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Design, Fabrication and Testing Of FRP Shell Counter-Flow Heat Exchanger

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Abstract: We know heat exchanger as an apparatus or equipment in which the process of heating or cooling occurs, the heat is transferred from one fluid being cooled to another fluid being heated. The transfer of heat in an exchanger between two fluids could be carried out through direct contact of fluids or transmission through the value separating the fluids. So efforts are made to design the counter flow heat exchanger using the empirical application of practical formulas by estimation heat rate that is required to be transferred, estimation of heat transfer area in counter heat exchanger, and determination of number of pipe for particular length of heat exchanger. This study is specific to conventional single pass counter flow heat exchanger design to assure judiciously customization of counter flow heat exchanger inline with the system parameter requirements to yield optimal solutions. This will help industry to converse heat energy, which is very vital when it comes to saving cost of fuels, if applied properly. The world is moving towards green management with activities of recovering heat if properly adopted with customizing will no only help organization but also society as a whole.

Index Terms: **Design of heat exchanger, counter flow heat exchanger, effectiveness of heat exchanger.**

I. INTRODUCTION

Heat exchange is an apparatus or equipment in which the process of heating or cooling occurs, the heat is transferred from one fluid being cooled to another fluid being heated. The transfer of heat in an exchanger between two fluids could be carried out through direct contact of fluids or transmission through the value separating the fluids. The former type is called direct contact heat exchanger while the later as regenerators, recuperators or surface heat exchangers. Direct contact heat exchanger: The process of heat transfer occurs through direct contact and mixing of the hot and cold fluids.

In regenerators: The hot and cold fluids flow alternatively. The heat carried by the hot fluid is accumulated in the valves of the equipment and is then transferred to cold fluid when it is passes over the surface next.

The heat transfer process consists of convection between the fluids and wall, conduction through the wall and convection between the wall and other fluid. In case temperature difference between a wall and fluid is large, radiation heat exchange may also occurs. Such heat exchangers are used where cooling and heating fluids can not be allowed to mix. The economizer, air pre heaters of boiler plant, radiators of motor car and milk chillers of pasteurizing plant all belong to this category.

II. PRINCIPLE OF HEAT EXCHANGER

It is based on the principle that heat transfer takes place between to bodies at different temperatures, from the one at higher temperature to one at lower temperature.

III. CLASSIFICATION OF HEAT EXCANGER

According to their working features hear-exchangers are classified into the following groups:

A. RECUPERATIVE

Two fluids performing the heat exchange of heat in the exchanger can flow.

- With each other in same direction (Parallel)
- In opposite direction (Counter-flow)
- At right angle to one another (Cross-flow)

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- With both type of flow a single or multi-pass arrangement is possible.

B. REGENRATIVE

In this type the hot and cold fluids flow through one and same passage and heated surface I alternatively exposed to hot and cold fluids. Therefore the periods of heating and cooling's are of equal duration, continuous heating requires two apparatus, while the hot fluid is cooled in apparatus, the cold fluid is heated in the other. After that the apparatus is switched over and heat-transfer process reversed. This is also known as storage type heat exchanger. It has complex temperature distribution and temperature differences, in time and space precise calculations.

C. MIXED TYPE HEAT EXCHANGER

As the name implies, the two fluid between which heats is to be exchanged are mixed with one another. The fluids are directly in contact with each other. It is more complex phenomenon of heat transfer where heat and mass transfer takes place simultaneously

IV. ASPECTS CONSIDERATION FOR HEAT EXCHANGERS DESIGN

When heat exchanger are designed for particular application following consideration are taken:

- Thermal analysis and heat transfer requirement.(Fig. 2)
- The preliminary mechanical design
- Design for manufacture (Fig. 1)
- Pressure drop characteristics.
- Physical size and features (Fig.3)
- Cost

Thermal analysis s concerned with the determination of the heat transfer surface area required to transfer at specified rate for the given flow rand temperatures of the fluids. By forcing the fluid at higher velocities

