



**WOLLO UNIVERSITY**  
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**School of Mechanical and Chemical Engineering**  
**Chemical Engineering Department**  
***Chemical Engineering apparatus Design***  
**Heat Exchanger Design**

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## What is a Heat Exchanger?

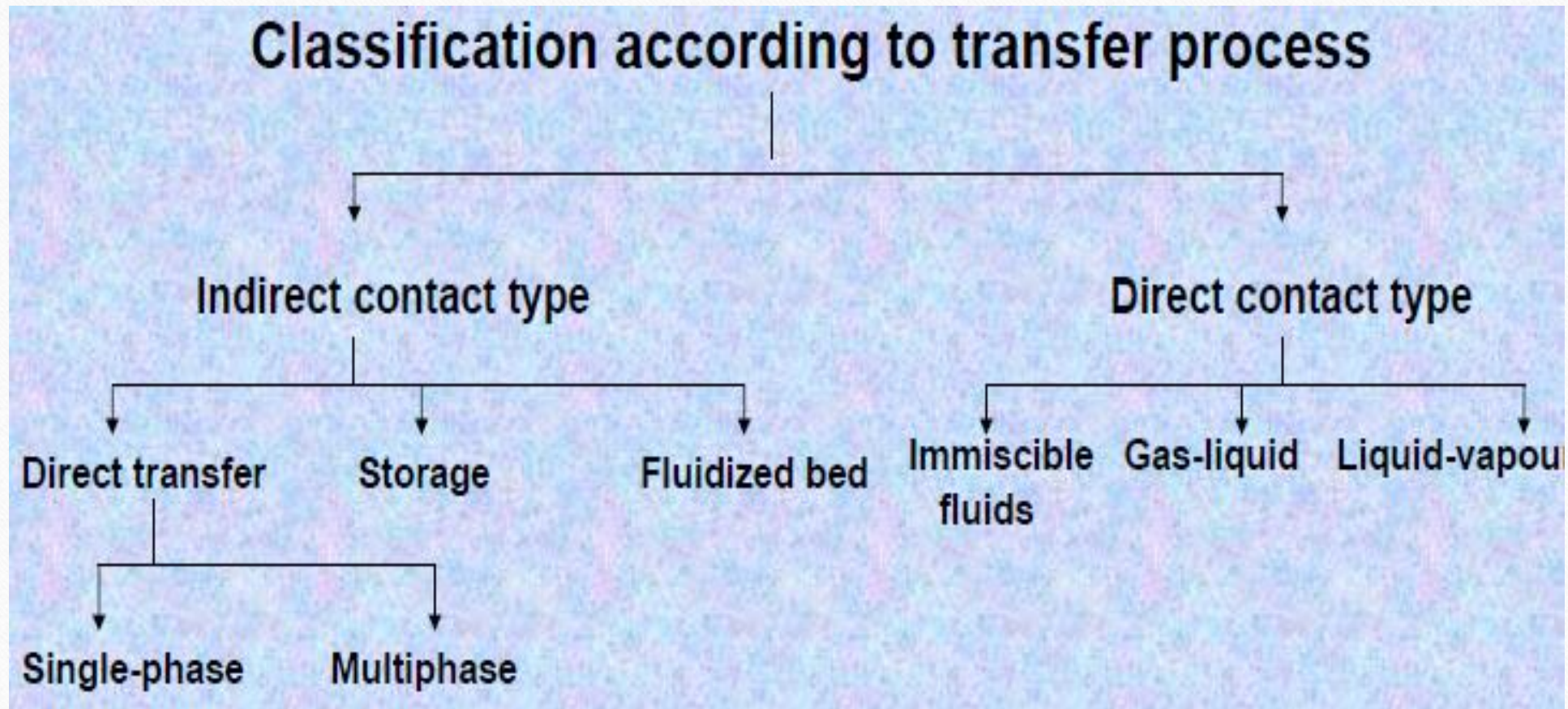
*A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact.*

**Heat exchangers are classified according to**

- Transfer process
- Number of fluids
- Degree of surface contact
- Design features
- Flow arrangements
- Heat transfer mechanisms



# Classification of Heat Exchangers





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### Classification according to number of fluids

Two-fluid

Three-fluid

N-fluid (N > 3)

