INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

IJARIIT

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 7, Issue 3 - V7I3-1948)
Available online at: https://www.ijariit.com

Performance analysis of "Shell and Tube" and "Plate Heat Exchanger"

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ABSTRACT

In this paper an experimental setup of one ton of refrigeration was developed. Shell and tube heat exchanger and plate heat exchanger were used as an evaporator. Plate heat exchanger for one ton capacity was available and "shell and tube" heat exchanger was manufactured for one ton capacity. The performance of both the heat exchangers were compared through experimentation. Also, these heat exchangers were compared on the basis of area, volume occupied.

Keywords— *Plate heat exchanger, shell and tube heat exchanger, heat transfer coefficient*

1. INTRODUCTION

1.1 Plate heat exchanger

Plate heat exchangers (PHE's) were first commercially introduced in the 1920's to meet the hygienic demands of the dairy industry. Design of this type of exchanger reached maturity in the 1960's with the development of more effective plate geometries, assemblies, and improved gasket material, and the range of possible applications has widened considerably. PHE's are nowadays widely used in a broad range of heating and cooling applications in food processing, chemical reaction processes, petroleum, pulp and paper, as well as in many water-chilling applications. Some basic features of PHE's include high efficiency and compactness (i.e., high heat transfer capacity per unit volume compared to conventional, shell-and-tube heat exchangers), high flexibility for desired load and pressure drop, easy cleaning, and cost competitiveness.

While PHE's became popular for liquid-to-liquid heat transfer duties, their use in phase-changing applications was not common initially. Before the 1990's such applications were mostly in the fields of concentrating liquid food and drying of chemicals. Applications in refrigeration systems were rare, mainly because of concerns over refrigerant leakage, and also because of the pressure limits required, especially on condensation applications. In the last two decades, with the introduction of semi-welded and brazed PHE's, this type of exchanger has been increasingly used in refrigeration systems, from domestic heat pumps to large ammonia installations for water-chilling duties [1].

1.2 Shell and tube heat exchanger

There are basically two types of evaporator systems in the refrigeration and air conditioning industry, flooded and direct expansion. The direct expansion, also known as dry expansion, works under the principle of total evaporation of the refrigerant with the exiting gas being dry superheated. Dry expansion shell and tube evaporators present evaporation on the tube side with water or brines flowing on the shell-side. In flooded evaporator evaporation of refrigerant takes place on the shell side while water flows on the tube side.

This exchanger is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid flow inside the tubes, the other flows across and along the tubes. The major components of this exchanger are tubes (or tube bundle), shell, frontend head, rear-end head, baffles, and tube sheets.

The three most common types of shell-and-tube exchangers are (1) fixed tube sheet design, (2) U-tube design and (3) floating-head type. In all three types, the front-end head is stationary while the rear-end head can be either stationary or floating , depending on the thermal stresses in the shell, tube, or tube sheet, due to temperature differences as a result of heat transfer.

A fixed tube sheet type of a shell and tube heat exchanger is shown in the figure. The cold fluid is flowing inside the shell while the hot fluid flows inside the tubes. Baffles direct the flow of water across the tubes so that fluid can come in contact with the tubes. Baffles are used to increase the turbulence in the flow which enhances the heat transfer in the heat exchanger.

1.3 Development of experimental set up

1.3.1 Experimental setup: The experimental set up consists of a simple vapour compression refrigeration system. In the set up PHE and the shell and tube heat exchangers are used as evaporators. The system is of 1 ton capacity. The experimental set up is as shown figure 1.

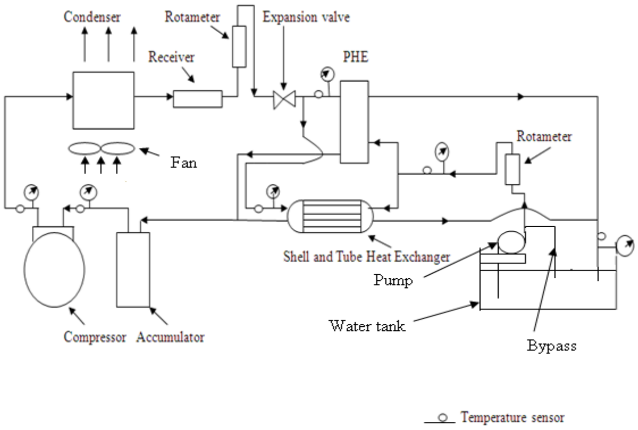

Figure 1: Layout of Experimental setup

First the experimental set up is developed for the plate heat exchanger used as an evaporator. Then the shell and tube heat exchanger are designed and manufactured. Then the shell and tube heat exchanger are installed in the set up. There are two circuits present in the system. First one is the refrigerant circuit. In this circuit there are four main components. The components are compressor, condenser, thermostatic expansion valve, plate heat exchanger and shell and tube heat exchanger used as an evaporator. The glass tube rota meter is used to measure the flow rate of the refrigerant. Pressure gauges are installed to measure the pressure of the refrigerant at inlet and at outlet of the evaporator. A digital temperature indicator is used for indication of the temperature. Bypass valves are used to put the individual systems in operation having shell and tube and plate heat exchanger as evaporators.