A. COUNTERFLOW IN HEAT EXCHANGER

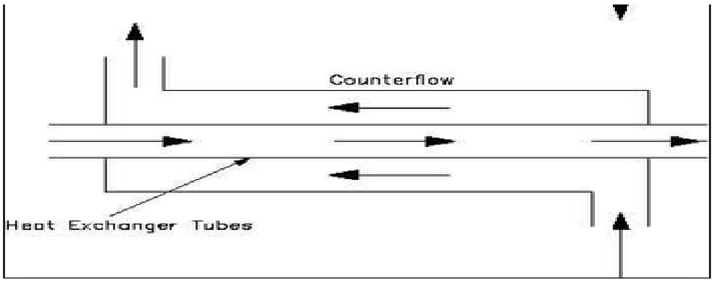

Fig 1. Counter flowing fluid in heat exchanger

A primary advantage of a hairpin or double pipe heat exchanger is that it can be operated in a true counter flow pattern, which is the most efficient flow pattern. That is, it will give the highest overall heat transfer coefficient for the double pipe heat exchanger.

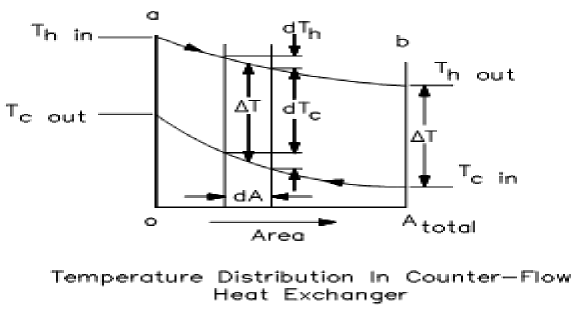

Fig. 2.

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Also, hairpin and double pipe heat exchangers can handle high pressures and temperatures well. When they are operating in true counter flow, they can operate with a temperature cross, that is, where the cold side outlet temperature is higher than the hot side outlet temperature.

For example, in the diagrams in this section, consider Fluid $_1$ to be the hot fluid and Fluid $_2$ to be the cold fluid. Then, in the counter flow diagram at the left, you can see that the cold side outlet temperature, T_{2out}, can approach the hot side entering temperature, T_{1in}, which is higher than the hot side outlet temperature, T_{2out}. For the parallel flow shown at the right, T_{2out} can only approach T_{1out}; it could not be greater.

Fig 3. The Skeleton of Counter flow Heat Exchanger

V. DESIGNING OF COUNTERFLOW HEAT EXCHANGER

Design of heat exchangers is an iterative (trial & error) process. Here is a set of steps for the process

- Calculate the required heat transfer rate, Q, in Btu/hr from specified information about fluid flow rates and temperatures.
- Make an initial estimate of the overall heat transfer coefficient, U, based on the fluids involved.
- Calculate the log mean temperature difference, ΔT_{lm}, from the inlet and outlet temperatures of the two fluids. (See more details in the next two sections.)
- Calculate the estimated heat transfer area required, using: $A = Q/(U\ \Delta T_{lm})$.
- Select a preliminary heat exchanger configuration.
- Make a more detailed estimate of the overall heat transfer coefficient, U, based on the preliminary heat exchanger configuration.
- Estimate the pressure drop across the heat exchanger. If it is too high, revise the heat exchanger configuration until the pressure drop is acceptable.
- If the new estimate of U is significantly different than the previous estimate, repeat point # 4 through 7 as many times as necessary until the two estimates are the same to the desired degree of accuracy.

