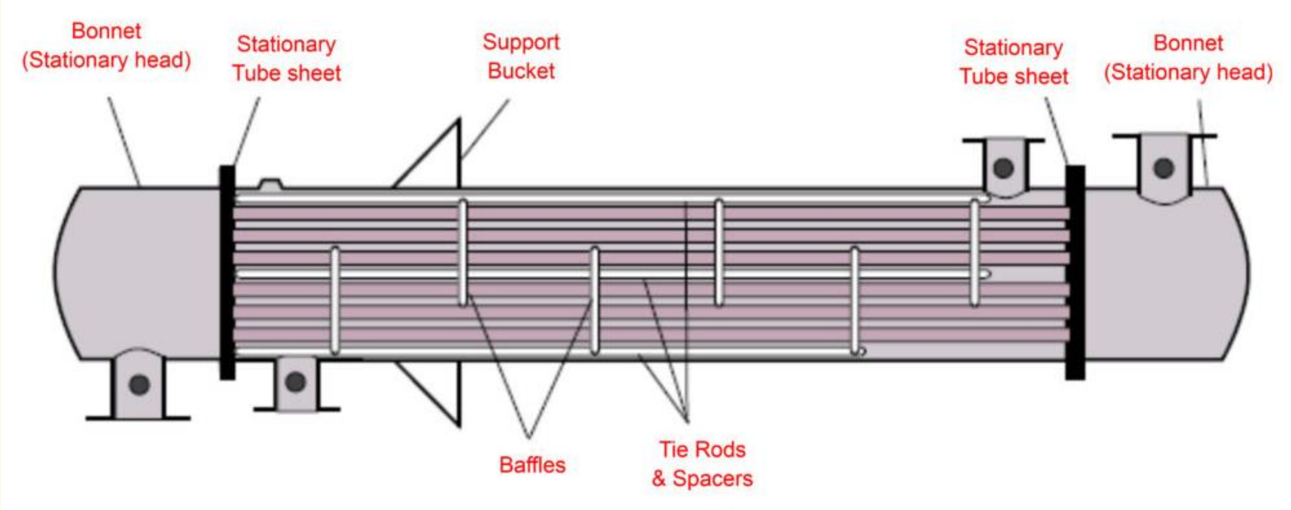
Heat Exchangers

Types of shell and tube heat exchangers

The types of exchangers, mechanical design features, fabrication, materials of construction and testing of shell and tube exchangers is given in the British Standard, BS 3274 or in the standards of the American Tubular Heat Exchanger Manufacturers Association (TEMA)

Fixed tube sheet/Fixed head exchanger

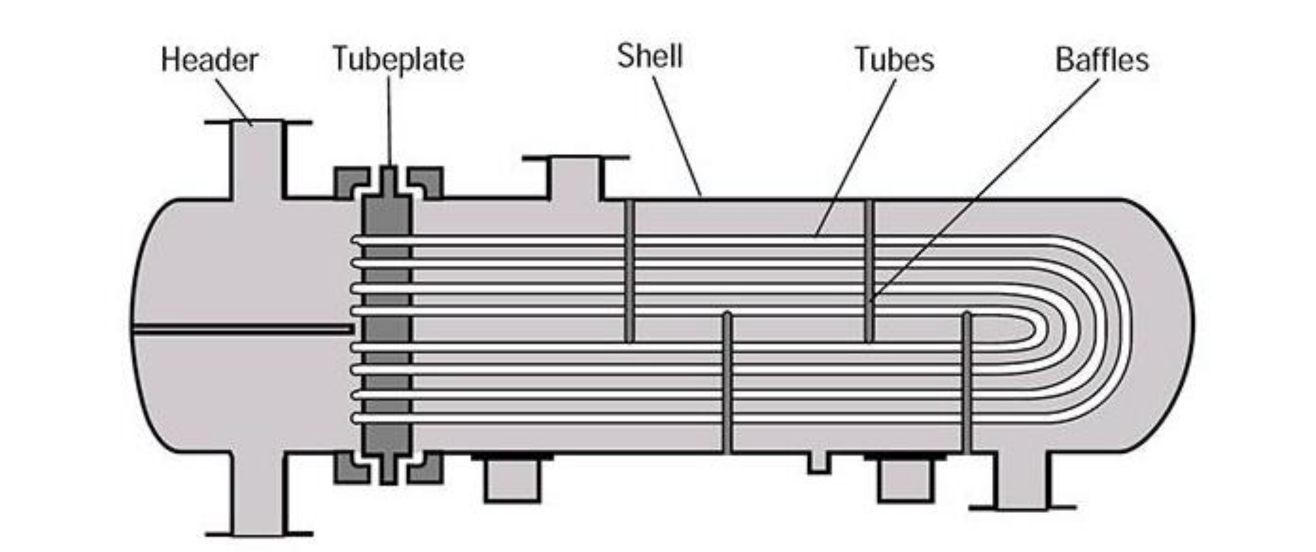
- A fixed tube exchanger is simple in construction and is economical
- In a fixed tube exchanger, the tube sheets are welded to the shell and there is no relative motion between the shell and the tube bundle and possibility of leakage is minimised
- The gasketed joints are minimum in such heat exchangers and there is minimum by passing of the shell side fluid between the tube bundle and shell
- The main *disadvantage* of this type of exchanger is that the (a) tube bundle cannot be removed for cleaning and (b) there is no provision for differential expansion of the shell and tubes
- Some of this thermal stress can be absorbed by the expansion joint
- This type of exchanger is limited to temperature differences up to about 80^{o}C, and shell pressure up to 8 bar