### Classification according to surface compactness

Gas-to-liquid

Liquid-to-liquid and phase-change

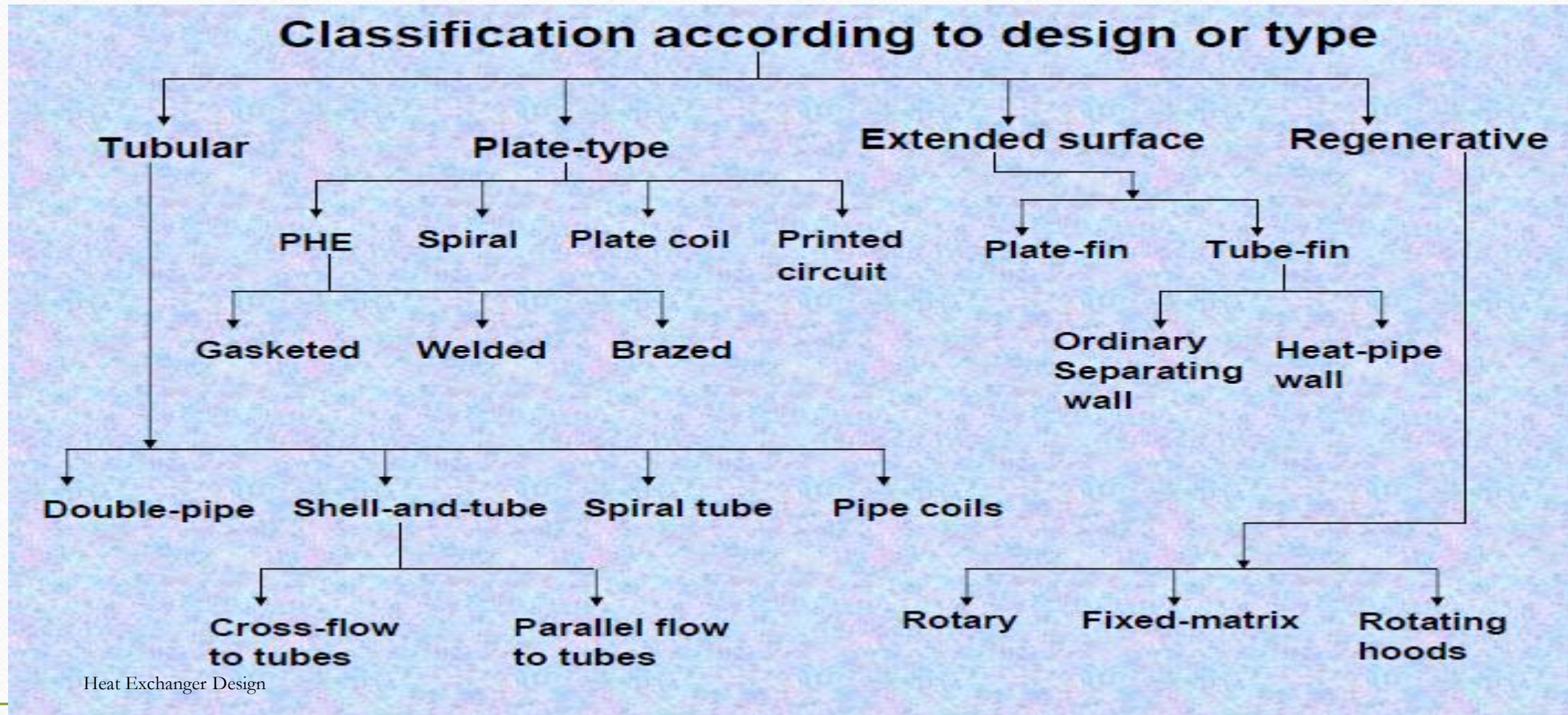
Compact  
 $\beta \geq 700 \text{ m}^2/\text{m}^3$

Non-compact  
 $\beta < 700 \text{ m}^2/\text{m}^3$

Compact  
 $\beta \geq 400 \text{ m}^2/\text{m}^3$

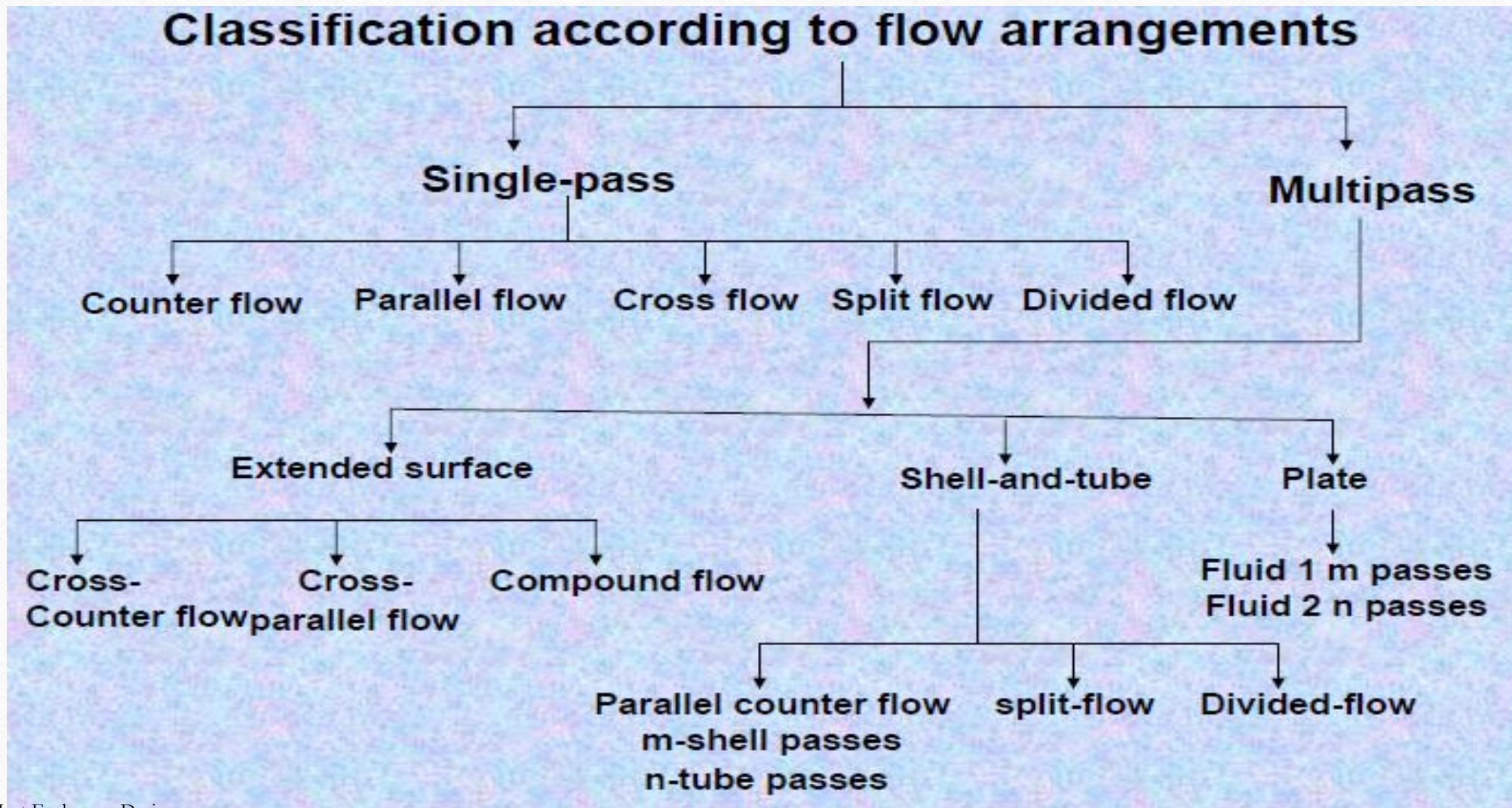
Non-compact  
 $\beta < 400 \text{ m}^2/\text{m}^3$

