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EXPERIMENTAL AND INVESTIGATION OF SHELL AND TUBE HEAT EXCHANGER

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Abstract:

The main objective of the research work aims to study on the heat transfer characteristics of various heat exchangers namely Shell and Tube Heat Exchanger, Cross Flow Plate Fin Heat Exchanger, Spiral Heat Exchanger and Plate Type Heat Exchanger using both miscible and immiscible systems. The various parameters employed in determining the heat transfer characteristics include Reynolds number, Nusselt number, Overall Heat Transfer Coefficient, Capacity Ratio, Number of Transfer Units (NTU), Effectiveness and Efficiency. Experiments are conducted on a 1-1 Shell and Tube Heat Exchanger, Spiral Heat Exchanger and Plate Type Heat Exchanger for parallel and counter current flow patterns with different cold side flow rates, and different composition (9%, 10%, 20% and 25% on volume basis) of cold fluid.

***Keywords* :Heat exchanger, Heat transfer.**

I. INTRODUCTION

Heat exchangers are a vital part of chemical engineering process designs. To illustrate, in prototype testing, an inventor discovers that his new device is prone to overheating, even though heat sinks are already installed to provide cooling to the system. To solve this problem, the engineer decides to install a heat exchanger into the system. A heat exchanger is a device that is commonly used when heat sinks alone cannot prevent a device from overheating . The most well-known application of heat exchangers are car radiators.Radiators use antifreeze to transfer heat energy from the engine, to the air surrounding the car.

Regenerative heat exchangers are a unique type of heat exchanger that are used to maintain a temperature, rather than vary it. In order to achieve this, initial thermal energy from a fluid is used to reheat that same fluid as it loses its thermal energy heat exchanger. Conversely, plate heat exchangers have many thin plates inside with small gaps between each plate. Alternating fluid then flows through each gap, causing the two fluids to exchange thermal energy. This type of heat exchanger can be used to either cool, or heat a fluid. Plate heat exchangers are commonly used in household refrigerators. Similar to a plate heat exchanger, a shell and tube heat exchanger utilizes two separate fluids to transfer thermal energy from one to the other. To achieve this, one fluid is routed through a tube inside a hollow shell. The shell has the second fluid flowing through it, allowing heat to transfer between the two. Shell and tube heat exchangers are used widely in many different chemical processes because of their numerous advantages. Shell and tube heat exchangers are capable of having a large surface area for heat transfer to take place. This is because of their numerous tubes. This design also minimizes the necessary overall length. Shell and tube heat exchangers also offer a lot of versatility when it comes to operating pressure and temperature. Since there are limited pressure and temperature restrictions, small shell and tube heat exchangers can accommodate a higher heat duty. This is because additions can be made to neglect thermal expansion effects as well as variations to the thickness of the exchanger. The number of tubes and different types of baffles needed can be designed and implemented based off of specific operation conditions. One of the main concerns with shell and tube heat exchangers is they are susceptible to vibration problems caused from the fluid flowing throughout the pipes. Although the baffles within the system help hold these tubes in place to reduce vibrations, problems can still arise. Another concern is the maintenance of the tubes, which can be difficult. Because of this, fouling can occur. Buildup can greatly affect the overall heat transfer coefficient and efficiency of the unit. When assessing these issues, observations of the heat energy gained or lost by the system must be accomplished. For this experiment the equation used to determine this energy is

$$Q=MCp\Delta T.$$

M is the mass flow rate of the water, and is a measure of the flow of water into the system. In order for proper calculations, data must be collected when the system is at steady state. Cp is the specific heat capacity of the material, which is the amount of energy per unit mass required to raise the temperature of a substance by one degree. ΔT is the change in temperature of the fluid throughout the system.

