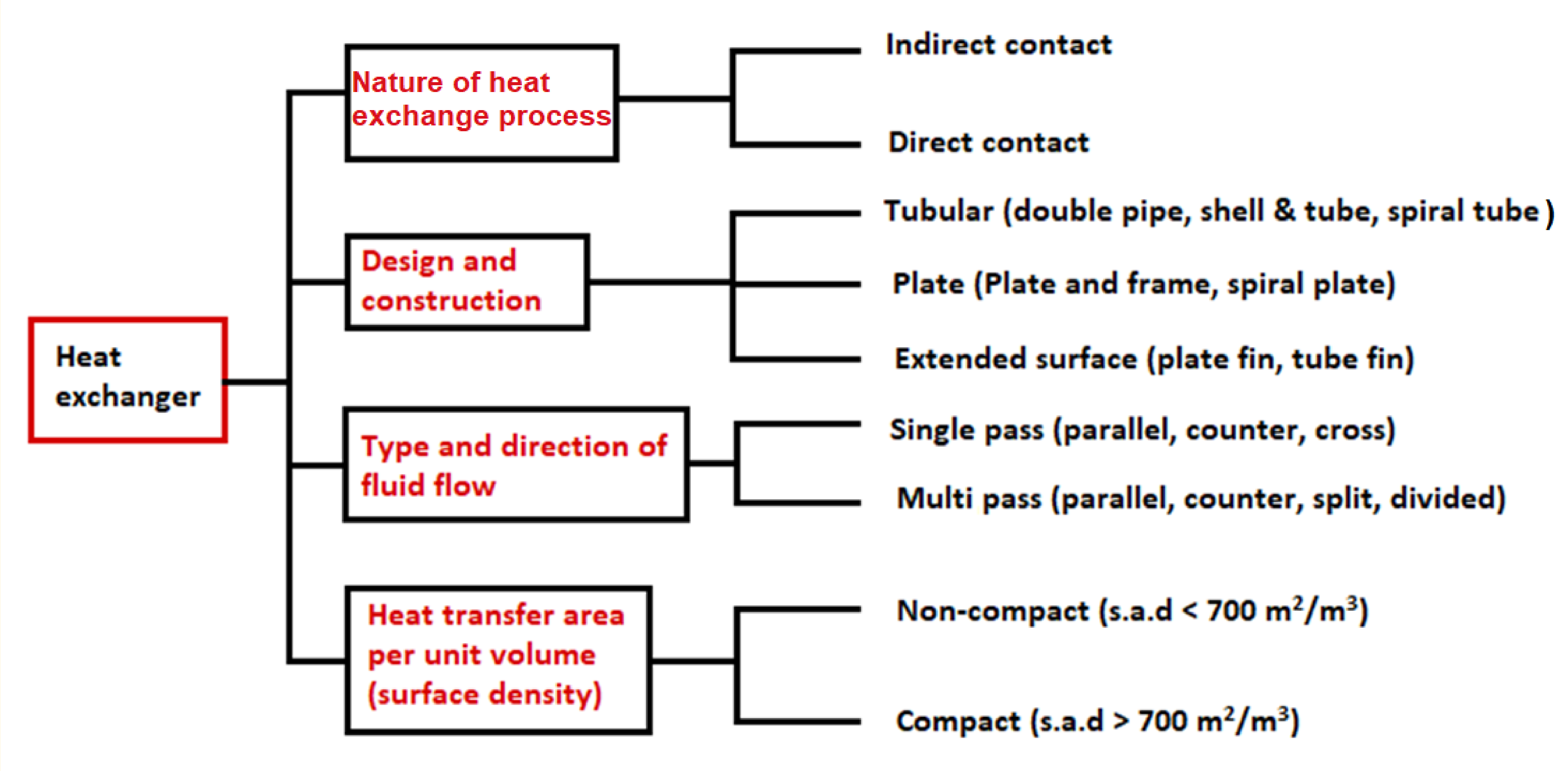
Heat Exchangers

- Apart from perhaps fluid flow and transport of process material, *the transfer of heat between two process streams is the most commonly encountered operation in process plant design*
- In order to carry out this operation, *equipment such as heat exchangers are required*