1:2 pass shell and tube heat exchanger

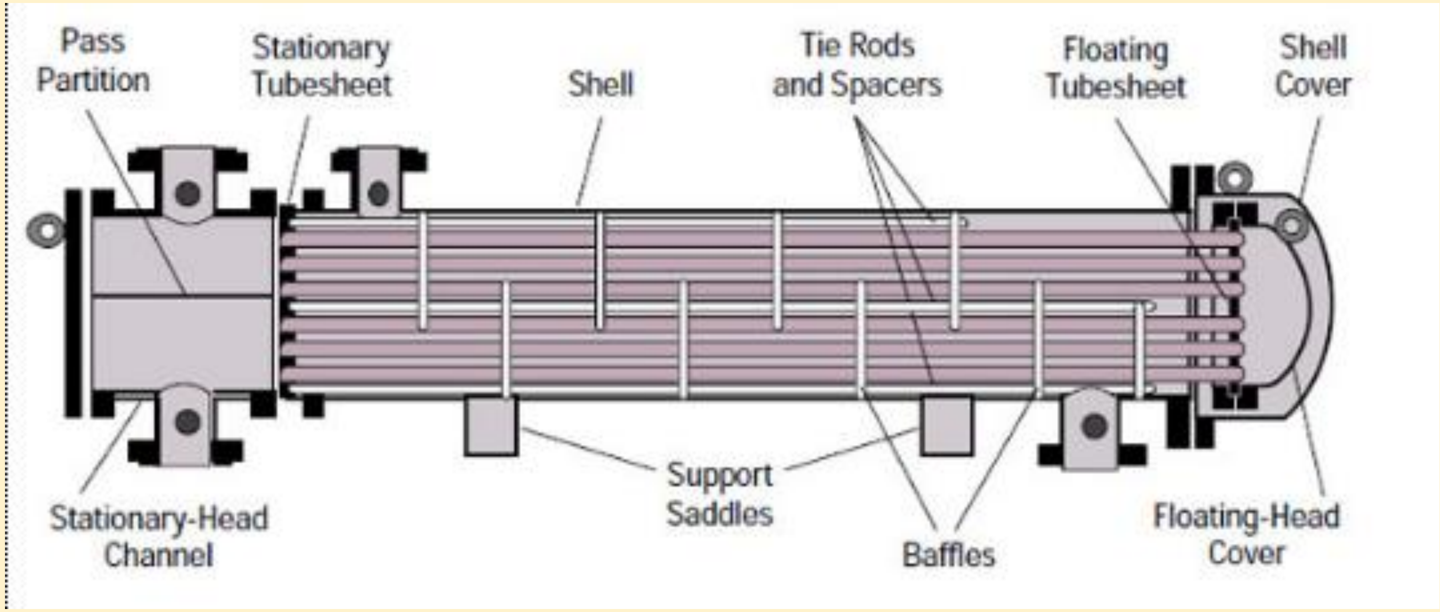
U-tube (U-bundle) head exchanger

- The U-tube exchanger has a single tube sheet
- The tubes are bent to form a ‘U’ and both the ends of the tube are fixed to the tube sheet
- The length of an ‘inner’ tube in a bundle is smaller than that of an ‘outer’ tube
- The tubes can contract and expand freely and does not need any provision to take care of thermal stress due to the temperature difference between fluids of the shell and tube
- The U-tube bundle can easily be removed by unbolting the tube sheet and pulling the bundle out
- The main disadvantage of this type of exchanger is that the tubes becomes weak at the bends
- This type of exchanger can accommodate only two tube side passes
- Cleaning inside the tubes in the portion near the bends is not possible and this leads to problems if fluid is dirty



Floating head (removable bundle) head exchanger

- In a floating heat exchanger, one tube sheet is bolted to the flange while the other tube sheet floats or slides inside the channel or bonnet permitting a relative movement between the shell and the tube bundle
- The floating head cover is bolted to the tube sheet and the entire bundle can be withdrawn from the channel end
- As the bundle can be removed and cleaned easily, such exchangers can be used for dirtier fluids



- The floating head is movable, hence the tubes can expand
- As this exchanger is capable of handling thermal stresses, it can be used for high temperature differentials
- The disadvantage of the pull through floating head design is that the clearance between the outermost tubes in the bundle and the shell must be made greater than in the fixed or U-tube designs to accommodate the floating head flange
- This causes the shell side fluid to bypass the tubes
- It also reduces the number of tubes that may be placed in the tube bundle

Fouling factor (Dirt factor) in a heat exchanger

- Most process and service fluids contain suspended matter or dissolved solids
- When such a fluid flows through the exchanger for a long period of time, these materials deposit on the tube surfaces and cause ***fouling***
- The deposited materials normally have a relative low thermal conductivity and act as a resistance to heat transfer
- The heat transfer resistance offered by the deposit or scale is called the ***fouling factor*** or ***dirt factor*** – this value is zero for a new exchanger
- While designing an exchanger, the value of the fouling factor is included as an additional resistance
- These factors cannot be predicted or estimated, they are determined from experimental data
- The estimation of overall heat transfer coefficient is done as:

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{r_o \ln\left({}^{r_o}/_{r_i}\right)}{k_w} + \frac{r_o}{r_i} \times \frac{1}{h_{id}} + \frac{r_o}{r_i} \times \frac{1}{h_d}$$

h_{od} : outside dirt coefficient h_{id} : inside dirt coefficient

$$\frac{1}{U_o} = \frac{1}{h_o} + R_{do} + \frac{r_o \ln\left({}^{r_o}/_{r_i}\right)}{k_w} + \frac{r_o}{r_i} \times R_{di} + \frac{r_o}{r_i} \times \frac{1}{h_d}$$

R_{do}: outside dirt factor R_{di}: inside dirt factor

Some typical fouling factors are:

Fluid	Dirt coefficient ($W/m^{2o}C$) (h_d)	Fouling factor (resistance) ($m^{2o}C/W$) (R_d)
River water	3000 - 12000	0.0003 – 0.0001
Cooling water	3000 - 6000	0.0003 – 0.00017
Steam condensate	1500 - 5000	0.00067 – 0.0002
Organic liquids	5000	0.0002