This calculation is done for the cold and hot side of the heat exchanger to obtain Qcold and Qhot. To determine the efficiency of the unit, the equation

$$Q_{hot}= Q_{cold} + Q_{loss} \quad (2)$$

can be used to determine Q loss. This quantity will determine how much heat has been lost during the experiment. Since the shell-side is the hot side, some of the energy escapes through conduction to the outside environment, contributing to this value. For an efficient system, Q loss should be minimized. Another calculation used when analyzing heat exchange is calculating heat transfer between two elements. The equation used is

$$Q = UA\Delta T_{lm}F. \quad (3)$$

U is the overall heat transfer coefficient. This heat transfer coefficient is a function of the fluid properties and material composition of the heat exchanger. U varies based on the design of the heat exchanger. Q in this equation is calculated from Equation 1, and is the energy gained or lost by the system. F is a correction factor that must be used for this heat exchanger to accommodate for concurrent or parallel flow in the heat exchanger. In opposition, counter current flow occurs when the streams are flowing in opposite directions. This leads to a constant flow of heat at each point of contact and a higher rate of heat transfer. For this heat exchanger F is 0.96. A is the heat transfer surface area for the tubes which is 50 square inches. ΔTlm is the log mean temperature difference and can be calculated by using the equation

$$(\Delta T2-\Delta T1)/\ln(\Delta T2/\Delta T1) \quad (4)$$

where ΔT1 and ΔT2 are

$$\Delta T2 = T(hot, in) - T(cold, out), \quad (5)$$

and

$$\Delta T1 = T(hot, out) - T(cold, in). \quad (6)$$

The log mean temperature difference is unlike the other ΔT’s calculated in previous equations. It is the temperature difference between two streams. In previous calculations, ΔT was simply the temperature change over each single stream analyzed. Since in the system, temperatures are constantly changing along a path, the log mean temperature difference is used to give an average temperature gradient.

The two technical objectives of the experiment are to evaluate the effect of the tube-side flow rate and shell-side flow rate on the steady-state heat duty and the overall heat transfer coefficient of the heat exchanger. To accomplish this, flow rates were adjusted on one side, while keeping the other side constant. The data used from steady state was used to determine how a difference in flow rate affected the calculated values.

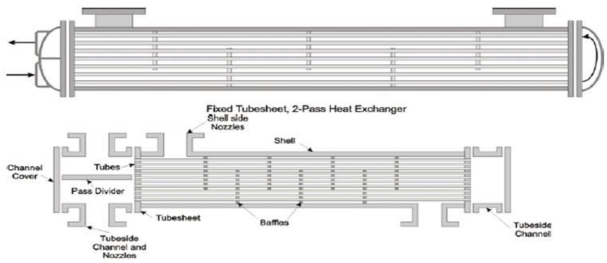
I. THERMAL DESIGN

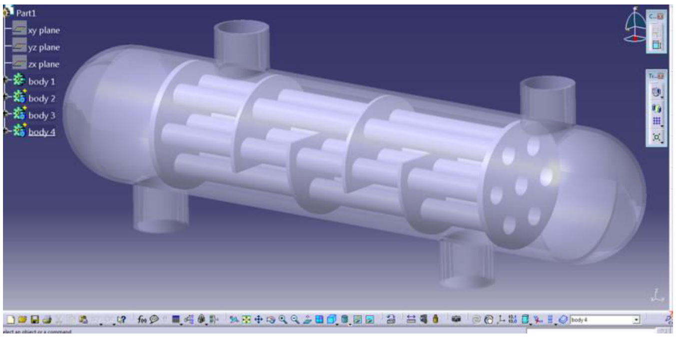
The thermal design of a shell and tube exchanger is an iterative process which is normally carried out using computer programs from organizations such as the Heat transfer and Fluid Flow Service (HTFS) or Heat Transfer Research

Incorporated (HTRI). However, it is important that the engineer understands the logic behind the calculation. In order to calculate the heat transfer coefficients and pressure drops, initial decisions must be made on the sides the fluids are allocated, the front and rear header type, shell type, baffle type, tube diameter and tube layout. The tube length, shell diameter, baffle pitch and number of tube passes are also selected and these are normally the main items that are altered during each iteration in order to maximize the overall heat transfer within specified allowable pressure drops.

