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Thermal Design of Tube and shell Type Heat Exchanger –a Review

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A feature of heat exchanger design is the process of specifying a design. Heat transfer area and pressure drops and checking whether the assumed design satisfies all requirement or not. The idea of this paper is how to design the shell and tube heat exchanger which is the majority type of liquid –to- liquid heat exchanger. General design consideration and design processes are also illustrated in this paper. In design computation HTRI software is used to check the manually calculated results.

KEY WORDS: heat exchanger, constructional details, pressure drop, heat transfer coefficient, TEMA .Logarithmic mean temperature difference (LMTD)

INTRODUCTION

Heat Exchanger is a device which provides a flow of thermal energy between two or more fluids at different temperatures. Heat exchangers are used in a wide diversity of engineering applications like power generation, waste heat recovery, manufacturing industry, air-conditioning, refrigeration, space applications, petrochemical industries etc. Heat exchanger may be classified according to the following main criteria.

1. Recuperators and Regenerators.
2. Transfer process: Direct contact and Indirect contact.
3. Geometry of construction: tubes, plates and extended surfaces.
4. Heat transfer mechanisms: single phase and two phase.
5. Flow arrangements: parallel, counter and cross flows.

Shell and tube heat exchangers are most versatile type of heat exchanger; they are used in process industries, in conventional and nuclear power station as condenser, in steam generators in pressurized water reactor power plants, in feed water heaters and in some air conditioning refrigeration systems.

Shell and tube heat exchanger provide relatively large ratio of heat transfer area to volume and weight and they can be easily cleaned. Shell and tube heat exchanger offer great flexibility to meet almost any service requirement. Shell and tube heat exchanger can be designed for high pressure relative to the environment and high pressure difference between the fluid streams.

Basic Components of Shell and Tube Heat Exchanger:

Shell and tube heat exchanger are built of round tubes mounted in a cylindrical shell with the tubes parallel to the shell. One fluid flow inside the tubes, while the other fluid flows across and along the axis of the exchanger, the major components of this exchanger are tubes (tube bundles), shell, front end head, rear end head, baffles and tube sheets. Typical parts and their arrangement are show in figure 1.

TEMA Standards:

The standard of the Tubular Exchanger Manufacturers Association (TEMA) describe various components in detail of shell and tube heat exchanger (STHE).

STHE is divided into three parts: the front head, the shell and the rear head. Figure 1 illustrates the TEMA nomenclature for the various construction possibilities. Exchangers are described by the letter codes for the three sections.

Each part has different construction and specific function. The construction of front and rear head as well as flow patterns in the shell are defined by the TEMA standards - for example, a BFL exchanger has a bonnet cover, a two-pass shell with a longitudinal baffle and a fixed tubesheet rear head.

Classification Based on TEMA Construction:

There three basic classification based on TEMA based on their end connection and shell type.