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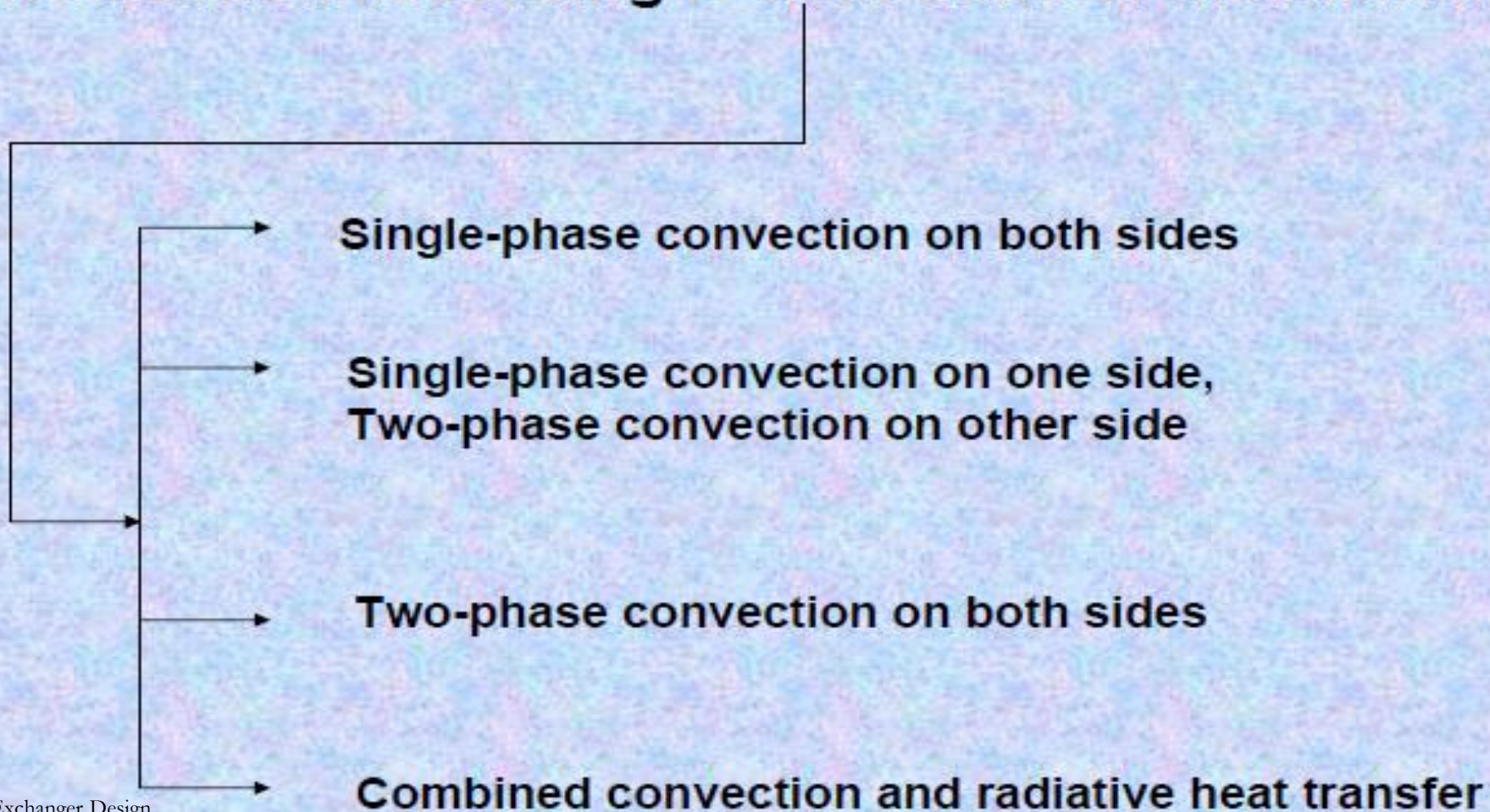
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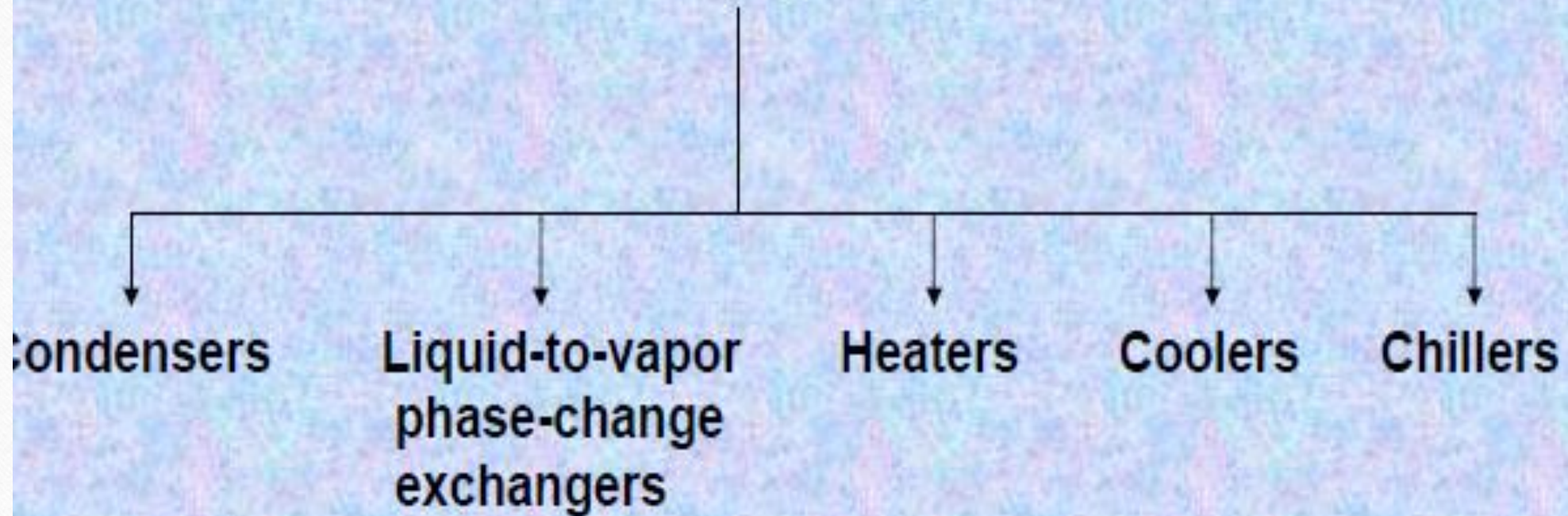
## Classification according to heat transfer mechanisms





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## Classification according to process function





❖ Amongst of all type of exchangers, shell and tube exchangers are most commonly used heat exchange equipment.