The other circuit is the water circuit. In the water circuit the pump is used to circulate the water through the evaporator. A water tank is used as a reservoir of water. The level of the tank is always kept full. A rota meter is used to measure the flow rate of water. A bypass valve is connected in the discharge line of the pump to vary the flow rate of water.

1.4 List of specifications of the components

Specifications of the components are given in table 1.

Table 1: List of Specification of the components

Sr. no.	Name of component	Specification	Status
1	Compressor	Hermetic type KCJ513HAE, 3.5kW capacity, Kirloskar make	Purchased
2	Plate heat exchanger	Plate dimensions - 310 (L) x 72 (W), Plate Thickness=0.4mm Actual Heat Transfer Area of plate = 0.022 m², Spacing between 2 plates = 2mm, SWEP Make	Available
3	Condenser	Size- 17”. × 22”x 3 row. Air Cooled 1type	Available
4	Shell and tube heat exchanger	Ds = 0.1216 m, Nt = 10 , Tube dia. OD=9.5mm, ID=7mm , B= 0.0605m, Ntp = 2, Square pitch layout, Lt=0.45m Pitch size= 0.0154m	Manufactured
5	Thermostatic expansion valve	TX2, orifice 0.2 Danfoss make	Purchased
6	Pressure gauge	0-150 psig (2 nos.) 0-500 psig (1 no.) 0-30 psig (2 no.) Wika make	Purchased
7	Fan motor	(1/10) HP	Purchased
8	Fan blade	16 in. dia.	Available
9	Drier	(3/8) in. connection size	Purchased
10	Pump	(1/4) HP, Kirloskar make	Purchased
11	Accumulator	1.5 TR	Purchased
12	Temperature indicator	K-type thermocouple, range (-10 to 100 º C)	Purchased
13	Refrigerant rota meter	10-100 LPH, CVG make.	Purchased
14	Water rota meter	0-600 LPH, CVG make.	Purchased
14	Voltmeter	0-20 Amp.	Purchased
15	Mains wire	20 Amp.	Purchased
16	Energy meter	0-20 Amp.	Purchased
17	Ammeter	0-20 Amp.	Purchased

1.5 Experimental work

The experimental work is carried out to predict the performance of the plate heat exchanger and shell and tube heat exchanger. The heat load on the system is varied by varying the mass flow rate of water in the evaporator. This has affected the mass flow rate of refrigerant, evaporator pressure and condenser pressure, temperature drop of water at the evaporator.

For a particular mass flow rate of water, following readings are taken.

(a) Mass flow rate of refrigerant.
(b) Evaporator and condenser pressure.
(c) Inlet and outlet temperatures at condenser and evaporator
(d) Water inlet and outlet temperature at evaporator.

Then the values for capacity of the evaporator, heat transfer rate, refrigerant side heat transfer coefficient, and overall heat transfer coefficient are calculated.

1.6 Comparison of shell and tube heat exchanger and plate heat exchanger

- **Variation of heat transfer rate with the mass flow rate of the water:** Comparison of shell and tube heat exchanger and plate heat exchanger for heat transfer rate is shown in figure 2.

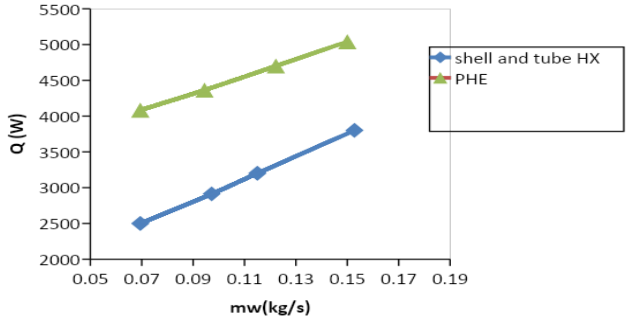

Figure 2: Comparison of shell and tube and PHE

Figure 2 shows that

(a) The heat transfer values for the given mass flow rate for PHE's are higher than the corresponding values for the shell and tube heat exchanger.
(b) This increase in heat transfer rate is about 40% for the plate heat exchanger.
(c) Therefore, PHE gives better heat transfer as compared to the shell and tube heat exchange.