a. BEM b. CFU c. AES

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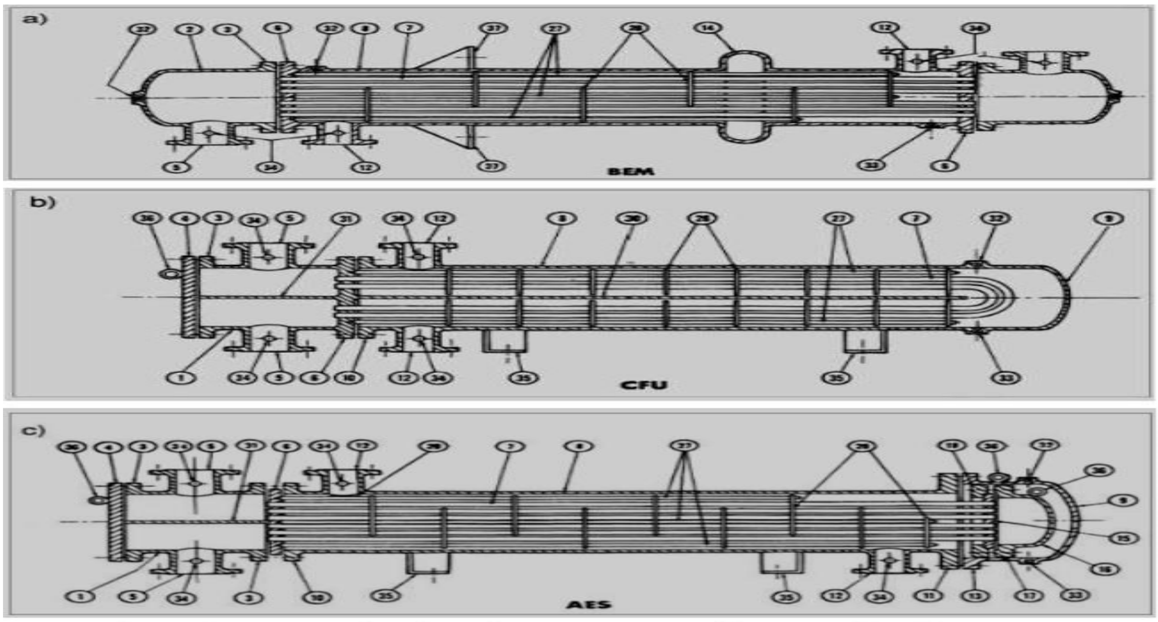

1	Stationary (Front) Head—Channel	20	Slip-on Backing Flange
2	Stationary (Front) Head—Bonnet	21	Floating Tubesheet Skirt
3	Stationary (Front) Head Flange	22	Floating Tubesheet Skirt
4	Channel Cover	23	Packing Box Flange
5	Stationary Head Nozzle	24	Packing
6	Stationary Tubesheet	25	Packing Follower Ring
7	Tubes	26	Lantern Ring
8	Shell	27	Tie Rods and Spacers
9	Shell Cover	28	Transverse Baffles or Support Plates
10	Shell Flange—Stationary Head End	29	Impingement Baffle or Plate
11	Shell Flange—Rear Head End	30	Longitudinal Baffle
12	Shell Nozzle	31	Pass Partition
13	Shell Cover Flange	32	Vent Connection
14	Expansion Joint	33	Drain Connection
15	Floating Tubesheet	34	Instrument Connection
16	Floating Head Cover	35	Support Saddle
17	Floating Head Flange	36	Lifting Lug
18	Floating Head Backing Device	37	Support Bracket
19	Split Shear Ring		

Figure 1: Construction Parts and Connections

There are various types of STHE, but most of process industries and chemical industries mostly use fixed-tube sheet shell and tube type heat exchanger because

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of its low cost, simple construction and low maintenance cost. From industrial point of view it is necessary to operate shell and tube heat exchanger at optimal condition thus it reduce an operating and maintenance cost.

Mass velocity strongly influences the heat-transfer coefficient. For turbulent flow, the tube side heat-transfer coefficient varies to the 0.8 power of tube side mass velocity, whereas tube side pressure drop varies to the square of mass velocity. Thus, with increasing mass velocity, pressure drop increases more rapidly than does the heat-transfer coefficient. Consequently, there will be an optimum mass velocity above which it will be wasteful to increase mass velocity further. The construction geometry and thermal parameters such as mass flow rate, heat transfer coefficient etc are strongly influenced by each other. A detail study of research of design procedures, effect and variation of thermal parameters under different conditions and optimization methods implemented for STHE has been carried out in literature review.