- ***A heat exchanger is a device in which two fluid streams, one hot and one cold are brought in 'thermal contact' in order to bring about transfer of heat from the hot stream to the cold stream***
- The purpose of this heat exchange is to (a) get a desired process fluid at a desired temperature as well as (b) energy economizing or recovery of waste heat from a process stream

- Usually the term of **heat exchanger** is used if **heat is transferred from a hot to cold fluid**
- **Heaters** are used primarily to **heat process fluids** – steam or hot circulating oil (in oil refineries) are usually used for this purpose
- **Coolers** are used to **cool process fluids**, mainly using water
- The term **condenser** is used when there is a **phase change** and latent heat is removed to undergo the phase change
- The purpose of a **reboiler** is to **provide heat (as latent heat**) in a distillation process

Classification of heat exchangers



Nature of heat exchange process

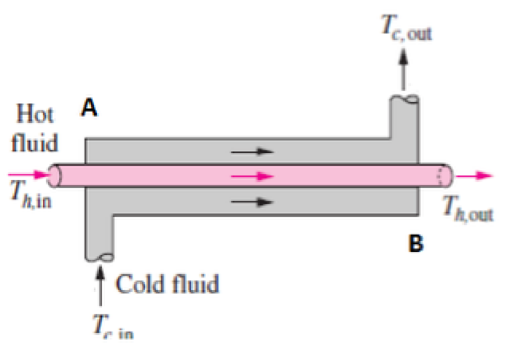
- Most heat exchangers are ones where the hot and cold fluid are separated by impervious surfaces – indirect contact, hence, no mixing and no problem of contamination or separation
- The most common example of direct contact exchanger where the fluids are brought in direct physical contact for the purpose of heat exchange is the cooling tower
- Direct contact exchangers can be used in conditions which require rapid rates of heat transfer and no harm due to mixing of fluids

Design and construction

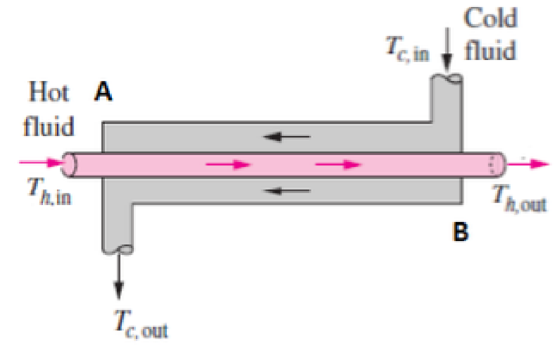
- There will be extensive discussions on the type of heat exchangers based on construction and design in later part of this chapter

Type and direction of fluid flow

- Single-pass and multi-pass denotes how the fluid flows through the exchanger
- If the fluid passes just once it is called a **single-pass** – this may be in **co-current (parallel)** mode (both fluids move in the same direction) or in **counter-current mode** (two fluids move in opposite directions)



