

PROCESS DESIGN OF HEAT EXCHANGER

PROCESS DESIGN OF SHELL AND TUBE EXCHANGER FOR SINGLE PHASE HEAT TRANSFER

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Classification of heat exchangers

Transfer of heat from one fluid to another is an important operation for most of the chemical industries. The most common application of heat transfer is in designing of heat transfer equipment for exchanging heat from one fluid to another fluid. Such devices for efficient transfer of heat are generally called Heat Exchanger. Heat exchangers are normally classified depending on the transfer process occurring in them. General classification of heat exchangers is shown in the **Figure 1.1**.

Amongst of all type of exchangers, shell and tube exchangers are most commonly used heat exchange equipment. The common types of shell and tube exchangers are:

Fixed tube-sheet exchanger (non-removable tube bundle): The simplest and cheapest type of shell and tube exchanger is with fixed tube sheet design. In this type of exchangers the tube sheet is welded to the shell and no relative movement between the shell and tube bundle is possible (**Figure 1.2**).

Removable tube bundle: Tube bundle may be removed for ease of cleaning and replacement. Removable tube bundle exchangers further can be categorized in floating-head and U-tube exchanger.

- **Floating-head exchanger:** It consists of a stationery tube sheet which is clamped with the shell flange. At the opposite end of the bundle, the tubes may expand into a freely riding floating-head or floating tube sheet. A floating head cover is bolted to the tube sheet and the entire bundle can be removed for cleaning and inspection of the interior. This type of exchanger is shown in **Figure 1.3**.

- U-tube exchanger: This type of exchangers consists of tubes which are bent in the form of a 'U' and rolled back into the tube sheet shown in the **Figure 1.4**. This means that it will omit some tubes at the centre of the tube bundle depending on the tube arrangement. The tubes can expand freely towards the 'U' bend end.

The different operational and constructional advantages and limitations depending on applications of shell and tube exchangers are summarized in **Table 1.1**. TEMA (USA) and IS: 4503-1967 (India) standards provide the guidelines for the mechanical design of unfired shell and tube heat exchangers. As shown in the **Table 1.1**, TEMA 3-digit codes specify the types of front-end, shell, and rear-end of shell and tube exchangers.