BAFFLE

Baffles serve two important functions. They support the tubes during assembly and operation and help prevent vibration from flow induced eddies and direct the shell side fluid back and forth across the tube bundle to provide effective velocity and Heat Transfer rates. The diameter of the baffle must be slightly less than the shell inside diameter to allow assembly, but must be close enough to avoid the substantial performance penalty caused by fluid bypass around the baffles. Shell roundness is important to achieve effective sealing against excessive bypass. Baffles can be made from a variety of materials compatible with the shell side fluid. They can be punched or machined. Some baffles are made by a punch which provides a lip around the tube hole to provide more surfaces against the tube and eliminate tube wall cutting from the baffle edge. The tube holes must be precise enough to allow easy assembly and field tube replacement, yet minimize the chance of fluid flowing between the tube wall and baffle hole, resulting in reduced thermal performance and increased potential for tube wall cutting from vibration. Baffles do not extend edge to edge, but have a cut that allows shell side fluid to flow to the next baffled chamber. For most liquid applications, the cuts areas represent 20-25% of the shell diameter. For gases, where a lower pressure drop is desirable, baffle cuts of 40-45% is common.

Baffles must overlap at least one tube row in order to provide adequate tube support. They are spaced throughout the tube bundle somewhat evenly to provide even fluid velocity and pressure drop at each baffled tube section. Single-segmental baffles force the fluid or gas across the entire tube count, where is changes direction as dictated by the baffle cut and spacing. This can result in excessive pressure loss in high velocity gases. In order to affect Heat Transfer, yet reduce the pressure drop, double-segmental baffles can be used. This approach retains the structural effectiveness of the tube bundle, yet allows the gas to flow between alternating sections of tube in a straighter overall direction, thereby reducing the effect of numerous changes of direction.

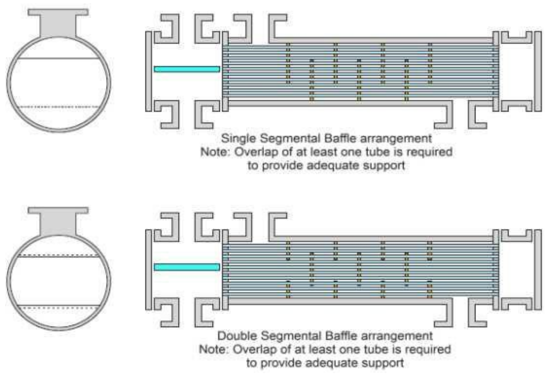

Figure:2

Type of baffles: Baffles are used to support tubes, enable a desirable velocity to be maintained for the shell side fluid, and prevent failure of tubes due to flow-induced vibration. There are two types of baffles: plate and rod. Plate baffles may be single-segmental, double-segmental, or triple-segmental as shown in Figure 2.

Baffle spacing: Baffle spacing is the centerline-to-centerline distance between adjacent baffles. It is the most vital parameter in STHE design. The TEMA standards specify the minimum baffle spacing as one-fifth of the shell inside diameter or 2 in., whichever is greater.

Closer spacing will result in poor bundle penetration by the shell side fluid and difficulty in mechanicallycleaning the outsides of the tubes. Furthermore, a low baffle spacing results in a poor stream distribution as will be explained later.

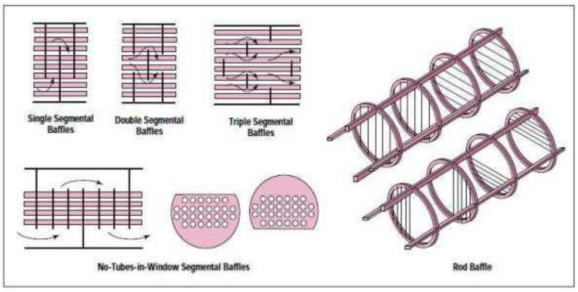

Figure:3. Types of Baffles

The maximum baffle spacing is the shell inside diameter. Higher baffle spacing will lead to predominantly longitudinal flow, which is less efficient than cross-flow, and large unsupported tube spans, which will make the exchanger prone to tube failure due to flow-induced vibration. Optimum baffles pacing. For turbulent flow on the shell side (Re > 1,000), the heat-transfer coefficient varies to the 0.6–0.7 power of velocity; however, pressure drop varies to the 1.7–2.0 power. For laminar flow (Re < 100), the exponents are 0.33 for the heat-transfer coefficient and 1.0 for pressure drop. Thus, as baffle spacing is reduced, pressure drop increases at a much faster rate than does the heat-transfer coefficient. This means that there will be an optimum ratio of baffle spacing to shell inside diameter that will result in the highest efficiency of conversion of pressure drop to heat transfer. This optimum ratio is normally between 0.3 and 0.6.

