exchangers are mainly used for gas to gas heat transfer applications and most of the gases are low density gases, so the pumping power requirement in a gas-to-gas heat exchanger is high as compared to that in a liquid-to-liquid heat exchanger. This fact makes it mandatory to have an accurate estimation of friction characteristics of the heat exchanger surfaces in gas application. The friction factor is defined on the basis of an equivalent shear force in the flow direction per unit friction area. This shear force can be either viscous shear (skin friction) or pressure force (form drag) or a combination of both.

It can be seen that temperature does not appear directly in the expression of friction factor also. Therefore, the f data determined at one temperature /pressure level are directly usable at other temperature / pressure level. But it is seen that j and f are strong functions of fin geometries like fin height, fin spacing, fin thickness etc. Because fins are available in varied shapes, it becomes necessary to test each configuration individually to determine the heat transfer and flow friction characteristics for specific surface. For a given fin geometry, in general, increase in heat transfer performance is associated with increase in flow friction and vice versa. Customarily the ratio of j/f is taken as a measure of the goodness of the fin surface.

Several attempts have been made towards the numerical prediction of heat transfer coefficient and friction factor; but they have generally been unable to match experimental data and several empirical correlations, Generated data from have found extensive application in industry, particularly in less-critical designs. For critical applications, direct experimental determination of **j** and **f** factors for each fin geometry remains the only choice.

In a plate fin heat exchanger the common range of Reynolds number is 500 to 3000 for most of the applications. The Reynolds number is kept low because the hydraulic diameter of the flow passages is generally small due to closely spaced fins and in such conditions operation with low density gases leads to excessive pressure drop unless the gas velocity in the flow passage is kept low.

IV OBJECTIVES OF THE STUDY

The main objective of the present work is to evaluate the performance parameters of a counter flow plate fin heat exchanger through hot testing, which includes-

(i) Design and fabrication of the test rig for plate fin heat exchanger.
(ii) To determine the thermal performance parameters like overall heat transfer coefficient, effectiveness and pressure drop of plate fin heat exchanger through hot testing under balanced flow condition.
(iii) To compare the experimentally obtained values of effectiveness, overall heat transfer coefficient with the values that are obtained from various correlations.

V METHODOLOGY DURING THE TENURE OF THE PLANNING OF WORK

(a) Plate fin heat exchanger: 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, Figure 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 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. 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 co-efficient f etc are calculated to measure its performance.

(b) The component used during experiment:- Twin- screw compressor 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 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.

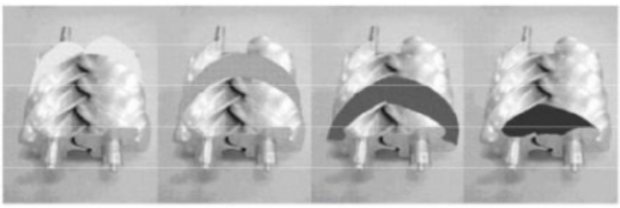


Fig.2 screw compressor

(c) The Compressor specification is given below:

Make : Kaeser (Germany)
Model : BSD 72
Profile of screw : Sigma
Free air delivery : 336 m3 /hr

Suction pressure: : Atmospheric
Maximum Pressure :11 bar
Operating temperature :75-1000c
Motor :37kw, 74amps, 3Φ, 50Hz, 415V±10%, 3000rpm
Oil capacity: 24 L
Cooling: Air

(d) Heating element- This heating element was fully designed and developed in our cryogenics lab the location of the heater is as shown in the P&I diagram. It is basically having a shell and tube type of configuration in which incoming cold side fluid i.e. air enters the equipment and leaves the heater through the series of baffles. Our heater contains seventeen number of aluminum baffles through which a five set of heating tube passes. Load of heater is 1575 W, power source 220/230 V, single phase 50Hz AC Supply.

(e) Resistance temperature detectors (RTDS)
Resistance thermometers also called as resistance temperature detectors (RTD's) or resistive thermal devices are temperature sensors that exploit, the predictable change in electrical resistance of some materials with changing temperature. It is a positive coefficient device, Typical elements used for RTD's include nickel (Ni), copper (Cu), but platinum (Pt) is by far the most common, because it has the best accuracy and stability in comparison to other RTD materials. Platinum is required to fabricate a sensor and making platinum costs competitive with other RTD materials. The RTD's are slowly replacing the use of thermocouples in many industrial applications below 600 ^{0}C, due to higher accuracy and reliability.

RTD's are available with three different lead wire configurations. The selection of a particular configuration depends on the desired accuracy and instruments to be used for the measurement.

(i) Two wire configuration

(ii) Three wire configuration and

(iii) Four wire configuration.

They cannot be used for measurement of temperature above 660 ^{0}C and below - 270 ^{0}C. Also they are less sensitive to small temperature changes.

