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Thermal Design Procedure for Shell and Tube Heat Exchanger

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ABSTRACT: Transfer of heat from one fluid to another is an important process for most of industries. Heat transfer equipment for exchanging heat from one fluid to another fluid is generally called Heat Exchanger. Amongst of all type of exchangers, shell and tube exchangers are most commonly used heat exchange equipment. In this paper entitled as “Thermal Design Procedure for Shell and Tube Heat Exchanger” gives the relevant information about thermal design procedure. The basic procedures for calculation of Heat transfer and pressure drop calculation are revealed in this manuscript.

KEYWORDS: Sizing, Bell’s Method, fouling, heat transfer, heat exchanger.

I. INTRODUCTION

Shell and tube heat exchangers are becoming the most popular device for the transfer of heat in industrial process applications. Shell and tube heat exchangers transfer large amounts of heat at a relatively lost cost, provide cost effective tube surface while minimizing the requirements of floor space, liquid volume and weight and are available in a variety of diameters and lengths. Shell and tube heat exchangers have been around for over 150 years. Their thermal technology and manufacturing methods are well defined and applied by the modern manufacturer [1]. Tube surfaces range from standard to exotic metals with plain or enhanced surface characteristics. They can help provide the least costly mechanical design for the flows, liquids and temperatures involved.

II. THERMAL DESIGN PROCEDURES

The overall design procedure of a shell and tube heat exchanger is quite lengthy and hence it is necessary to break down this procedure into distinct steps [5]:

1. Approximate sizing of shell and tube heat exchanger.
2. Evaluation of geometric parameters also known as auxiliary calculations..
3. Correction factors for heat transfer and pressure drop.
4. Shell-side heat-transfer coefficient and pressure drop.
5. Tube-side heat-transfer coefficient and pressure drop.
6. Evaluation of the design.

2.1 Approximate Sizing of a Shell and Tube Heat Exchanger by Bell's Method

The approximate design involves arriving at a tentative set of heat exchanger parameters and if the design is accepted after rating then this becomes the final design. Various stages of approximate design include the following:

- Compute heat-transfer rate required
- Compute overall heat-transfer coefficient
- Compute the heat-transfer area required
- Design the geometry

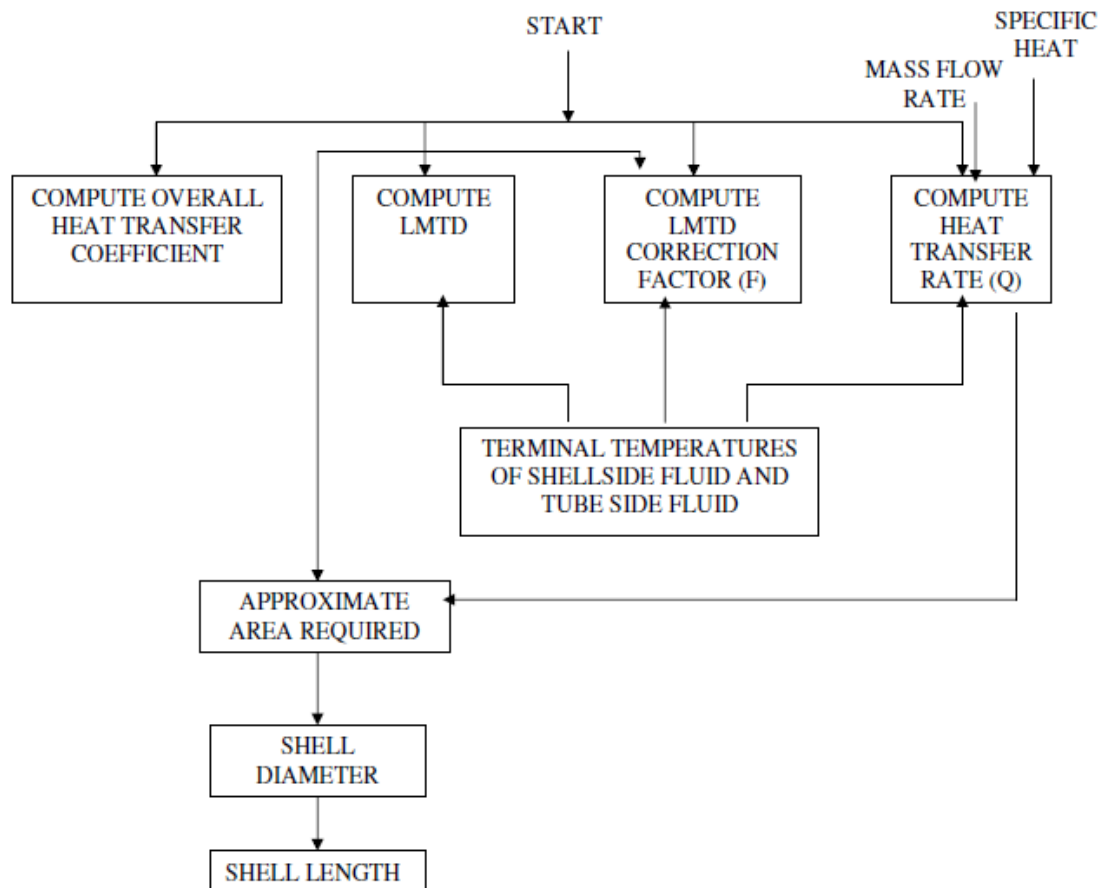
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2.2 A flow chart for approximate sizing