PRESSURE DROP IN STHE

PRELIMINARY CALCULATION

A selected shell and tube heat exchanger must satisfy the process requirements with the allowable pressure drops until the next scheduled cleaning of plant. The methodology to evaluate thermal parameters is

explained with suitable assumptions. The following are the major assumptions made for the pressure drop analysis;

1. Flow is steady and isothermal, and fluid properties are independents of time.
2. Fluid density is dependent on the local temperature only or is treated as constant.
3. The pressure at a point in the fluid is independent of direction.
4. Body force is caused only by gravity.
5. There are no energy sink or sources along streamline; flow stream mechanical energy dissipation is idealized as zero.
6. The friction factor is considered as constant with passage flow length.

Heat transfer or the size of heat transfer exchanger can be obtained from equation,

$$Q = U_o A_o \Delta T_m \qquad (1)$$

The overall heat transfer coefficient Uo based on the O.D. of tubes can be estimated from the estimated values of individual heat transfer coefficients, the wall and fouling resistance and the overall surface efficiency using equation

$$\frac{1}{U_o} = \frac{A_o}{A_i}\left[\frac{1}{\eta_i h_i} + \frac{R_{fi}}{\eta_i}\right] + A_o R_w + \frac{R_{fo}}{\eta_o} + \frac{1}{\eta_o h_o}$$

(2) For the single tube pass, purely countercurrent heat exchanger, F= 1.00. For preliminary design shell with any even number of tube side passes, F may be estimated as 0.9 Heat load can be estimated from the heat balance as:

$$Q = (mC_p)_c (T_{c2} - T_{c1}) = (mC_p)_h (T_{h2} - T_{h1})$$

(3)

If one stream changes phases:

Q = mhfg (4) LMTD (Log Mean Temperature Difference Method) calculation:

If three temperatures are known, the fourth one can be found from the heat balance,

$$\Delta T_{lm} = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln \frac{(T_{h1} - T_{c2})}{(T_{h2} - T_{c1})}}$$

(5) Heat transfer area can be calculated from equation (3.1). Number of tubes of diameter (do), shell diameter (Ds) to accommodate the number of tubes (Nt), with given tube length (L) can be estimated,

$$A_o = \pi_e N_t L$$

(6)

One can find the shell diameter (Ds), which would contain the right number of tubes (Nt), of diameter (dt).

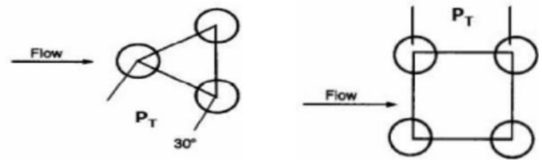

Figure 4: Square and Triangular Pitch Tube Layout

The total number of tubes can be predicted in fair approximation as function of the shell diameter by taking the shell circle and dividing it by the projected area of the tube layout (fig 4) pertaining to a single tube A1.

$$N_t = (CTP)\frac{\pi D_s^2}{4A_i}$$

(7) Where CTP is the tube count calculation constant that accounts for the incomplete coverage of the shell diameter by the tubes. Based on fixed tube sheet the following values are suggested:

One tube pass: CTP = 0.93 Two tube pass: CTP = 0.90 Three tube pass: CTP = 0.85

A1 = (CL) (PT)2 (3.8)

Where CL is the tube layout constant: CL = 1.0 for 90 and 45

CL = 0.87 for 30 and 60 Equation (3.7) can be written as:

$$N_t = 0.875\left(\frac{CTP}{CL}\right)\frac{D_s^2}{(P_r)^2 d_o^2}$$

(8) Where PR is the Tube Pitch Ratio (PR = PT/do).The shell diameter in terms of main construction diameter can be obtained as from equations (3.6) and (3.9),

$$Ds = 0.637\sqrt{\frac{CL}{CTP}}\left(\frac{A_o (P_r)^2 d_o}{L}\right)^{1/2}$$

(9)