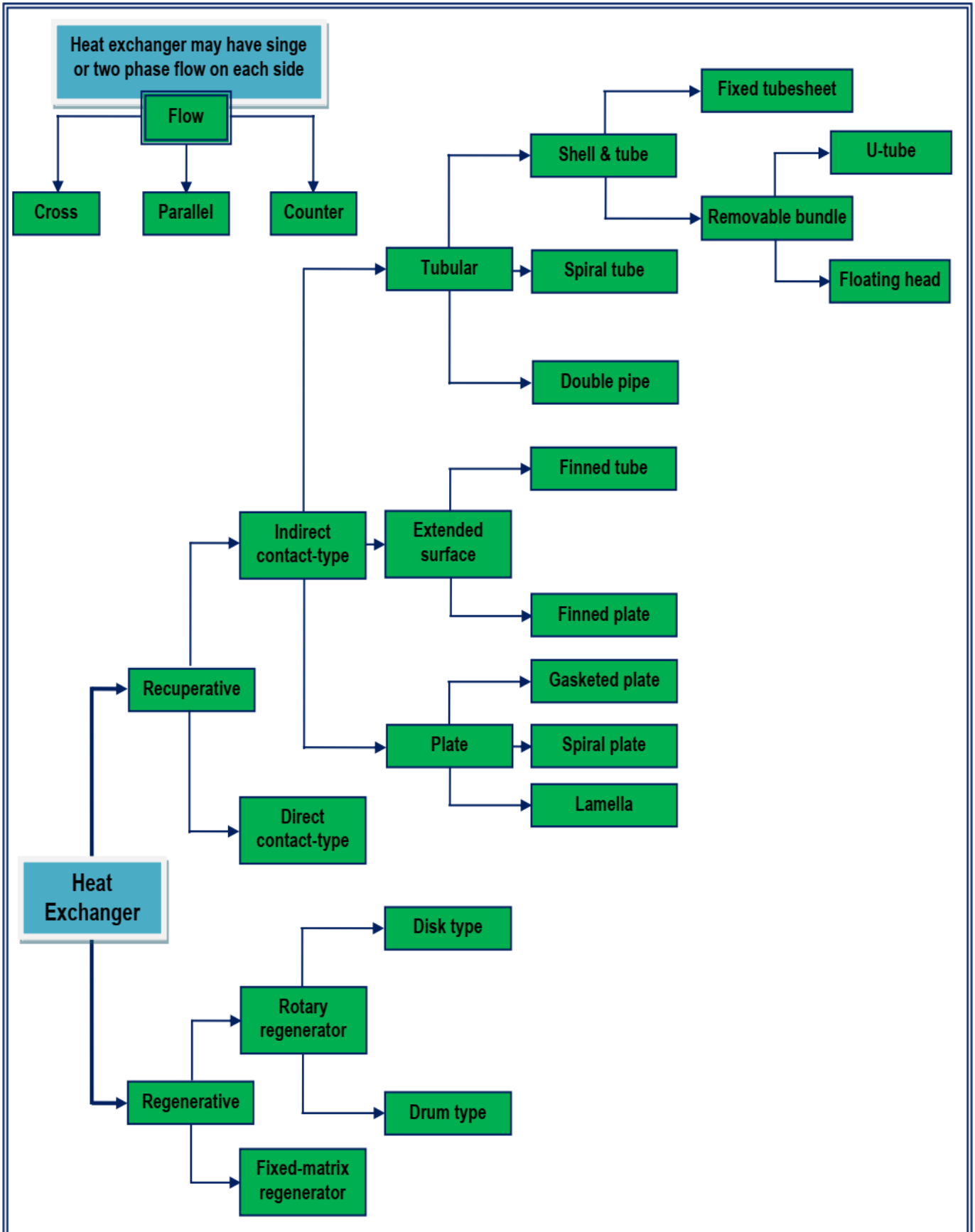


Figure 1.1. Classification of heat exchangers depending on their applications.

Table 1.1. Features of shell and tube type exchangers.

<i>Shell and Tube Exchangers</i>	<i>Typical TEMA code</i>	<i>Advantages</i>	<i>Limitations</i>
Fixed tube sheet	BEM, AEM, NEN	<p>Provides maximum heat transfer area for a given shell and tube diameter.</p> <p>Provides for single and multiple tube passes to assure proper velocity.</p> <p>Less costly than removable bundle designs.</p>	<p>Shell side / out side of the tubes are inaccessible for mechanical cleaning.</p> <p>No provision to allow for differential thermal expansion developed between the tube and the shell side. This can be taken care by providing expansion joint on the shell side.</p>
Floating-head	AEW, BEW, BEP, AEP, AES, BES	<p>Floating tube sheet allows for differential thermal expansion between the shell and the tube bundle.</p> <p>Both the tube bundle and the shell side can be inspected and cleaned mechanically.</p>	<p>To provide the floating-head cover it is necessary to bolt it to the tube sheet. The bolt circle requires the use of space where it would be possible to place a large number of tubes.</p> <p>Tubes cannot expand independently so that huge thermal shock applications should be avoided.</p> <p>Packing materials produce limits on design pressure and temperature.</p>
U-tube	BEU, AEU	<p>U-tube design allows for differential thermal expansion between the shell and the tube bundle as well as for individual tubes.</p> <p>Both the tube bundle and the shell side can be inspected and cleaned mechanically.</p> <p>Less costly than floating head or packed floating head designs.</p>	<p>Because of U-bend some tubes are omitted at the centre of the tube bundle.</p> <p>Because of U-bend, tubes can be cleaned only by chemical methods.</p> <p>Due to U-tube nesting, individual tube is difficult to replace.</p> <p>No single tube pass or true countercurrent flow is possible.</p> <p>Tube wall thickness at the U-bend is thinner than at straight portion of the tubes.</p> <p>Draining of tube circuit is difficult when positioned with the vertical position with the head side upward.</p>

Thermal Design Considerations

The flow rates of both hot and cold streams, their terminal temperatures and fluid properties are the primary inputs of thermal design of heat exchangers.

