HEAT EXCHANGERS

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- In the process Industries the transfer of heat between two fluids is generally done in heat exchangers.
- The most common type is one in which the hot and the cold fluid do not come into direct contact with each other but are separated by a tube wall or a flat or curved surface.
- *The transfer of heat is accomplished from the hot fluid to the wall or tube surface by convection, through the tube wall or plate by conduction and then by convection to the cold fluid.*
- *Remember,* $Q = U\,A\,\Delta T$
- In the design of heat exchange equipment, heat transfer equations are applied to calculate the transfer of energy so as to carry it out efficiently and under controlled conditions.

Continuous-flow Heat Exchangers

- One of the fluids is usually passed through pipes or tubes, and the other fluid stream is passed round or across these.

- At any point in the equipment, the local temperature differences and the heat transfer coefficients control the rate of heat exchange.

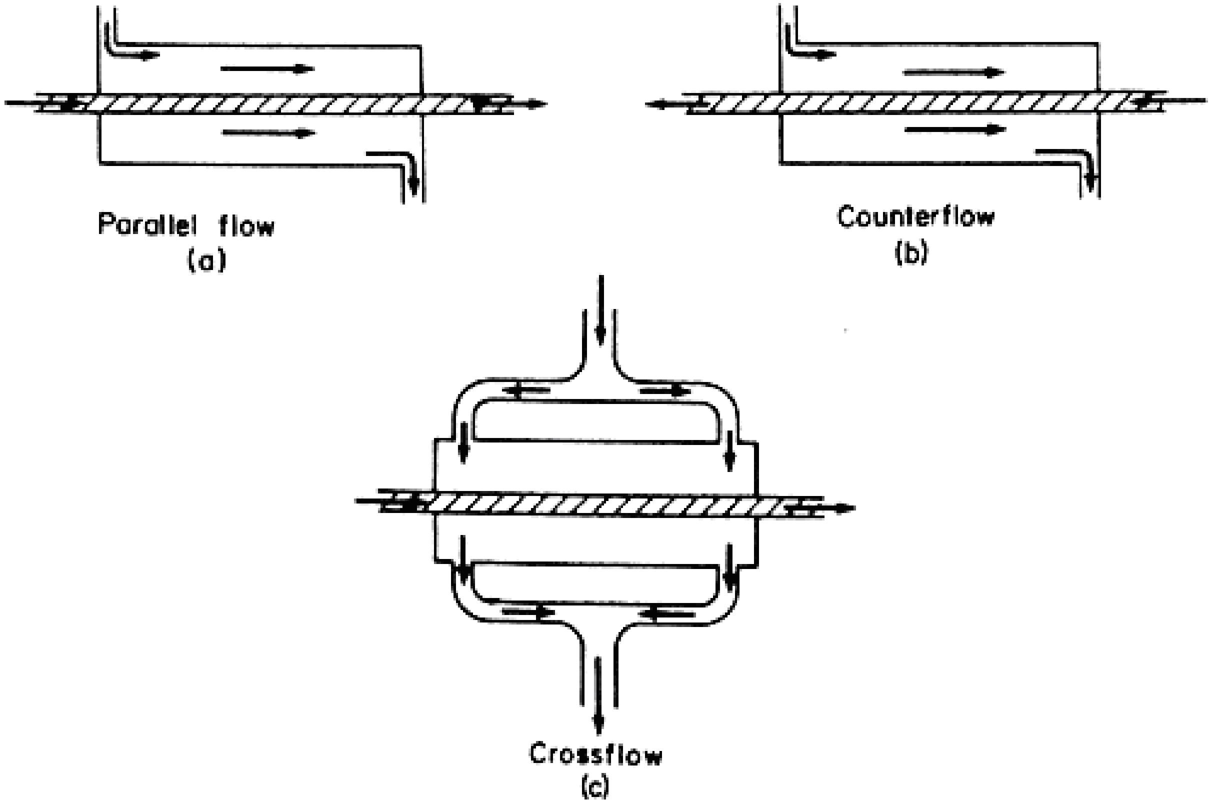
- The fluids can flow in the same direction through the equipment, this is called ***parallel flow***;

- they can flow in opposite directions, called ***counter flow***;

- they can flow at right angles to each other, called ***cross flow***.

- *Various combinations of these directions of flow can occur in different parts of the exchanger.*

- Examples of these exchangers are illustrated in **Figure**



- In parallel flow, at the entry to the heat exchanger, there is the maximum temperature difference between the coldest and the hottest stream, but at the exit the two streams can only approach each other's temperature.