- **Variation of refrigerant heat transfer coefficient with the increase in the heat flux**

Comparison of shell and tube heat exchanger and plate heat exchanger for variation of refrigerant side heat transfer coefficient with heat load is shown in following figure. Figure 3 shows that the values of refrigerant heat transfer coefficient are 50 % higher than the corresponding values of shell and tube heat exchanger.

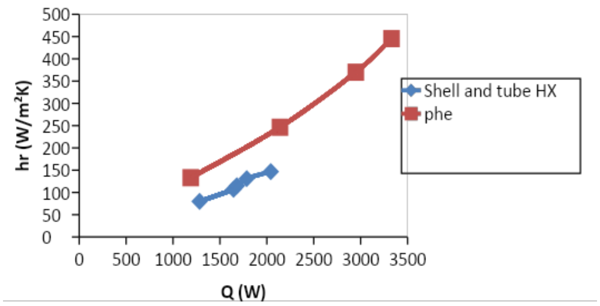

Figure 3: Variation of refrigerant heat transfer coefficient with the heat load

- **Variation of overall heat transfer coefficient with the heat load**

Effect of the heat load on the overall heat transfer coefficient of shell and tube heat exchanger and plate heat exchanger is shown in following figure. Figure 4 shows that the overall heat transfer coefficient values for PHE are higher than the shell and tube heat exchanger by small amount.

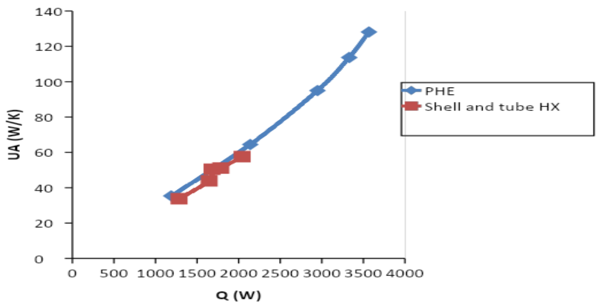

Figure 4: Variation of overall heat transfer coefficient with the heat flux

- **Surface area per unit volume**

(a) The surface area per unit volume of the plate heat exchanger is 4 times higher than the shell and tube heat exchanger.
(b) This represents the compactness of the plate heat exchanger as compared to the shell and tube heat exchanger.

- **Fouling**

(a) Since the plate heat exchanger has corrugation patterns on its plates, which leads to high turbulence of the fluid flowing through it.
(b) This reduces the fouling as well as increases the heat transfer coefficient.
(c) While in shell and tube heat exchanger the heat transfer coefficient is less due to less turbulence. Hence there is more possibility of fouling in shell and tube heat exchanger.

- **Overall volume, and space requirements**

(a) The overall volume of the shell and tube heat exchanger is 0.00551953 m^3 which is near about six times higher than the volume of the plate heat exchanger (0.0008928 m^3).
(b) The increase in volume of the shell and tube heat exchanger leads to increase in space requirement of it. While plate heat exchanger has less overall volume, therefore it can install in a very small space due to its compactness.

2. CONCLUSIONS

- The heat transfer rate and heat transfer coefficient values for plate heat exchanger are 50% higher than the shell and tube heat exchanger.
- The surface area per unit volume of the plate heat exchanger is 4 times higher than the shell and tube heat exchanger. This represents the compactness of the plate heat exchanger as compared to the shell and tube heat exchanger.
- Construction of the shell and tube heat exchanger is rugged and simple. While in case of plate heat exchangers the geometry of the plate is complicated.
- Plate heat exchanger is used in the food industries where hygienic conditions are required. Shell and tube heat exchangers are not used there due to corrosion problems.
- The overall volume of the shell and tube heat exchanger is about four times higher than the plate heat exchanger. The increase in volume of the shell and tube heat exchanger leads to increase in space requirement of it.
- Since the plate heat exchanger has corrugation patterns on its plates, which leads to high turbulence of the fluid flowing through it. This reduces the fouling as well as increases the heat transfer coefficient. While in shell and tube heat exchanger the heat transfer coefficient is less due to less turbulence. Hence there is more possibility of fouling in shell and tube heat exchanger.
- The standard plate materials for plate heat exchanger are AISI 316 stainless steel, vacuum-brazed with pure copper filler or nickel-based filler. For demanding applications, the plates can be made of SMO 254, a stainless steel with a higher content of molybdenum.
- For shell and tube heat exchanger fabrication, mild steel or stainless steel is used for the shell. For tubes, copper or stainless steel is used as the material. For baffles mild steel is used as the material.

3. ACKNOWLEDGEMENT

I like to thank my guide Mr. Joshi M. S. for their valuable guidance in the project. I would also like to thank Mr. Kamble from Refrigeration and air conditioning laboratory for helping me to build the set up. I want to thank all my M. Tech. classmates for their help in my project work.

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