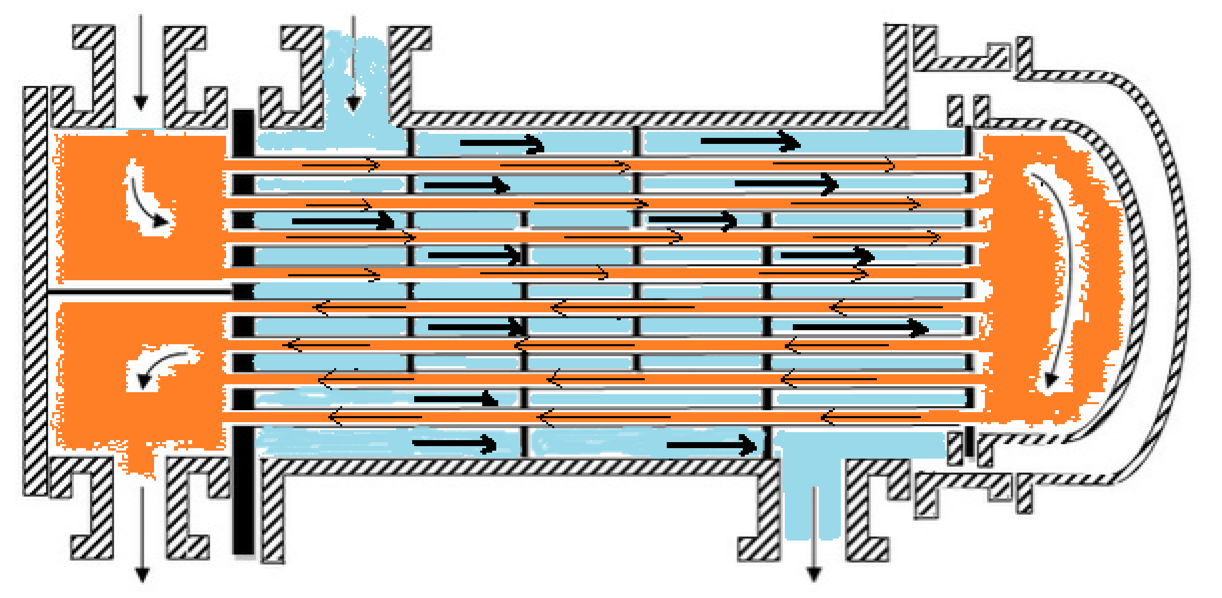
LMTD correction factor

- In the case of a co or counter-current double pipe heat exchanger or a co or counter-current shell and tube heat exchanger, the temperature driving force varies with position
- The log mean temperature difference (LMTD) is used as the average driving force
- Values of LMTD differ for co-current and counter-current cases with counter-current usually having a higher value
- However, in the case of *multi-pass shell and tube heat exchanger* (1-2, 1-4, 2-4 pass), *fluids are partly in counter current and partly in co-current flow*
- This deviation from true counter-current flow results in a change in the average driving force

- ***The true temperature driving force for a multi-pass exchanger is obtained by multiplying the LMTD (for counter-current) with a correction factor, F_T***

$$\Delta T_m = F_T \times \Delta T_{LMTD}$$

- The correction factor is a function of the shell side and tube side fluid temperatures and the number of shell and tube passes



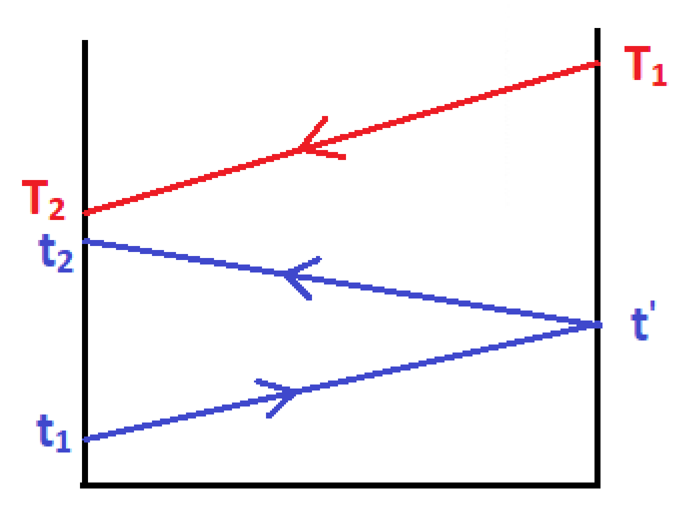
LMTD correction factor

- LMTD is normally correlated as a function of two dimensionless temperature ratios

$$R = \frac{(T_1 - T_2)}{(t_2 - t_1)} \quad \text{and} \quad S = \frac{(t_2 - t_1)}{(T_1 - t_1)}$$