Here are the main advantages of shell-and-tube heat exchangers

1. Condensation or boiling heat transfer can be accommodated in either the tubes or the shell, and the orientation
2. can be horizontal or vertical.
2. The configuration gives a large surface area in a small volume.
3. Good mechanical layout: a good shape for pressure operation.
4. Uses well-established fabrication techniques.
5. Can be constructed from a wide range of materials.



**Fig. 1.1: shell and tube heat exchanger**



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4. The pressures and pressure drops can be varied over a wide range.
5. Thermal stresses can be accommodated inexpensively.
6. There is substantial flexibility regarding materials of construction to accommodate corrosion and other concerns.
7. Extended heat transfer surfaces (fins) can be used to enhance heat transfer.
8. Cleaning and repair are relatively straightforward, because the equipment can be dismantled for this purpose.



**The common types of shell and tube exchangers are:**

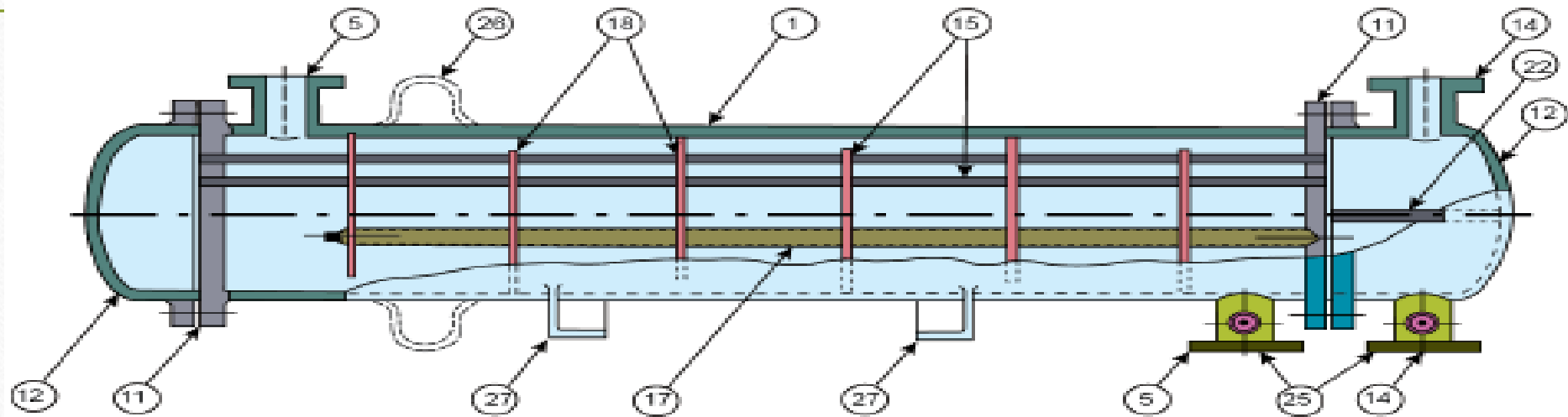
**Fixed tube-sheet exchanger** : The simplest and cheapest type of shell and tube exchanger is with fixed tube sheet design. In this type of exchangers the tube sheet is welded to the shell and no relative movement between the shell and tube bundle is possible (Figure 1.2).

**Removable tube bundle:** Tube bundle may be removed for ease of cleaning and replacement.

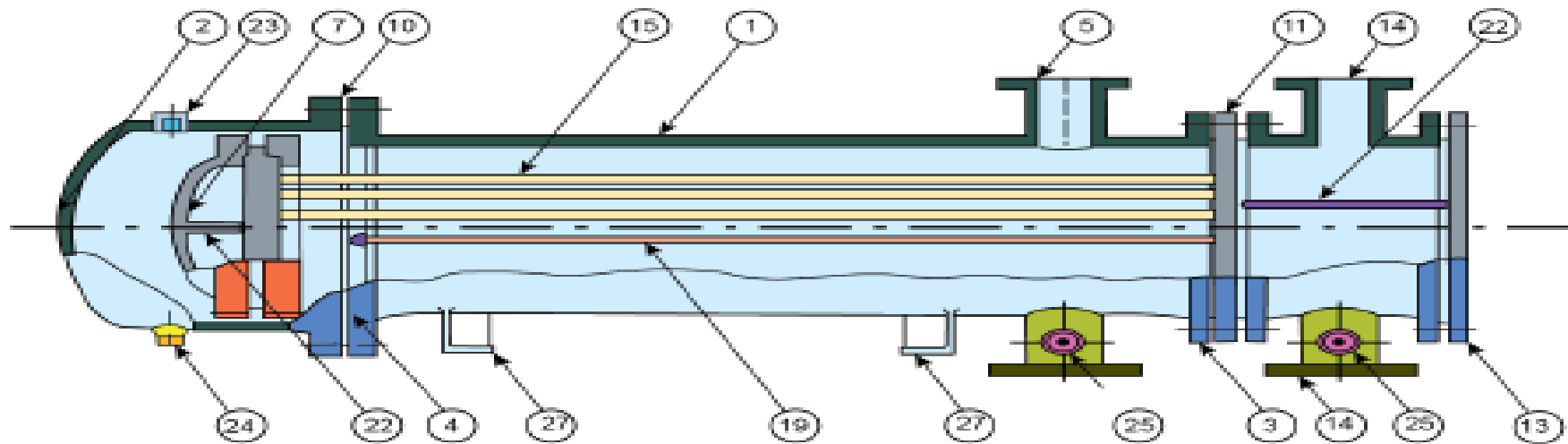
Removable tube bundle exchangers further can be categorized in floating-head and U-tube exchanger.