Formulae used

$Q = \pm (m_1)(C_{01})(T_{1in} - T_{1out})$
$Q = \pm (m_2)(C_{02})(T_{2in} - T_{2out})$
$\Delta T_{lm} = [(T_{1in} - T_{2out}) - (T_{1out} - T_{2in}) / \ln[(T_{1in} - T_{2out})/(T_{1out} - T_{2in})]$

A. ESTIMATION OF HEAT TRANSFER RATE

Inputs				**Calculations**		
Fluid$_1$ Mass Flow				**Heat Transfer Rate, Q=**	**925.000**	**Btu/hr**
Rate, m_1=	**25.000**	**lb/hr**				
				Log Mean Temp	**79.58**	**^{0}F**
Fluid$_1$ Temp. in, T_{1in} =	**190**	**^{0}F**		**Diff., ΔT_{lm} =**		
Fluid$_1$ Temp. out, T_{1out}=	**140**	**^{0}F**		**Heat Transfer Area, A=**	**96.86**	**ft^2**

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Fluid1 sp. Heat, C_{p1}=	**0.74**	**Btu/lb-^{0}F**		**Fluid$_2$ Mass Flow**		
				Rate , m_2=	**55.00**	**lb/hr**
Fluid$_2$ Temp.in, T_{2in}=	**50**	**^{0}F**				
Fluid$_2$ Temp.out, T_{2out}=	**120**	**^{0}F**				
Fluid$_2$ sp.heat, C_{p2}=	**1.0**	**Btu/lb-^{0}F**				
Over all Heat Transf.						
Coeff. Estim.,U=	**120**	**Btu/hr-ft^2-^{0}F**				

B. CALCULATIONS OF HEAT EXCHANGE AREA

Calculatation of preliminary estimate of the heat exchanger area needed for cooling 55,000 lb/hr of a light oil (specific heat = 0.74 Btu/lb-^{0}F) from 190^{o}F to 140^{0}F using cooling water that is available at 50^{0}F. The cooling water can be allowed to heat to 90^{0}F. An initial estimate of the overall heat transfer coefficient is 120 Btu/hr-ft^2-^{0}F. Also calculated the required mass flow rate of cooling water

Calculate the required heat transfer rate based on the required light oil cooling:

$$Q = (55{,}000 \text{ lb/hr})(0.74 \text{ Btu/lb-}^0\text{F})(190 – 140)^0\text{F} = 2{,}035{,}000 \text{ Btu/hr}.$$

Next calculate the log mean temperature difference:

$$\Delta T_{lm} = [(190 – 90) – (140 – 50)]/\ln[(190 – 90)/(140 – 50)] = 94.9^0\text{F}$$

The preliminary area estimate can now be calculated as:

$$A = Q/(U\ \Delta T_{lm}) = 2{,}035{,}000/(120)(79.58) = 178.7 \text{ ft}^2 = A$$

The required mass flow rate of water can be calculated from $Q = m\ Cp\ \Delta T$.

Rearranging: $m = Q/Cp\ \Delta T$ = (2,035,000 Btu/hr)/(1 Btu/lb-0F)(400F) = 50,875 lb/hr

C. DETERMINATION OF PIPE LENGTH NEEDED (For known heat transfer area)

Inputs				Calculations		
Heat Transfer Area, A=	96.86	ft^2		Tube Diam. In ft, D=	0.5000	ft
(from calculations above)				Pipe length needed, L=	61.7	ft
Pipe Diameter, D_{in}=	6	in				
(in inches)						

Formule Used

$D = D_{in}/12$
$A = \Pi DL$

D. ESTIMATION OF NUMBER OF TUBES

A shell and tube heat exchanger is to be used for the light oil cooling described above , so we estimated number of tubes of 3 inch diameter and 10 ft length
Formula Used $A = \pi DL$

The surface area per tube will be $\pi DL = \pi(3/12)(10)$ ft^2 = 7.854 ft^2. The number of tubes required would thus be:

n = 178.7 ft^2/7.854 ft^2/tube = 22.7 tubes (round up to 23 tubes).

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The next step would be to check on the pressure drop for this tube configuration and the specified flow. If the pressure drop is acceptable, then the overall heat transfer coefficient could be re-estimated for this heat exchanger configuration.