- For a 1-2 pass exchanger, the correction factor is

$$F_T = \frac{\sqrt{(R^2+1)}\, ln\left[\frac{(1-S)}{(1-RS)}\right]}{(R-1)\, ln\left[\frac{2 - S\left(R + 1 - \sqrt{(R^2+1)}\right)}{2 - S\left(R + 1 + \sqrt{(R^2+1)}\right)}\right]}$$



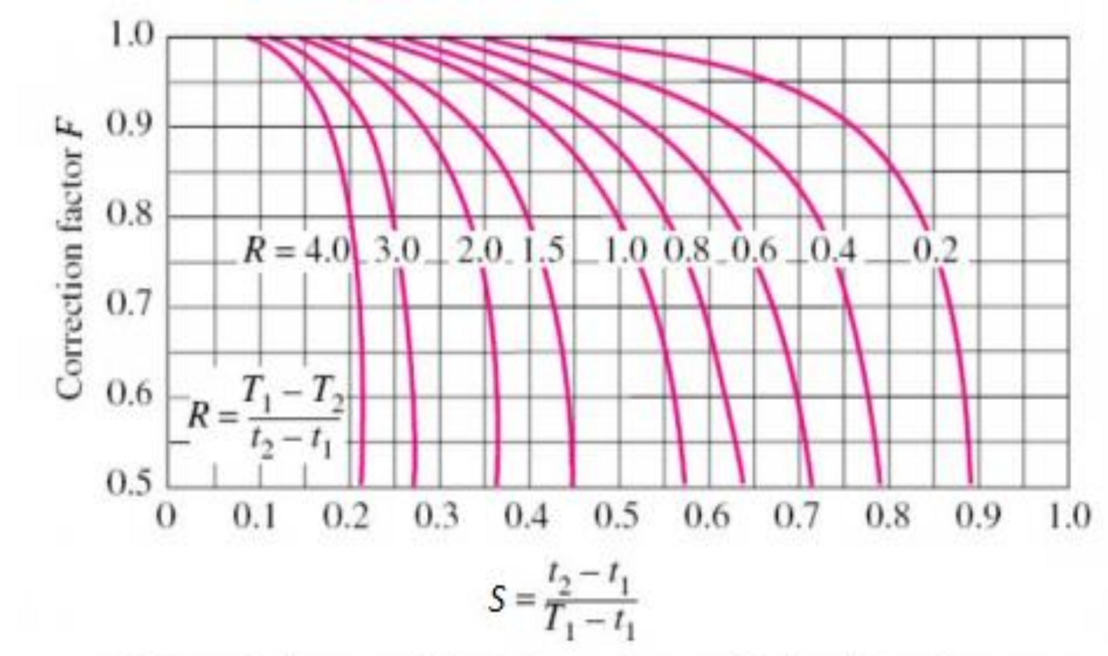
T_1 = inlet temp of hot fluid
T_2 = outlet temp of hot fluid
t_1 = inlet temp of cold fluid
t_2 = outlet temp of cold fluid
t' = intermediate temp of cold fluid