II. MECHANICAL DESIGN

The mechanical design of a shell and tube heat exchanger provides information on items such as shell thickness, flange thickness, etc. These are calculated using a pressure vessel design code such as the Boiler and Pressure Vessel code from ASME (American Society of Mechanical Engineers) and the British Master Pressure Vessel Standard, BS 5500. ASME is the most commonly used code for heat exchangers and is in 11 sections. Section VIII (Confined Pressure Vessels) of the code is the most applicable to heatexchangers but Sections II—Materials and Section V—Non Destructive Testing are also relevant. Both ASME and BS5500 are widely used and accepted throughout the world but some countries insist that their own national codes are used. In order to try and simplify this the International Standards Organization is now attempting to develop a new internationally recognized code but it is likely to be a some time before this is accepted.





FRONT VIEW OF HEAT EXCHANGER

SIDE VIEW OF HEAT EXCHANGER

III. CALCULATION PROCEDURE

The main steps in the calculation are given below together with calculation methods in the open literature:

1. Calculate the shell side flow distribution [Use *Bell-Delaware Method*, see Hewitt, Shires, and Bott (1994)].
2. Calculate the shell side heat transfer coefficient (Use Bell- Delaware Method)
3. Calculate tube side heat transfer coefficient (see, for example, Tubes: Single Phase Heat Transfer In).
4. Calculate tube side pressure drop (see, for example, Pressure Drop, Single Phase).

5. Calculate wall resistance and overall heat transfer coefficient (see *Overall Heat Transfer Coefficient* and Fouling).
6. Calculate mean temperature difference (see Mean Temperature Difference).
7. Calculate area required.
8. Compare area required with area of assumed geometry and allowed tube side and shell side pressure drop with calculated values.
9. Adjust assumed geometry and repeat calculations until Area required is achieved within the allowable pressure drops.

Books by E. A. D. Saunders [Saunders (1988)] and G. F. Hewitt, G. L. Shires, and T. R. Bott [Hewitt et al. (1994)] provides a good overview of tubular thermal design methods and example calculations.

IV. OBSERVATION AND CALCULATION

Shell Flow Rates (according to flow meter)						
Time (s)	Weight of water (kg)	Flow (kg/s)	Flow (gal/min)	Flow (lbm/s)	Average (lbm/s)	Std. Dev.
5 gpm, with hose						
27.41	9.02	0.329	5.225	0.726		
25.28	8.51	0.337	5.345	0.742		
27.88	9.29	0.333	5.291	0.735		
28.22	9.42	0.334	5.300	0.736	0.735	0.007
10 gpm, with hose						
13.10	8.57	0.654	10.388	1.443		
14.13	9.44	0.668	10.608	1.473		
15.09	9.73	0.645	10.239	1.422		
13.34	8.81	0.660	10.487	1.456	1.448	0.022
18 gpm, full flow						
7.85	8.93	1.138	18.064	2.508		
7.63	8.59	1.126	17.877	2.482		
7.59	8.48	1.117	17.741	2.464		
7.84	8.8	1.122	17.823	2.475		
7.69	8.69	1.130	17.944	2.492	2.484	0.017

Tube Flow Rates (according to computer)						
Time (s)	Weight of water (kg)	Flow (kg/s)	Flow (gal/min)	Flow (lbm/s)	Average (lbm/s)	Std. Dev.
Valve open 50%, or 16.5 gpm						
8.29	7.59	0.916	14.538	2.019		
9.28	8.67	0.934	14.835	2.060		
8.88	8.14	0.917	14.556	2.021		
9.34	8.55	0.915	14.536	2.018	2.030	0.020
valve open 75%, or 31 gpm						
3.94	7.85	1.992	31.637	4.393		
4.31	8.24	1.912	30.358	4.216		
3.97	7.86	1.980	31.438	4.366		
3.94	7.94	2.015	32.000	4.444	4.354	0.098
valve open 100%, or 35 gpm						
3.41	8.15	2.390	37.951	5.270		
3.63	8.74	2.408	38.232	5.309		
3.37	7.96	2.362	37.506	5.208		
3.41	7.99	2.343	37.206	5.167	5.238	0.063