RTD's are commonly categorized by their nominal resistance at 0 ^{0}C. By far the most common RTD's used in the industry have a nominal resistance of 100 ohms at 0 ^{0}C are called as the PT-100 sensors. The relationship between resistance and temperature is very nearly linear and follows the equation.

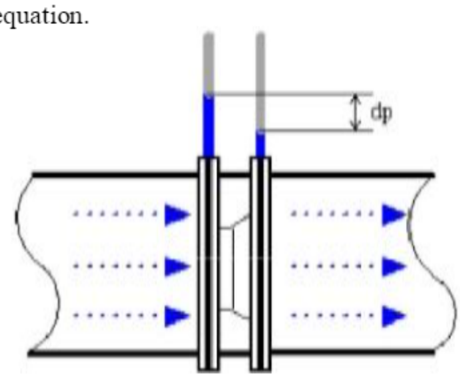


Fig.3 Orifice plate

(f) Orifice mass flow meter- A flow meter or flow sensor is an instrument used in almost all mechanical and electrical instrumentation process to measure the flow rate of liquid or gas. An orifice meter is a device used for measuring the rate of fluid flow. Its working is based on the Bernoulli's principle. The fluid is forced to go through the small hole of varying cross section, the point of maximum convergence actually occurs shortly downstream of the physical orifice, and is called as the point of vena contracta. Both the velocity and pressure of the fluid changes while it passes through the orifice plate. Beyond the vena contracta, the fluid expands and the velocity and pressure change once again. The volumetric and mass flow rates are obtained from the Bernoulli's equation by measuring the difference in fluid pressure between the normal pipe section and at the vena contracta,

The calibration chart is being given below:

(g) Autotransformer or Variac- Variac also called as an Autotransformer is an electrical transformer with only one winding. The auto prefix refers to the single coil acting on itself rather than any automatic mechanism. In an autotransformer portions of the same winding act as both the primary and secondary. The winding has at least three taps where electrical connections are made. Autotransformers are often used to step up or step own between voltages in the 110-117-120 volt range and voltages in the 220-230-240-volt range. We have used two variacs.

Table 3

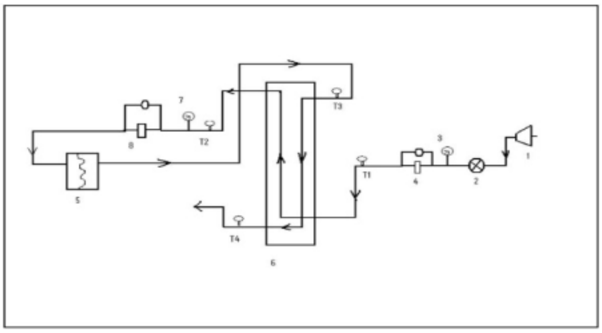
Calibration Chart

THERMOMETER(0C)	RTD 1(0C)	RTD 2(0C)	RTD 3(0C)	RTD4 (0C)
30.5	31.85	31.8	31.98	37.04
34	34.87	34.84	35.01	34.03
39	40.31	40.31	40.46	39.48
43.5	44.98	44.98	45.13	44.11
47	48.9	48.89	45.13	44.11
50	51.72	51.69	51.84	50.76
65	66.67	66.71	66.78	65.54
68	70.04	70.06	70.24	69.1
85	86.69	86.81	86.87	85.57
90	91.64	91.79	91.89	90.64
94.5	96.21	96.34	96.45	95.04
100	101.8	101.91	101.99	100.51
105.5	107.55	107.73	107.77	106.38

Different taps on the winding correspond to different voltages, measured from the common end. In a step-down transformer the source is usually connected across the entire winding while the load is connected by a tap across only a portion of the winding. In a step-up transformer, conversely, the load is attached across the full winding while the source is connected to a tap across a portion of the winding.

(h) Test Rig consists of the following components:-

- Compressor
- Control Valve
- 3,7 Pressure taps
- Manometer
- Heater
- Test Section



VI PROCEDURE FOR HOT TESTING

Air is used as the as working fluid in this experiment. The apparatus was connected to a compressor system which is capable of continuously delivering dry air .The compressed air from the compressor enters the laboratory through a control valve which is used to regulate the flow rate through the heat exchanger and then routed to the testing heat exchanger. This is the cold side fluid which is made to enter the heat exchanger from the bottom side and when it comes out it is made to pass through the heater, where it gets heated up and which is then again fed into the heat exchanger from top end and The heat supplied to the heater is controlled with the help two variacs. These pressure taps was connected with tubing and which is connected to a U-tube manometer to give an average reading of the pressure drop. The air inlet and outlet temperatures at both ends of heat exchanger core were measured using four RTD's. The air flow rate was measured using the Rota meter and the mass flow rate of both the fluids can be measured using orifice meter. The pressure drop across the orifice plate can be measured by using U-tube manometers.

VII EXPECTED OUTCOME OF THE PROPOSED WORK

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 66 degree. 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.

VIII 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 can be used.

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