- ***The LMTD correction factor, F_T is always < 1 for multi-pass exchangers***

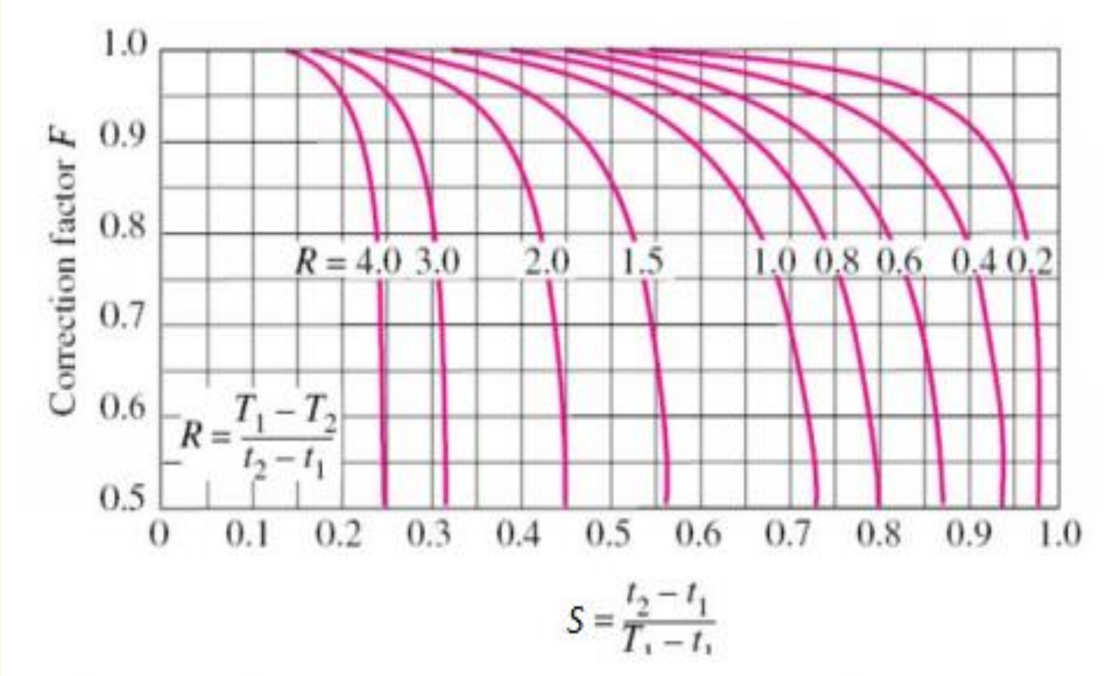
- The tube passes which are parallel with the shell fluid do not contribute as effectively as the passes which are in the counter-current mode – this results in $F_T < 1$ and the actual temperature difference being less than what it would have been for a purely counter-current exchanger

- An economic exchanger cannot normally be achieved if the correction factor. F_T falls below 0.75

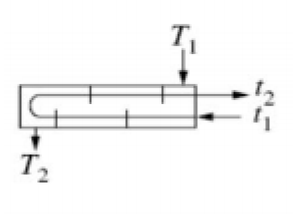
- The F_T values are usually obtained from charts
- The chart for a 1-2 pass exchanger can also be used for 1-4, 1-6 and 1-8 exchangers
- Other charts are available for 2-4 exchangers, and other orientations