Thermal design considerations

Thermal design of a shell and tube heat exchanger typically includes the determination of heat transfer area, number of tubes, tube length and diameter, tube layout, number of shell and tube passes, type of heat exchanger (fixed tube sheet, removable tube bundle etc), tube pitch, number of baffles, its type and size, shell and tube side pressure drop etc.

Shell

Shell is the container for the shell fluid and the tube bundle is placed inside the shell. Shell diameter should be selected in such a way to give a close fit of the tube bundle. The clearance between the tube bundle and inner shell wall depends on the type of exchanger. Shells are usually fabricated from standard steel pipe with satisfactory corrosion allowance. The shell thickness of 3/8 inch for the shell ID of 12-24 inch can be satisfactorily used up to 300 psi of operating pressure.

Tube

Tube OD of 3/4 and 1" are very common to design a compact heat exchanger. The most efficient condition for heat transfer is to have the maximum number of tubes in the shell to increase turbulence. The tube thickness should be enough to withstand the internal pressure along with the adequate corrosion allowance. The tube thickness is expressed in terms of BWG (Birmingham Wire Gauge) and true outside diameter (OD). The tube length of 6, 8, 12, 16, 20 and 24 ft are preferably used. Longer tube reduces shell diameter at the expense of higher shell pressure drop. Finned tubes are also used when fluid with low heat transfer coefficient flows in the shell side. Stainless steel, admiralty brass, copper, bronze and alloys of copper-nickel are the commonly used tube materials:

Tube pitch, tube-layout and tube-count

Tube pitch is the shortest centre to centre distance between the adjacent tubes. The tubes are generally placed in square or triangular patterns (pitch) as shown in the **Figure 1.5**.

The widely used tube layouts are illustrated in **Table 1.2**.

The number of tubes that can be accommodated in a given shell ID is called tube count.

The tube count depends on the factors like shell ID, OD of tube, tube pitch, tube layout, number of tube passes, type of heat exchanger and design pressure.

Tube passes

The number of passes is chosen to get the required tube side fluid velocity to obtain greater heat transfer co-efficient and also to reduce scale formation. The tube passes vary from 1 to 16. The tube passes of 1, 2 and 4 are common in application. The partition built into exchanger head known as partition plate (also called pass partition) is used to direct the tube side flow.

Table 1.2. Common tube layouts.

Tube OD, in	Pitch type	Tube pitch, in
3/4	Square	1
1		1 1/4
3/4	Triangular	15/16
3/4		1

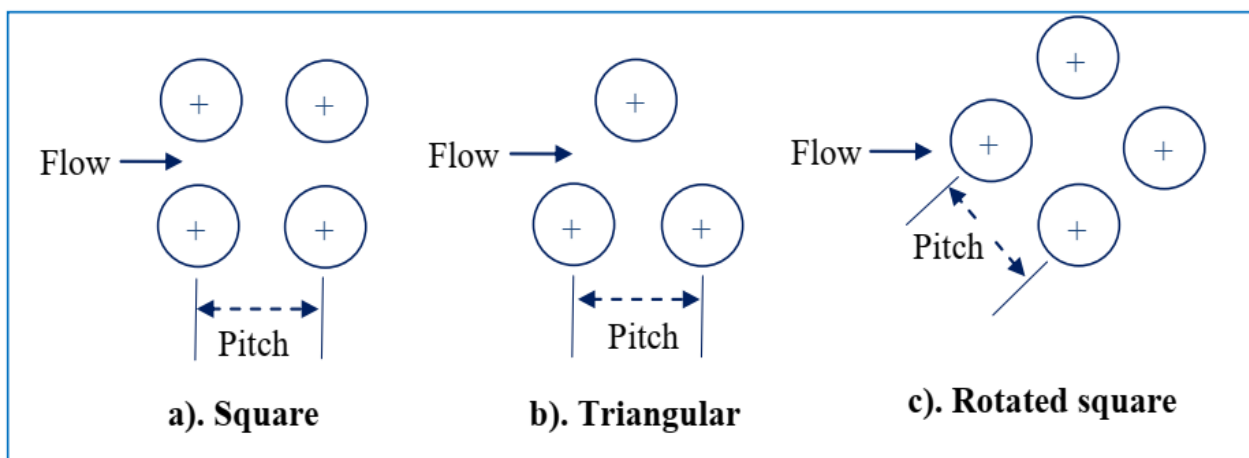


Figure 1.5. Heat exchanger tube-layouts.