2.3 Estimation of Heat Load.

The heat load is calculated in-the general case from

$$Q = M_h C_{ph}(T_{h,i} - T_{h,o}) = M_c C_{pc}(T_{c,o} - T_{c,i})$$

Where $C_{p,h}$ and $C_{p,c}$ are the specific heats of the hot and cold fluids, $T_{h,i}$ and $T_{h,o}$ are the inlet and outlet temperatures of the hot stream, and $T_{c,i}$ and $T_{c,o}$ are the inlet and outlet temperatures of the cold stream.

2.4 Estimation of Log Mean Temperature Difference

Determine the logarithmic mean temperature difference for countercurrent flow using the temperatures as defined earlier:

$$LMTD = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln[(T_{h,i} - T_{c,o}) / (T_{h,o} - T_{c,i})]}$$

2.5 LMTD Correction Factor

Values of F can be found from the thermal relation charts for a variety of heat exchanger flow configurations. However, for estimation purposes, a reasonable estimate may often be obtained without restoring to the charts [2].

1. For a single tube pass, purely countercurrent heat exchanger, $F = 1.0$.
2. For a single shell with any even number of tube-side passes, F should be between 0.8 to 1.0.

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2.6 Method to Determine Number of Shells

Quickly check the limits:

$2T_{h,o} \geq T_{c,i} + T_{c,o}$ hot fluid on the shell side

$2T_{c,o} \leq T_{h,i} + T_{h,o}$ cold fluid on the shell side

If these limits are approached, it is necessary to use multiple $1-2N$ shells in series. There is a rapid graphical technique for estimating a sufficient number of $1-2N$ shells in series. The procedure is discussed here. The terminal temperatures of the two streams are plotted on the ordinates of an arithmetic graph paper sheet. The distance between the ordinates is arbitrary: starting with the cold fluid outlet temperature, a horizontal line is laid off until it intercepts the hot fluid line. From that point a vertical line is drawn to the cold fluid temperature. The process is repeated until a vertical line intercepts the cold fluid operating line at or below the cold fluid inlet temperature. The number of horizontal lines (including the one that intersects the right-hand ordinate) is equal to the number of shells in series that is clearly sufficient to perform the duty. Following this procedure will usually result in a number of shells having an overall F close to 0.8 [3, 4].