□ **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. This type of exchanger is shown in Figure 1.3.

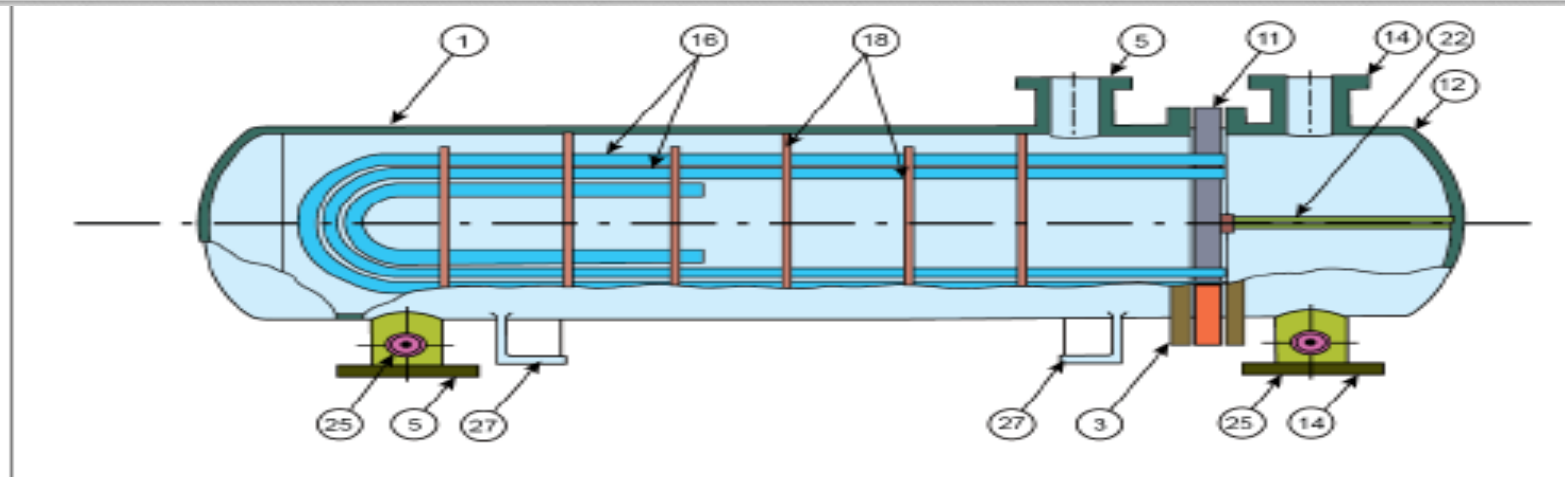
□ **U-tube exchanger:** This type of exchangers consists of tubes which are bent in the form of a „U“ and rolled back into the tube sheet shown in the Figure 1.4. This means that it will omit some tubes at the centre of the tube bundle depending on the tube arrangement.



**Figure 1.2. Fixed-tube heat exchanger ([1]).**



**Fig:1.3 Floating-head exchanger**



**Figure 1.4. Removable U-tube heat exchanger [1].**

Typical parts and connections shown in Figures 1.2, 1.3 and 1.4 (IS: 4503-1967) are summarized below.

1. Shell	16. Tubes (U-type)
2. Shell cover	17. Tie rods and spacers
3. Shell flange (channel end)	18. Transverse (or cross) baffles or support plates
4. Shell flange (cover end)	19. Longitudinal baffles
5. Shell nozzle or branch	20. Impingement baffles
6. Floating tube sheet	21. Floating head support
7. Floating head cover	22. Pass partition
8. Floating head flange	23. Vent connection
9. Floating head gland	24. Drain connection
10. Floating head backing ring	25. Instrument connection
11. Stationary tube sheet	26. Expansion bellows
12. Channel or stationary head	27. Support saddles
13. Channel cover	28. Lifting lugs
14. Channel nozzle or branch	29. Weir
15. Tube (straight)	30. Liquid level connection



### Shell And Tube Exchangers: General Design Considerations

#### Fluid allocation: shell or tubes

❖ Where no phase change occurs, the following factors will determine the allocation of the fluid streams to the shell or tubes.

**Corrosion:** The more corrosive fluid should be allocated to the tube-side. This will reduce the cost of expensive alloy or clad components.

**Fouling:** The fluid that has the greatest tendency to foul the heat-transfer surfaces should be placed in the tubes. This will give better control over the design fluid velocity, and the higher allowable velocity in the tubes will reduce fouling. Also, the tubes will be easier to clean.

**Fluid temperatures :** If the temperatures are high enough to require the use of special alloys placing the higher temperature fluid in the tubes will reduce the overall cost. At moderate temperatures, placing the hotter fluid in the tubes will reduce the shell surface temperatures, and hence the need for lagging to reduce

Heat Exchanger Design  
heat loss, or for safety reasons

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**Operating pressures:** *The* higher pressure stream should be allocated to the tube-side.

High-pressure tubes will be cheaper than a high-pressure shell.

**Pressure drop:** For the same pressure drop, higher heat-transfer coefficients will be obtained on the tube-side than the shell-side, and fluid with the lowest allowable pressure drop should be allocated to the tube-side.

❖ **Viscosity:** Generally, a higher heat-transfer coefficient will be obtained by allocating the more viscous material to the shell-side, providing the flow is turbulent. The critical

❖ Reynolds number for turbulent flow in the shell is in the region of 200. If turbulent flow cannot be achieved in the shell it is better to place the fluid in the tubes, as the tube-side

❖ heat-transfer coefficient can be predicted with more certainty.

**Stream flow-rates:** Allocating the fluids with the lowest flow-rate to the shell-side will normally give the most economical design.

## Shell and tube fluid velocities

- ❖ High velocities will give high heat-transfer coefficients but also a high-pressure drop.
- ❖ The velocity must be high enough to prevent any suspended solids settling, but not so high as to cause erosion. High velocities will reduce fouling. Plastic inserts are sometimes used to reduce erosion at the tube inlet. Typical design velocities are given below:

### *Liquids*

- ❖ Tube-side, process fluids: 1 to 2 m/s, maximum 4 m/s if required to reduce fouling; water: 1.5 to 2.5 m/s.
- ❖ Shell-side: 0.3 to 1 m/s.