Tube sheet

The tubes are fixed with tube sheet that form the barrier between the tube and shell fluids. The tubes can be fixed with the tube sheet using ferrule and a soft metal packing ring. The tubes are attached to tube sheet with two or more grooves in the tube sheet wall by 'tube rolling'. The tube metal is forced to move into the grooves forming an excellent tight seal. This is the most common type of fixing arrangement in large industrial exchangers. The tube sheet thickness should be greater than the tube outside diameter to make a good seal. The recommended standards (IS:4503 or TEMA) should be followed to select the minimum tube sheet thickness.

Baffles

Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. The distance between adjacent baffles is called baffle-spacing. The baffle spacing of 0.2 to 1 times of the inside shell diameter is commonly used. Baffles are held in positioned by means of baffle spacers. Closer baffle spacing gives greater transfer co-efficient by inducing higher turbulence. The pressure drop is more with closer baffle spacing. The various types of baffles are shown in **Figure 1.6**. In case of cut-segmental baffle, a segment (called baffle cut) is removed to form the baffle expressed as a percentage of the baffle diameter. Baffle cuts from 15 to 45% are normally used. A baffle cut of 20 to 25% provide a good heat-transfer with the reasonable pressure drop. The % cut for segmental baffle refers to the cut away height from its diameter. **Figure 1.6** also shows two other types of baffles.