TUBE SIDE PRESSURE DROP

The tube side pressure drop can be calculated by knowing the number of tube passes (Np) and length (L) oh heat exchanger; the pressure drop for the tube side fluid is given by equation

$$\Delta P_t = 4f\frac{LN_p}{d_i}\rho\frac{\mu_m^2}{2}$$

(10)

$$\Delta P_t = 4f\frac{LN_p}{d_i}\frac{G_i^2}{2\rho}$$

(11) The change of direction in the passes introduction in the passes introduction an additional pressure drop due to sudden expansions and contractions that the tube fluid experiences during a return that is accounted for allowing four velocity head per pass

$$\Delta P_t = 4N_p\frac{\rho\mu_m^2}{2}$$

(12)

The total pressure drop of the side becomes:

$$\Delta P_t = \left(4f \frac{LN_p}{d_i} + 4N_p \right) \frac{\rho \mu_m^2}{2}$$

(13)

COMPONENTS DETAILS[2]

Some of the very basic components of a shell and tube type heat exchangers are as given below:

TUBES

The tubes are the basic components of a shell and tube type heat exchanger. The outer surfaces of the tubes are the boundary along which heat transfer takes place. It is therefore recommended that the tubes materials should be highly thermal conductive otherwise proper heat transfer will not occur. The tubes of Copper, Aluminium and other thermally conductive materials are commonly used in practice.

TUBE SHEETS

The tubes are held in place by being inserted into holes in the tube sheet and there either expanded into grooves cut into the holes or welded to the tube sheet where the tube protrudes from the surface. The tube sheet is usually a single round plate of metal that has been suitably drilled and grooved to take the tubes (in the desired pattern), the gaskets, the spacer rods and the bolt circle where it is fastened to the shell. However, where mixing between the two fluids (in the event of leaks where the tube is sealed into the tube sheet) must be avoided, a double tube sheet may be provided.

SHELL

The shell is simply the container for the shell side fluid, and the nozzles are the inlet and exit ports. The shell normally has a circular cross section and is commonly made by rolling a metal plate of the appropriate dimensions into a cylinder and welding the longitudinal joint (“rolled shells”).

IMPINGEMENT PLATES

When the fluid under high pressure enters the shell there are high chances that if the fluid will directly impinge over the tubes then their breakage or deformation may occur. To avoid the same the impingement plates are installed to waste the kinetic energy of fluid upto some extent so that the fluid may impact the tubes with lower velocity.

CHANNEL COVERS

The channel covers are round plates that bolt to the channel flanges and can be removed for the tube inspection without disturbing the tube side piping. In smaller heat exchangers, bonnets with flanged nozzles or threaded connections for the tube side piping are often used instead of channel and channel covers.

BAFFLES

Baffles serve two functions; Most importantly, they support the tubes in the proper position during assembly and operation and prevent vibration of the tubes caused by flow induced eddies, and secondly, they guide the shell side flow back and forth across the tube field, increasing the velocity and heat transfer coefficient.

CONCLUSION[1]

From literature review it can be concluded that,

- There is increase in pressure drop with increase in fluid flow rate in shell and tube heat exchanger which increases pumping power.
- Genetic algorithm provides significant improvement in the optimal designs compared to the traditional designs. Genetic algorithm application for determining the global minimum heat exchanger cost is significantly faster and has an advantage over other methods in obtaining multiple solutions of same quality. Thus, providing more flexibility to the designer.
- It also reveals that the harmony search algorithm can converge to optimum solution with higher accuracy in comparison with genetic algorithm.
- Tube pitch ratio, tube length, tube layout as well as baffle spacing ratio were found to be important design parameters which has a direct

  effect on pressure drop and causes a conflict between the effectiveness and total cost.

In brief, it is necessary to evaluate optimal thermal design for shell and tube heat exchanger to run at minimal cost in industries.

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