### *Vapours*

- ❖ For vapours, the velocity used will depend on the operating pressure and fluid density; the lower values in the ranges given below will apply to high molecular weight materials

Vacuum	50 to 70 m/s
Atmospheric pressure	10 to 30 m/s
High pressure	5 to 10 m/s

## **Stream temperatures**

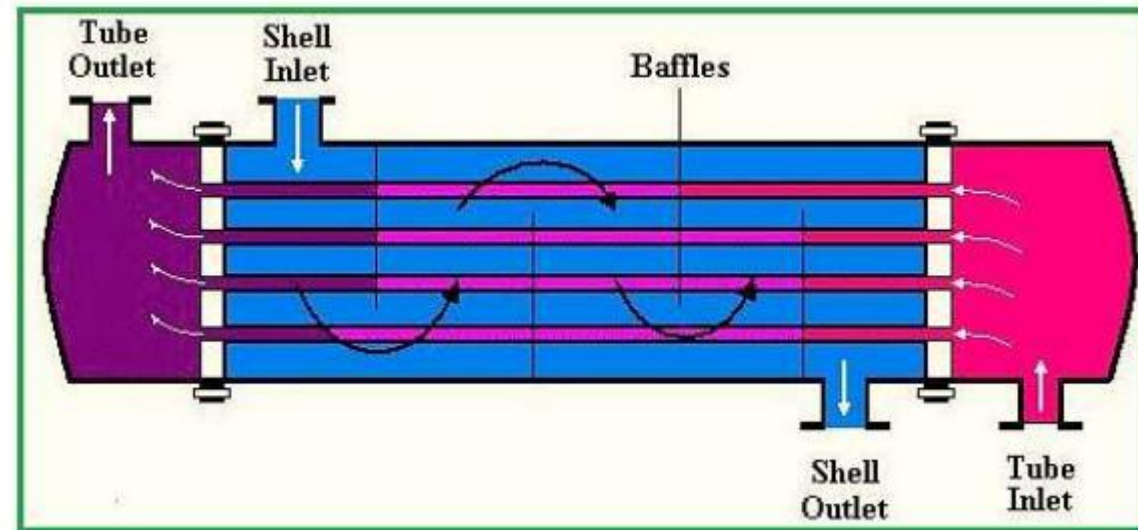
- ❖ The closer the temperature approach used (the difference between the outlet temperature of one stream and the inlet temperature of the other stream) the larger will be the heat-transfer area required for a given duty.
- ❖ The optimum value will depend on the application, and can only be determined by making an economic analysis of alternative designs.
- ❖ As a general guide the greater temperature difference should be at least  $20^{\circ}\text{C}$ , and the least temperature difference 5 to  $7^{\circ}\text{C}$  for coolers using cooling water, and 3 to  $5^{\circ}\text{C}$  using refrigerated brines.

## Pressure drop

- ❖ In many applications the pressure drop available to drive the fluids through the exchanger will be set by the process conditions, and the available pressure drop will vary from a few millibars in vacuum service to several bars in pressure systems.
- ❖ When the designer is free to select the pressure drop an economic analysis can be made to determine the exchanger design which gives the lowest operating costs, taking into consideration both capital and pumping costs.
- ❖ However, a full economic analysis will only be justified for very large, expensive, exchangers.
- ❖ The values suggested below can be used as a general guide, and will normally give designs that are near the optimum.

**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

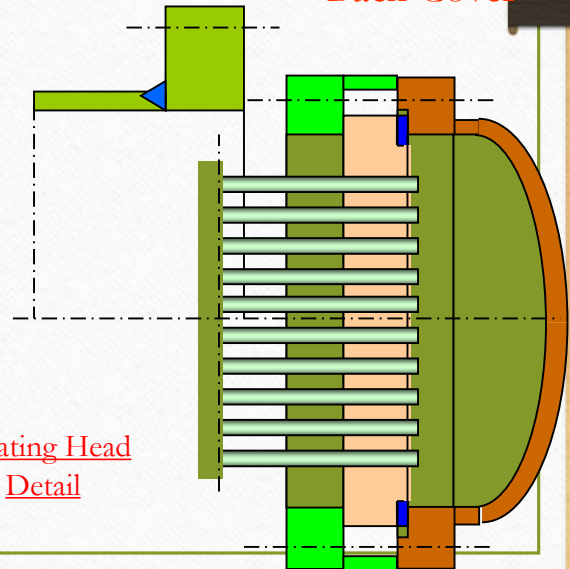
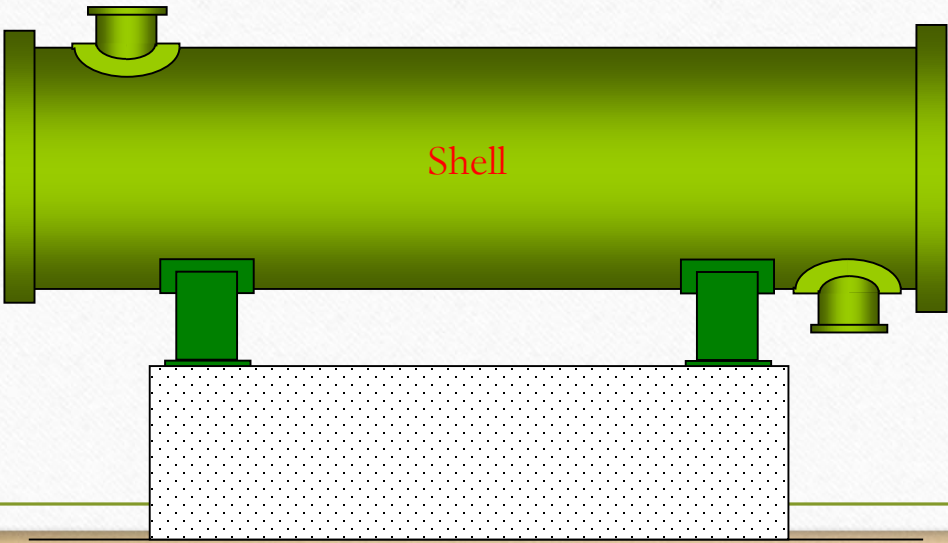
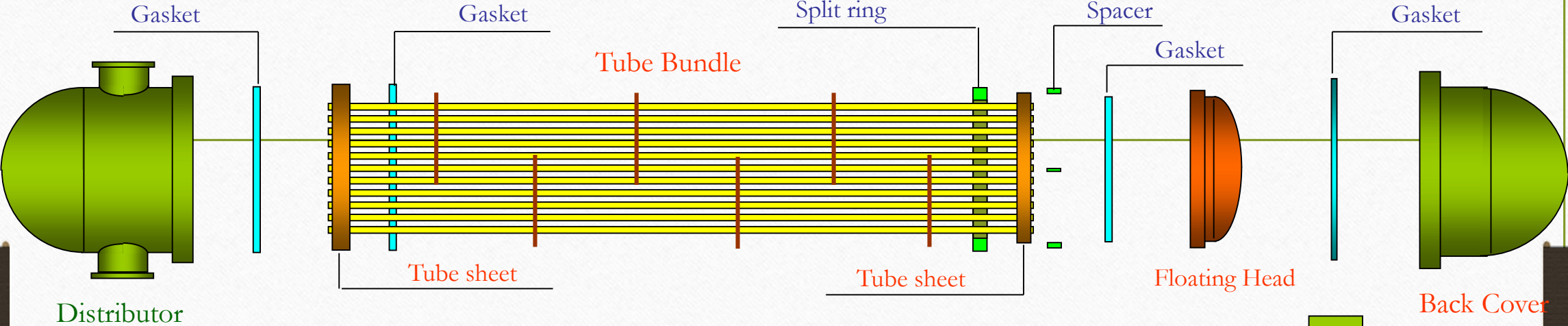