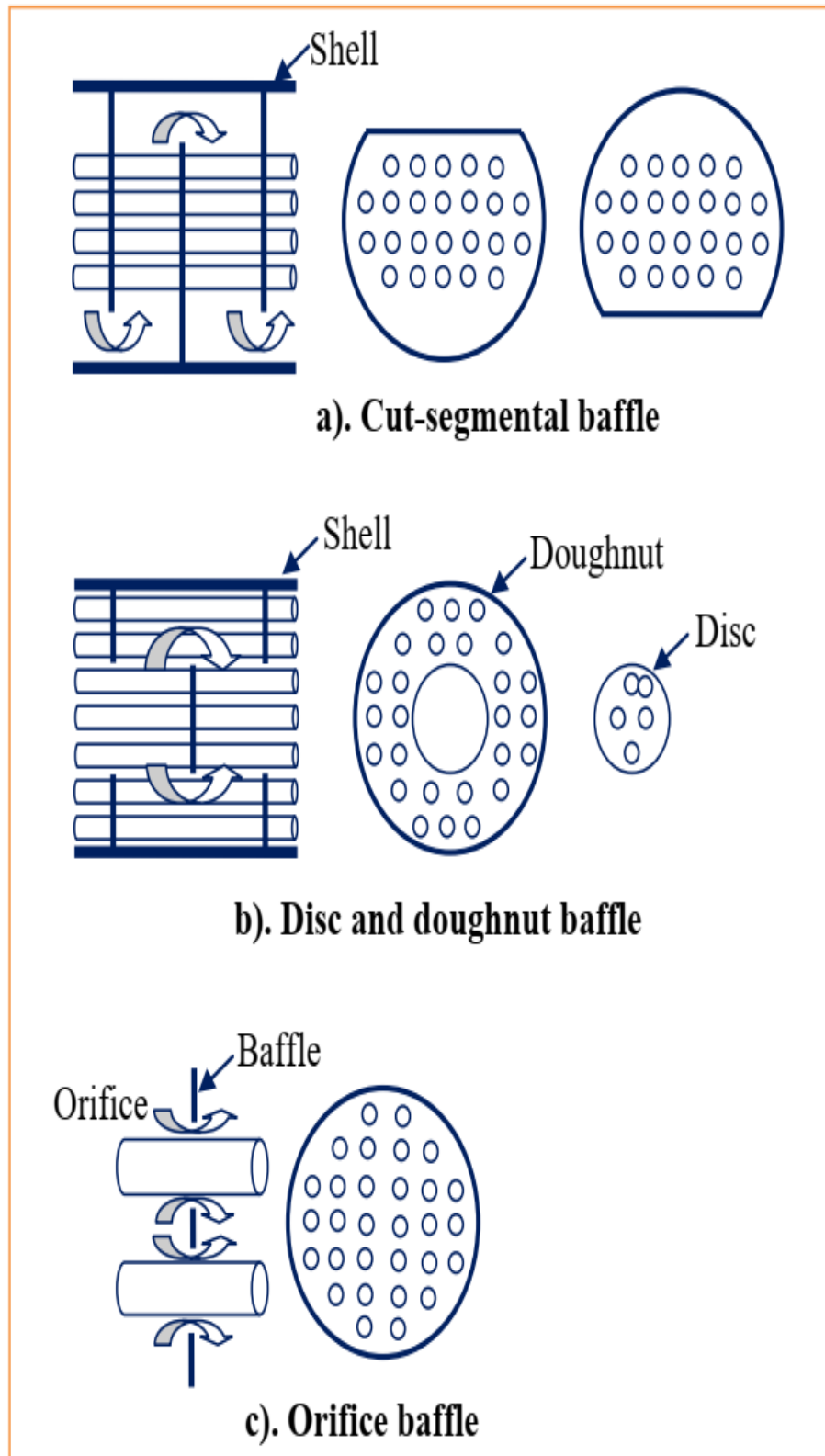


Figure 1.6. Different type of heat exchanger baffles: a). Cut-segmental baffle, b). Disc and doughnut baffle, c). Orifice baffle

Fouling Considerations

The most of the process fluids in the exchanger foul the heat transfer surface. The material deposited reduces the effective heat transfer rate due to relatively low thermal conductivity. Therefore, net heat transfer with clean surface should be higher to compensate the reduction in performance during operation. Fouling of exchanger increases the cost of (i) construction due to oversizing, (ii) additional energy due to poor exchanger performance and (iii) cleaning to remove deposited materials. A spare exchanger may be considered in design for uninterrupted services to allow cleaning of exchanger.

The effect of fouling is considered in heat exchanger design by including the tube side and shell side fouling resistances. Typical values for the fouling coefficients and resistances are summarized in **Table 1.3**. The fouling resistance (fouling factor) for petroleum fractions are available in the text book

Table 1.3. Typical values of fouling coefficients and resistances

Fluid	Coefficient ($\text{W}\cdot\text{m}^{-2}\cdot^{\circ}\text{C}^{-1}$)	Resistance ($\text{m}^2\cdot^{\circ}\text{C}\cdot\text{W}^{-1}$)
River water	3000-12,000	0.0003-0.0001
Sea water	1000-3000	0.001-0.0003
Cooling water (towers)	3000-6000	0.0003-0.00017
Towns water (soft)	3000-5000	0.0003-0.0002
Towns water (hard)	1000-2000	0.001-0.0005
Steam condensate	1500-5000	0.00067-0.0002
Steam (oil free)	4000- 10,000	0.0025-0.0001
Steam (oil traces)	2000-5000	0.0005-0.0002
Refrigerated brine	3000-5000	0.0003-0.0002
Air and industrial gases	5000-10,000	0.0002-0.000-1
Flue gases	2000-5000	0.0005-0.0002
Organic vapors	5000	0.0002
Organic liquids	5000	0.0002
Light hydrocarbons	5000	0.0002
Heavy hydrocarbons	2000	0.0005
Boiling organics	2500	0.0004
Condensing organics	5000	0.0002
Heat transfer fluids	5000	0.0002
Aqueous salt solutions	3000-5000	0.0003-0.0002

Selection of fluids for tube and the shell side

The routing of the shell side and tube side fluids has considerable effects on the heat exchanger design. Some **general guidelines** for positioning the fluids are given in **Table 1.4**. It should be understood that these guidelines are not ironclad rules and the optimal fluid placement depends on many factors that are service specific.

Table 1.4. Guidelines for placing the fluid in order of priority

<i>Tube-side fluid</i>	<i>Shell-side fluid</i>
Corrosive fluid	Condensing vapor (unless corrosive)
Cooling water	Fluid with large temperature difference ($>40^{\circ}\text{C}$)
Fouling fluid	
Less viscous fluid	
High-pressure steam	
Hotter fluid	