COCURRENT



COUNTERCURRENT

Type and direction of fluid flow

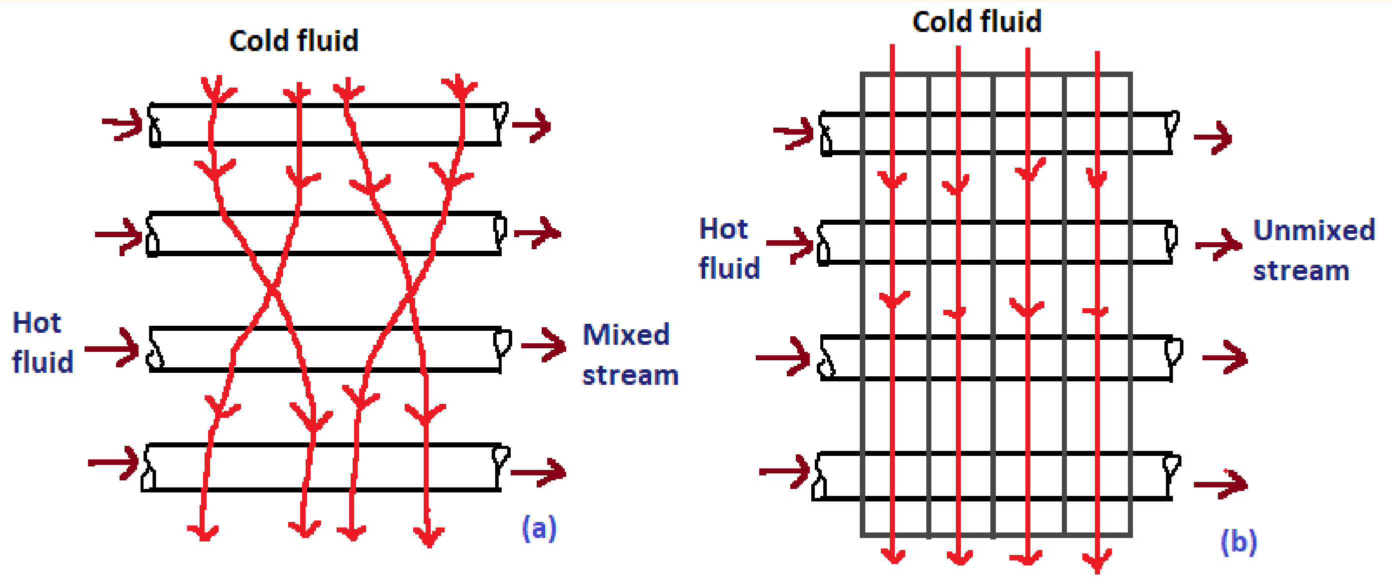
- If the fluid passes more than once it is called a multi-pass exchanger
- In the cross-flow mode the two fluids (hot and cold) cross one another at right angles

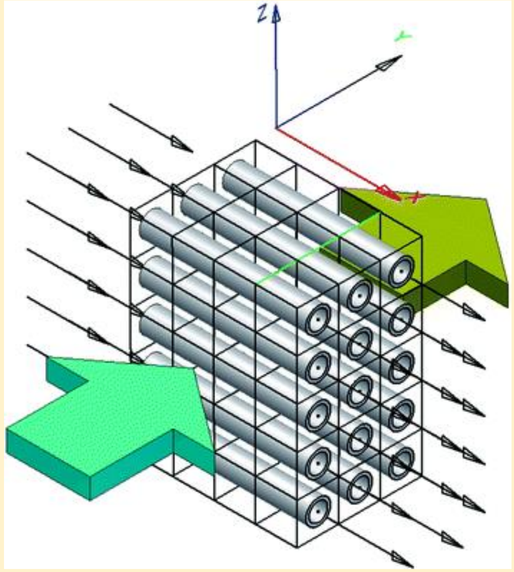
(a) One fluid is in the unmixed stream while the other is in the mixed stream

– hot fluid flows through separate tubes and there is no mixing of fluid streams

– cold fluid is perfectly mixed as it flows through the exchanger- temperature of this fluid is uniform across any section and varies only in the direction of flow

(b) Each fluid follows prescribed path and is unmixed, hence the temperature of the leaving fluid is uniform





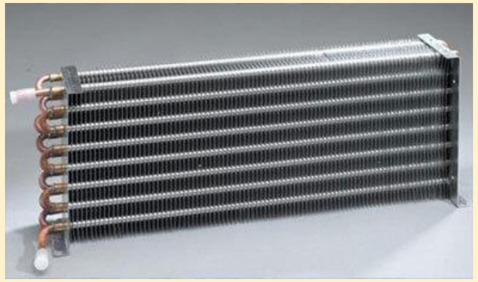
Heat transfer area per unit volume

- **Compact heat exchangers** such as a plate and frame, spiral tube and spiral frame exchangers accommodate very large heat transfer area in a small volume
- For **non-compact heat exchangers** such as double pipe, shell and tube exchanger etc, the surface area density is not very high