2.7 Estimation of U

The greatest uncertainty in preliminary calculations is estimating the overall heat-transfer coefficient. Approximate film coefficients for different type of fluids are given by Bell [6]. Thus, U can be calculated from the individual values of heat-transfer coefficient on the shell side and tube side, wall resistance, and fouling resistance (R_{fo} and R_{fi}), using the following equation:

$$U = \frac{1}{\left[\frac{1}{h_s} + R_{fo} + \frac{t_w}{k_w} \frac{A_o}{A_m} \left(R_{fi} + \frac{1}{h_i} \right) \frac{A_o}{A_i} \right]}$$

where t_w is the wall thickness and A_m is the effective mean wall heat-transfer area, which is approximated by the arithmetic mean, using the outside and inside radii, r_o and r_i :

$$A_m = pL(r_o + r_i)$$

For a bare tube:

$$\frac{A_o}{A_i} \rightarrow \frac{r_o}{r_i}$$

$$\frac{A_o}{A_m} \rightarrow \frac{r_o}{r_o + r_i}$$

2.8 Heat-Transfer Coefficient for Finned Tubes.

Bell suggests that the values given for plain tubes can be usually be used with caution for low-finned tubes if the controlling resistance is placed on the shell side; the values should be reduced by 10-30% if the shell-side fluid is of medium or high viscosity, and by 50% if the shell-side fluid is of high viscosity and is being cooled., reducing the value for finned tubes to 90% of those of plain tubes.

2.9 Fouling Resistance.

Fouling resistance values may be chosen from TEMA

Calculation of A_o , Once q , U , LMTD, and F are known, the total outside heat transfer area (including fin area) A_o is readily found from the following equation:

$$A_o = \frac{q}{UF(LMTD)}$$

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III. DETERMINATION OF SHELL SIZE AND TUBE LENGTH FROM HEAT TRANSFER AREA, A_o

The problem now arises of how to interpret the value of A_o in terms of tube length and shell diameter, when both values are not known. If the problem specification specifies the limitation on shell length and diameter, the problem can be simplified. In the absence of these values, A_o is given by

$$A_o = \pi d L_{ta} N_i$$

and for estimation purposes, the tube count N_i is given in terms of tube pitch, L_{tp} by

$$N_i = \frac{0.78 D^2 c t l}{C_i L_{tp}^2}$$

where C_i is the tube layout constant given by

$$C_i = 0.86 \quad \text{for } \theta_{tp} = 30^\circ$$

$$C_i = 1.0 \quad \text{for } \theta_{tp} = 45^\circ \text{ and } 90^\circ$$

Substituting the above equation, resulting equation is given by:

$$A_o = (0.78\pi) \frac{d}{C_i L_{tp}^2} [L_{ta} D^2 c t l]$$

IV. RESULTS AND DISCUSSIONS

In above equation, the first term is a constant. The second term reflects the tube size and tube layout geometry; and the third term includes the values of tube length and shell diameter (known as aspect ratio), which are the items to be determined. Heat-transfer surface A_o can be obtained by various combinations of length and diameter for any given tube layout pattern. An initially assumed aspect ratio of 8 is suggested. Some tube count tables are available in Refs. 8, 10, 11, 12, and 21, for various tube layout patterns, tube diameters, and shell diameters. This helps to calculate A_o easily. If such a source is not available, the designer must assume a rational tube length and calculate the corresponding diameter $Detl$ and finally the shell inside diameter.

V. CONCLUSION

This manuscript has studied the "Thermal Design Procedure for shell and tube heat exchanger" and shown the procedure to calculate heat load, LMTD, Correction factor, Overall heat transfer coefficient, Determination of shell of Heat Exchanger, Shell inside diameter.

Nomenclature

Q	Heat transfer rate	F	LMTD correction factor
U	Overall heat transfer coefficient	T_{hi}	Inlet fluid temperature (hot)
LMTD	Logarithmic mean temperature difference	T_{ho}	Outlet fluid temperature (hot)
N_i	Tube count	T_{co}	Outlet fluid temperature (cold)
A_o	Outer Heat transfer area	T_{ci}	Inlet fluid temperature (Cold)

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