VI. PROCEDURE FOR EXPERIMENT

To start the heat exchanger turns on the power switch and set the temperature controller to the desired temperature (60-70 ^{0}C). Turn off both of the control valves to allow the holding tank to heat without losing heat through the exchanger. Turn on the cold water at the faucet. Bleeding of the system can be accomplished by the valves located near the temperature mid thermometers. Slowly turn the valve until all the air is out. Do this for both of the valves First, set the following initial conditions: Controlled heat water temperature = 60 ^{0}C ; V_h = 2000 cc/min ; V_c = 1000 cc/min, Set the apparatus up for counter flow and repeat the other steps from 2. Calculate the power emitted, power absorbed, power lost, log mean temperature difference, overall heat transfer coefficient, and the efficiency. For heat exchanger specifications see the panel located on the apparatus. Plot the temperature distributions. Plot the graph

VII. GRAPHICAL OBSERVATION ON TEMPERATURE EFFICIENCY VS VELOCITY FLOW

The transferred heat of the studied cross flow heat exchanger with entry values as stated to the left is shown in the graph below (Fig. 4)

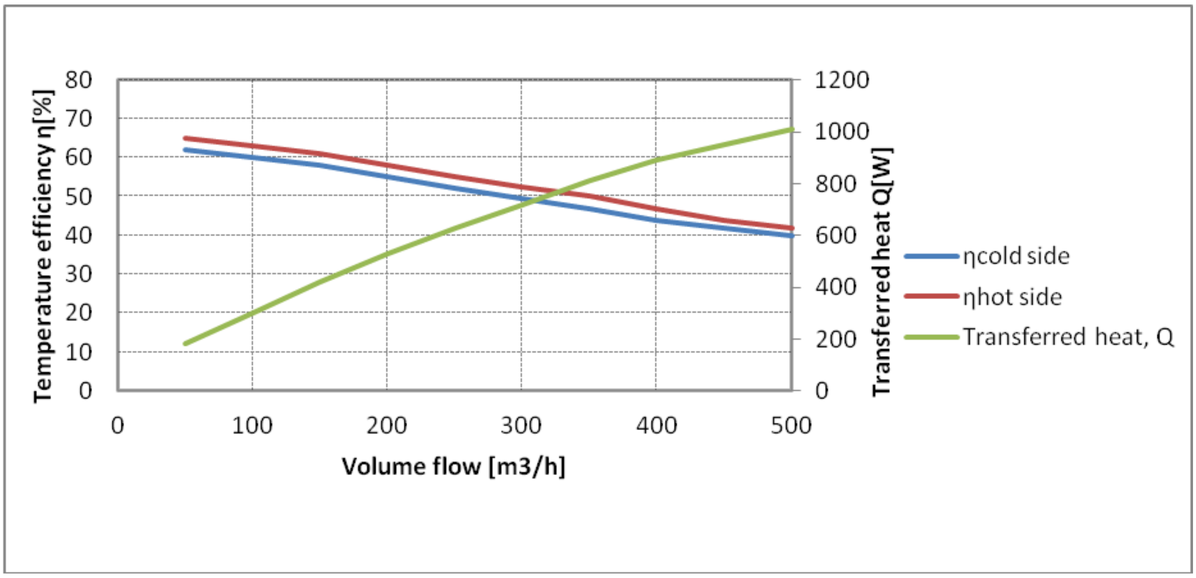

Fig 4. Graph against temperature efficiency vs volume flow (http://www.segerfrojd.com/performance.htm)

The transferred heat can also be affected by the heat exchanger design. The higher heat transfer area to volume ratio, gives a higher transferred heat to the cost of higher pressure drops.

In the graph above there are two plotted lines for the temperature efficiency. This is due to the fact that the temperature efficiency is defined differently for the hot and the cold media. The temperature efficiency is increased when taking counter flow effects into account. The cross flow heat exchangers can be mounted in two-stages or multiple-stages taking advantageous counter flow effects into account. This will also enable higher temperature efficiencies.

VIII. CONCLUSION

Engineers can evaluate increasing heat exchanger performance through a logical series of design steps. First identify the parameters which are crucial for counter flow heat exchanger. Heat transfer area plays major role to provide the effective performance. If number of tubes are correctly identified for the particular volume of flow than, we believe exchanger is correctly built to match the requirement. This will assure optimal performance with effectiveness.

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