Plate and frame heat exchanger

Spiral heat exchanger

Double pipe heat exchanger

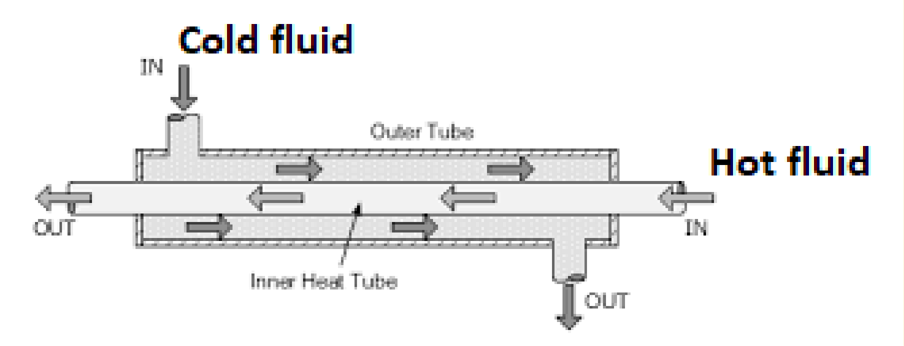


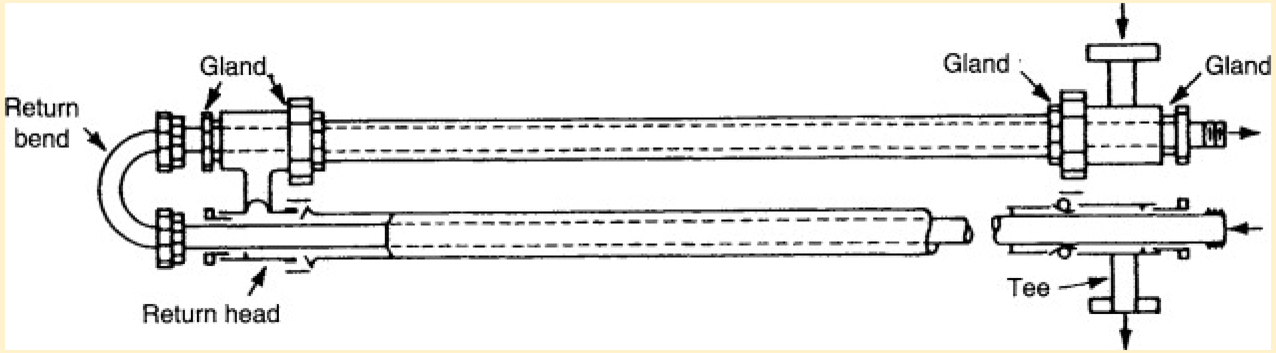
Finned tube heat exchanger

Shell and tube heat exchanger

Double pipe heat exchanger

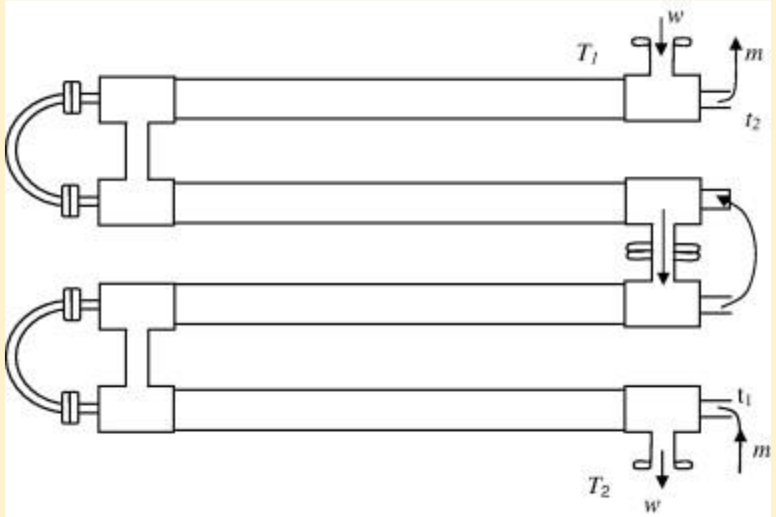
- This is the simplest type of heat exchanger consisting of *two concentric pipes welded at the ends and provided with nozzles for entry and exit of hot and cold fluids*
- One fluid flows through the inner pipe and the other through the annulus - hot and cold fluids are brought in thermal contact
- The flows of fluid may be co- or counter-current – in case of counter-current flow, the temperature difference (driving force) remains more or less uniform throughout the length of the exchanger and allows for better exchange of heat
- Double pipe exchangers are used when the *flow rates of the fluids and heat duty are small* (< 500kW)