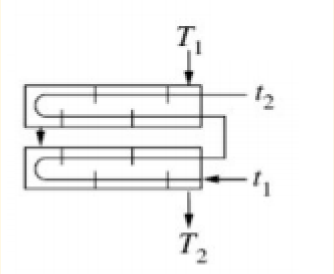


(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



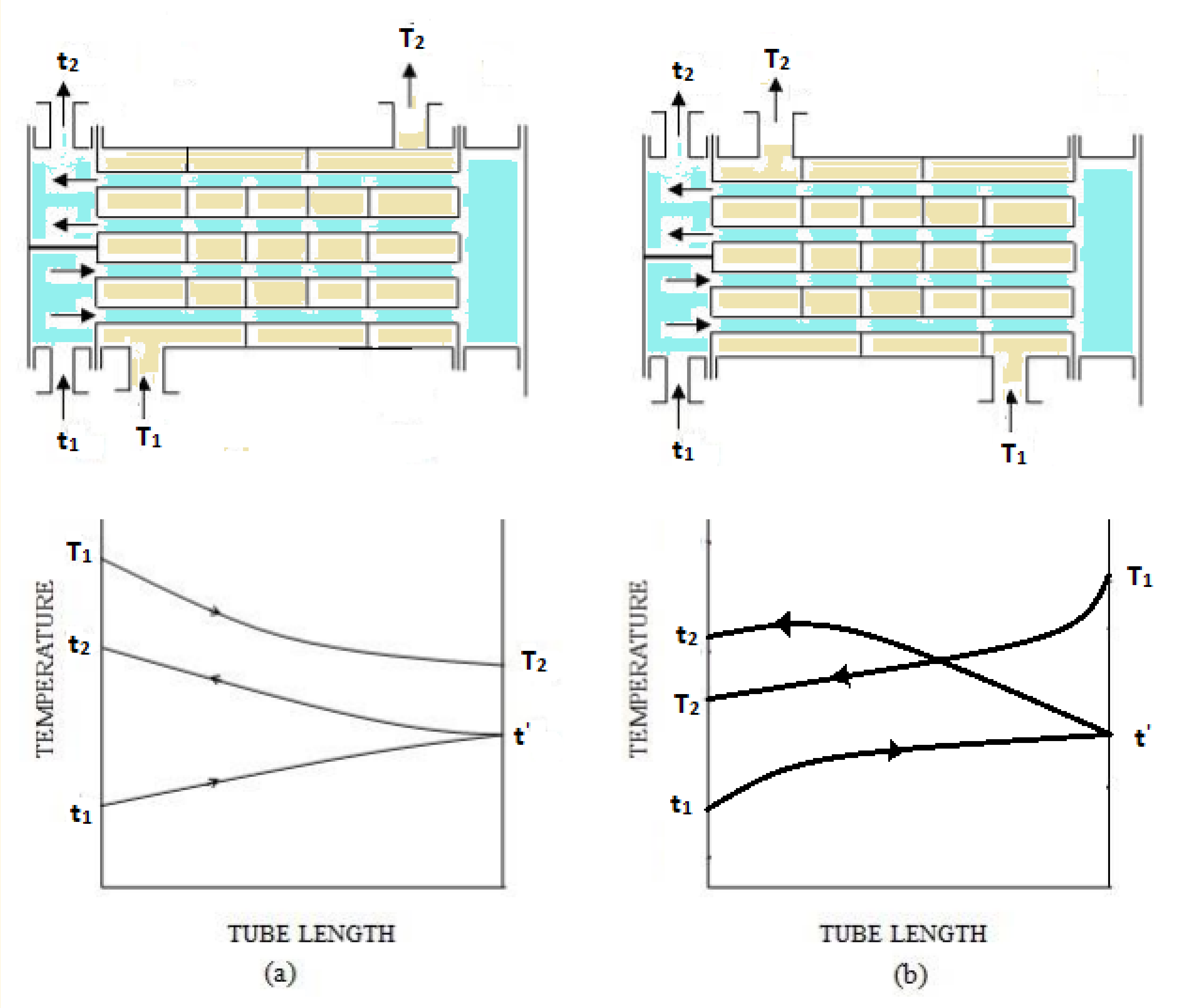
(*b*) Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes





Temperature distribution in multi-pass exchangers

- When the hot and cold fluids enter the exchanger at the same end, the temperature profile is shown by (a)
- However, if they enter at opposite ends, as in (b), a temperature cross may sometimes occur
- Temperature cross occurs when the difference between the cold and hot fluid is positive at the exchanger exit ($t_2 > T_2$)
- The cold fluid temperature reaches a maximum at a point inside the exchanger and not at the exit
- The quantity ($t_2 – T_2$) is called the ***temperature cross*** of the exchanger
- If the temperature cross does not happen, i.e., if $t_2 < T_2$, then ($t_2 – T_2$) is called the ***temperature approach***



Fluid allocation : shell and tube

The following factors help to determine the allocation of the fluid stream to the shell or tube side in case of no phase change:

Corrosion: The more corrosive fluid should be allocated to the tube-side

This reduces the cost of expensive alloy components

Fouling: The fluid that has a greater tendency to foul the heat transfer surfaces should be placed in the tubes

This gives better control over the design fluid velocity as higher allowable velocity in the tubes reduce fouling

Also, tubes are easier to clean

Fluid temperature: If temperature of the fluid is high enough to need special materials of construction, the fluid is placed in the tubes to reduce cost

Also, putting the hotter fluid in the tubes reduces the cost required for insulation on the shell to prevent heat loss

Operating pressure: The high pressure stream is allocated to the tube side

High pressure tubes are cheaper than high pressure shell

Pressure drop: For the same pressure drop, higher heat transfer coefficients are obtained on the tube side than the shell side

The fluid with the lowest allowable pressure drop should be allocated to the tube side

Viscosity: If the fluid flow is turbulent (critical Re for turbulent flow in shell is 200), a higher heat transfer coefficient will be obtained by allocating the more viscous material to the shell side

If the flow is not turbulent, the viscous fluid is placed in the tube side as the tube side heat transfer coefficient can be predicted with more certainty

Stream flowrate: The fluid with the lowest flow rate is allocated to the shell side

This gives the most economical design