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- ❖ Tube: Tube OD of  $\frac{3}{4}$  and 1" are very common to design a compact heat exchanger.
- ❖ The most efficient condition for heat transfer is to have the maximum number of tubes in the shell to increase turbulence.
- ❖ The tube thickness should 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:

# Shell And Tube Heat Exchanger

## Split View of Parts



## **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 is used to direct the tube side flow.

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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

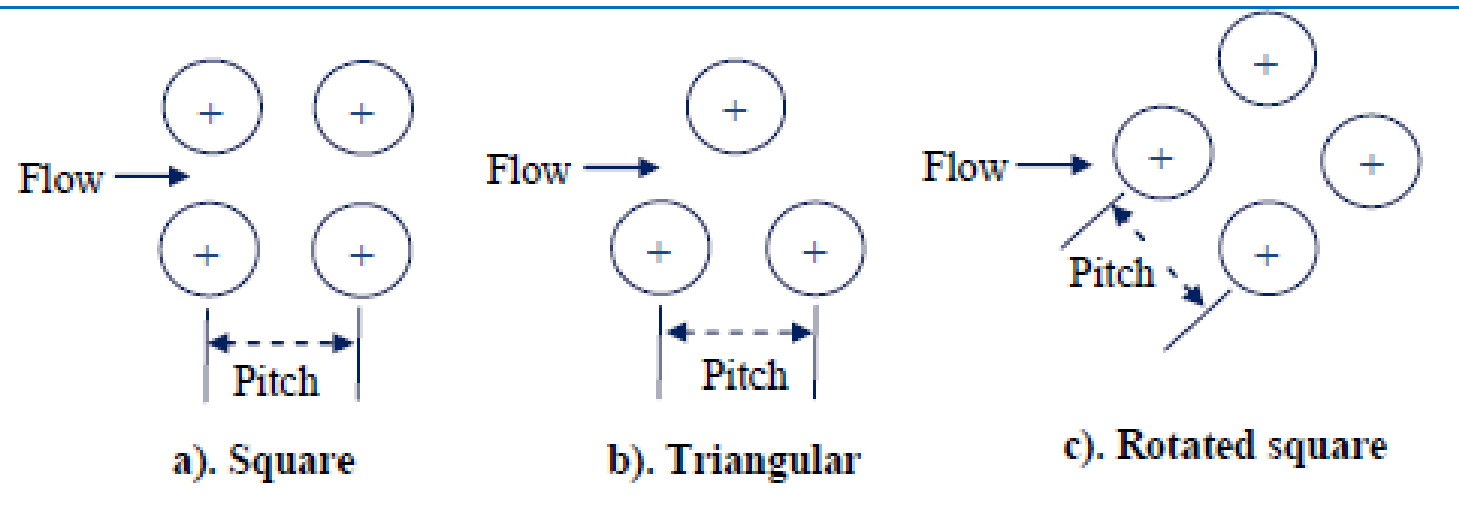


Figure 1.5. Heat exchanger tube-layouts.

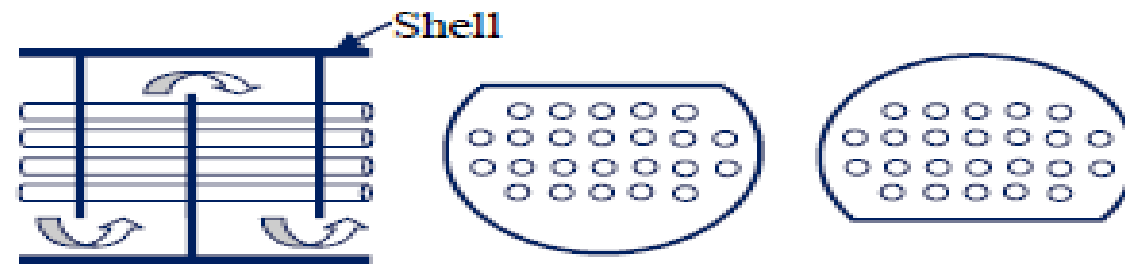
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**Tube sheet:** The tubes are fixed with tube sheet that form the barrier between the tube and shell fluids.