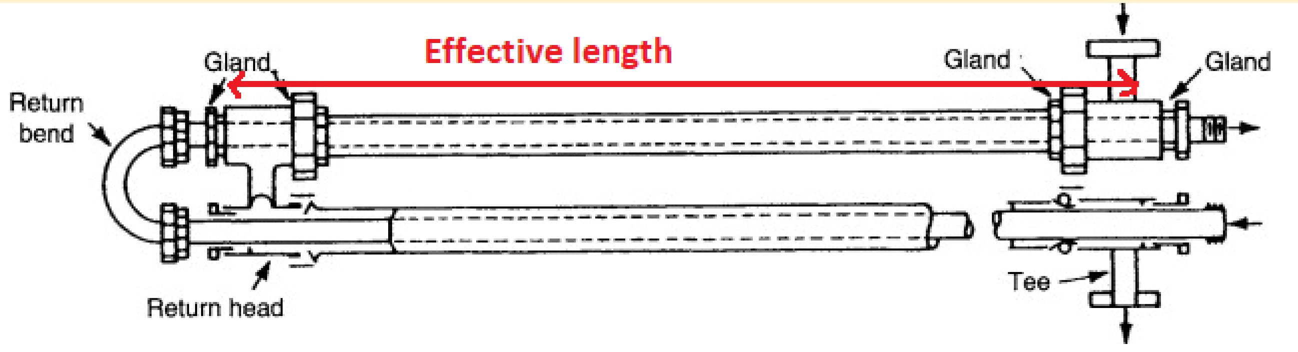




- If the area requirement is large or space available small to have two straight concentric pipes , the pipe is turned to form a 'U bend'. This type of construction is called a ***hairpin***
- Apart from two concentric pipes, there are two connecting tees, a return head and a return bend

- If the required heat transfer area is large, several hairpins may be connected in series
- The double pipe heat exchanger is the most expensive exchanger and can be easily constructed
- These exchangers are usually assembled in ***12, 15, 20 feet effective length*** (distance in each leg over which heat transfer occurs and excludes inner pipe protruding beyond the exchanger section)





- In case of length > 20 feet, the inner pipe tends to sag and touch the outer one
- A packing and gland arrangement near the inlet and exit ends of the assembly provides sealing to the annulus and supports the inner pipe
- The main disadvantage of this exchanger is the small heat transfer surface available

An overall heat balance can be written as,

$$Q = \dot{m}_h C_{ph}(T_{h1} - T_{h2}) = \dot{m}_c C_{pc}(T_{c1} - T_{c2})$$

Also,

$$Q = U_o A_o \Delta T_m$$

where U_o = overall heat transfer coefficient based on the outer area

A_o = outer area of the inner tube = $2\pi r_o L$ (r_o = outer radius of inner pipe)

ΔT_m = log mean temperature difference ($LMTD$)

$$\frac{1}{U_o} = \frac{r_o}{r_i h_i} + \frac{r_o \ln\left({r_o}/{r_i}\right)}{k_w} + \frac{1}{h_o}$$

h_i and h_o are determined from empirical equations

- For a process, ΔT_m or $LMTD$ is fixed, the rate of heat transfer can be increased by either increasing U or increasing A
- Increasing the velocity increases U, but also increases pressure drop – this causes an increase in the recurring expenses
- So, the only way Q can be increased is by increasing A
- Area can be enhanced by increasing length or number of hairpins
- There is an upper limit to the length of the exchanger (20 feet) or the pipe sags
- Larger number of hairpins result in larger floor area required for the exchanger (which is undesired)

  Also, it leads to a larger number of points at which leakage may occur