CALCULATION

Sample Calculation for Shell Side Reynolds Number

$$a_s = \frac{D_s c' B}{P_T} = \frac{6in(0.875in - 0.75in)(30.625in - 23.5in)}{0.875in} = 6.107in^2$$

$$De = \frac{4\left(\frac{\sqrt{3}}{4}P_T^{\,2} - \frac{\pi}{8}d_o^{\,2}\right)}{\frac{d_o\pi}{2}in} = \frac{4\left(\frac{\sqrt{3}}{4}(0.875in)^2 - \frac{\pi}{8}(0.75in)^2\right)}{\frac{0.75\pi}{2}in} = 0.376in$$

$$V_s = \frac{\dot{m}_s}{a_s\rho_s} = \frac{2.484\frac{lbm}{s}}{(6.107in^2)\left(\frac{1ft}{12in}\right)^2\left(62.43\frac{lbm}{ft^3}\right)} = 0.938\frac{ft}{s}$$

$$\mathrm{Re}_{shell} = \frac{DeV_s\rho_s}{\mu_s} = \frac{(0.3756in)\left(\frac{1ft}{12in}\right)\left(0.938\frac{ft}{s}\right)\left(62.43\frac{lbm}{ft^3}\right)}{6.73\cdot10^{-4}\frac{lbm}{ft\cdot s}} = 2723.49\,.$$

Sample Calculations for Tube Side Reynolds Number

$$a_t = \frac{n_t\left(\frac{\pi}{4}d_i^2\right)}{N_p} = \frac{28\left(\frac{\pi}{4}\right)(0.625in)^2}{2} = 4.295in^2$$

$$\mathrm{Re}_{tube} = \frac{d_i\dot{m}_t}{\mu_t a_t} = \frac{(0.625in)\left(5.238\frac{lbm}{s}\right)\left(\frac{1ft}{12in}\right)}{\left(6.73\cdot10^{-4}\frac{lbm}{ft\cdot s}\right)(4.295in^2)\left(\frac{1ft}{12in}\right)^2} = 13590.91\,.$$

V. ADVANTAGES

- Can be used in systems working under high temperatures and pressures
- Pressure drop across a tube cooler is less
- Less expensive than other types such as plate exchangers
- Tube leaks can easily spotted and plugged since pressure test is comparatively easy
- Easy to repair
- Tubular coolers in refrigeration system can act as receiver also.

VI. CONCLUSION

Ultimately, the goal of this experiment was to determine the effects of altering the flow rates of a small shell and tube heat exchanger. The two technical objectives of the experiment were to evaluate the effect of variations in flow of the cold, tube-side, and hot, shell-side of a shell and tube heat exchanger. These changes were observed through the steady-state heat duty and the overall heat transfer coefficient of the heat exchanger.

From the results, it can be concluded that as the flow rate of a shell and tube heat exchanger is altered, an effect on the heat duties, log mean temperature difference, and the heat transfer coefficient can be observed. When the cold side flow rate was incremented, the resulting heat duties for the cold side and hot side increased proportionately, resulting in a constant Q loss .When the hot side flow rate was 15incremented, both the heat duties of the cold side and hot side again increased, but the heat duty of the hot side increased at a faster rate. This resulted in more energy lost.

These results were confirmed when trial three was run. Although, the slight increase of Q loss in trials two and three did not have a noticeable effect on the log mean temperature difference and the heat transfer coefficient trends. All three of the trials noticed a decrease of the log mean temperature difference and an increase of the heat transfer coefficient as the flow rate for the heat exchanger increased. This means that increasing flow allows for more heat to be transferred between the two fluids.

These results can be very important when it comes to maximizing the efficiency of a shell and tube heat exchanger. In order to achieve maximum efficiency, an engineer can take a desired temperature needed and design the heat exchanger. By taking into account the size and flow rate, the desired temperature can be reached while maximizing efficiency and reducing costs.

Since altering the flow rate effects the heat transfer as proven by this experiment, flow rate is a vital part of the design in a shell and tube heat exchanger. Consequently, it is possible to increase efficiency of a heat exchanger by increasing flow rate while decreasing the temperature of the heating fluid in a case where a heat exchanger is used to increase the temperature of a cooler fluid. This means that less energy would be needed to reach the necessary temperature of the fluid being heated.

Therefore, the results from this experiment lead to information that will help to optimize the shell and tube heat exchanger. Since heat exchangers are very common in industry, designing a maximum efficiency heat exchanger at minimal costs will have a vast impact in furthering the development of the industrial world.

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