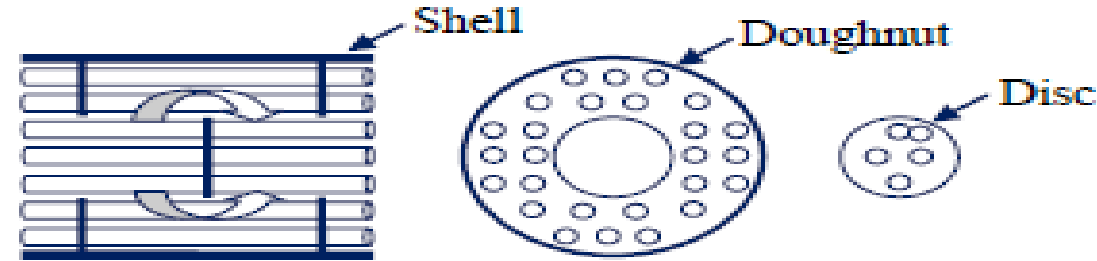
- ❖ The tubes are attached to tube sheet with two or more grooves in the tube sheet wall by „tube rolling“.
- ❖ The tube metal is forced to move into the grooves forming an excellent tight seal.
- ❖ This is the most common type of fixing arrangement in large industrial exchangers.
- ❖ The tube sheet 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.

- ❖ **1.2.6. 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 position 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.

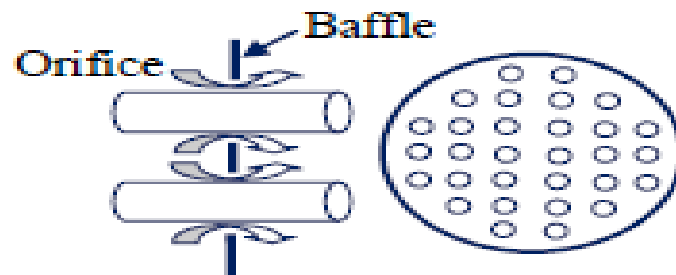
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a). Cut-segmental baffle



b). Disc and doughnut baffle



c). Orifice baffle

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

## **Steps to design shell and tube heat exchanger**

*Step 1; Specification*

*Step 2: Physical Properties*

*Step 3: Overall coefficient*

*Step 4: Exchanger type and dimensions*

*Step 5: Heat transfer area*

*Step 6: Layout and tube size*

*Step 7: Number of tubes*

*Step 8: Bundle and shell diameter*

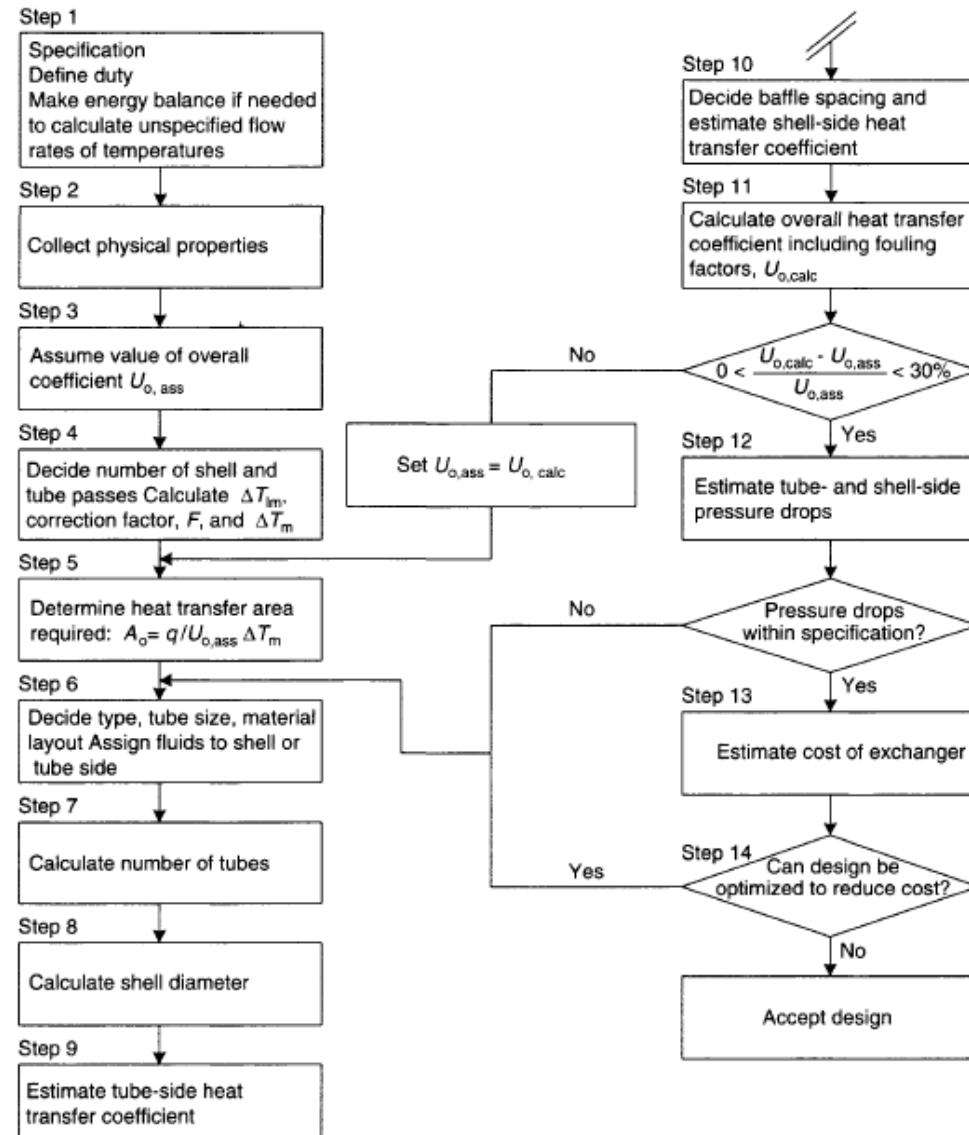
*Step 9: Tube-side heat transfer coefficient*

*Step 10: Shell-side heat transfer coefficient*

*Step 11: Overall coefficient*

*Step 12: Pressure drop*

## An algorithm for the design of shell-and-tube exchangers



Read the Text Book(**Coulson & Richardson's**, Volume 6, Third edition)

See Example 12.2 : Heat Exchanger Design Page 679



**THANK YOU**