- *In a counter flow exchanger, leaving streams can approach the temperatures of the entering stream of the other component and so counter flow exchangers are often preferred.*

- *Less heat can be transferred in parallel flow than in countercurrent flow: consequently, parallel flow is applied less frequently.*

Double-pipe heat exchanger

- The simplest exchanger is the double-pipe or concentric-pipe exchanger.
- This is shown in Fig., where the one fluid flows inside one pipe and the other fluid in the annular space between the two pipes.
- When one of the fluids is hotter than the other, heat flows from it through the wall of the inner tube into the other fluid.
- As a result, the hot fluid becomes cooler and the cold fluid becomes warmer.
- The fluids can be in co-current or countercurrent flow.
- This type of exchanger is useful mainly for small flow rates.

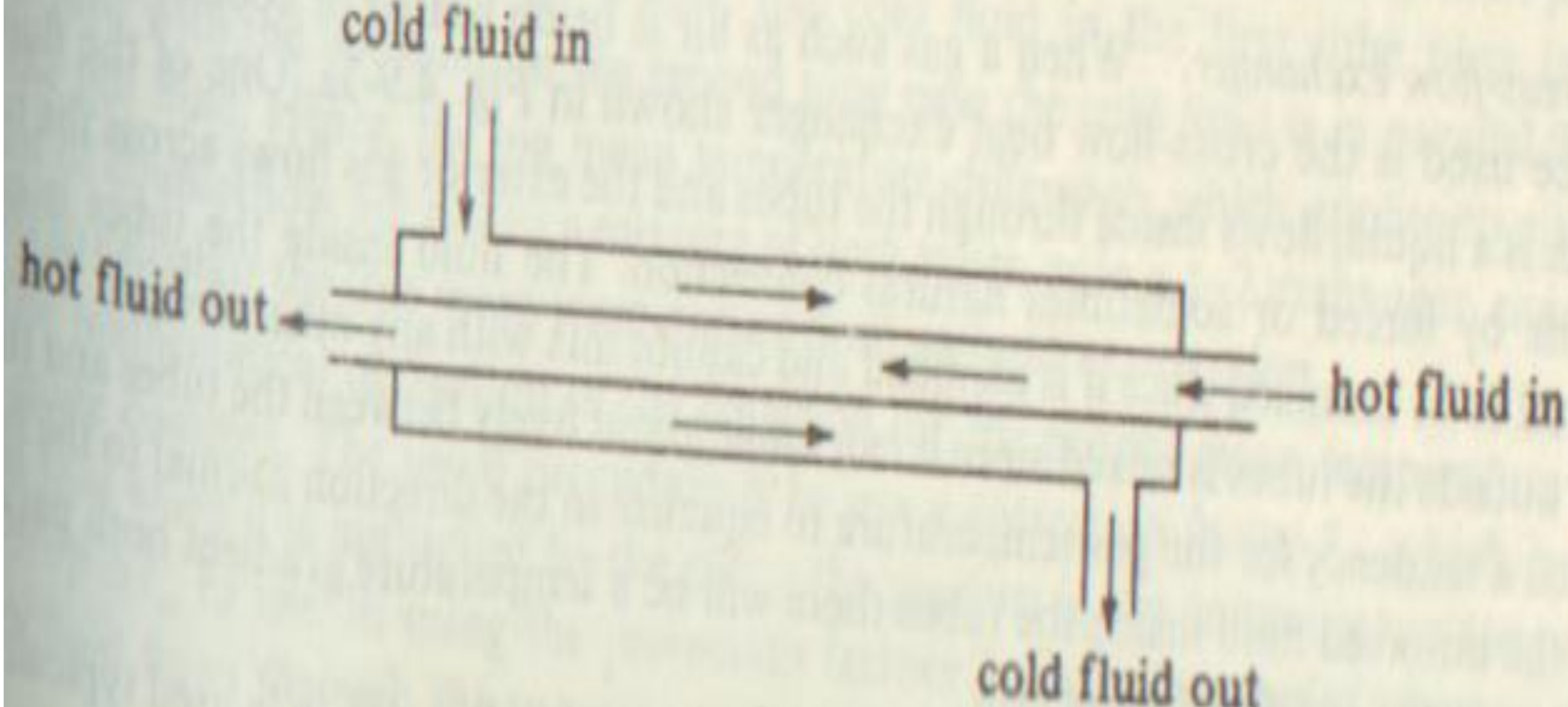


FIGURE 4.9-1. *Flow in a double-pipe heat exchanger.*

Figure 8.4 Temperature changes for countercurrent flow in a double-pipe heat exchanger.

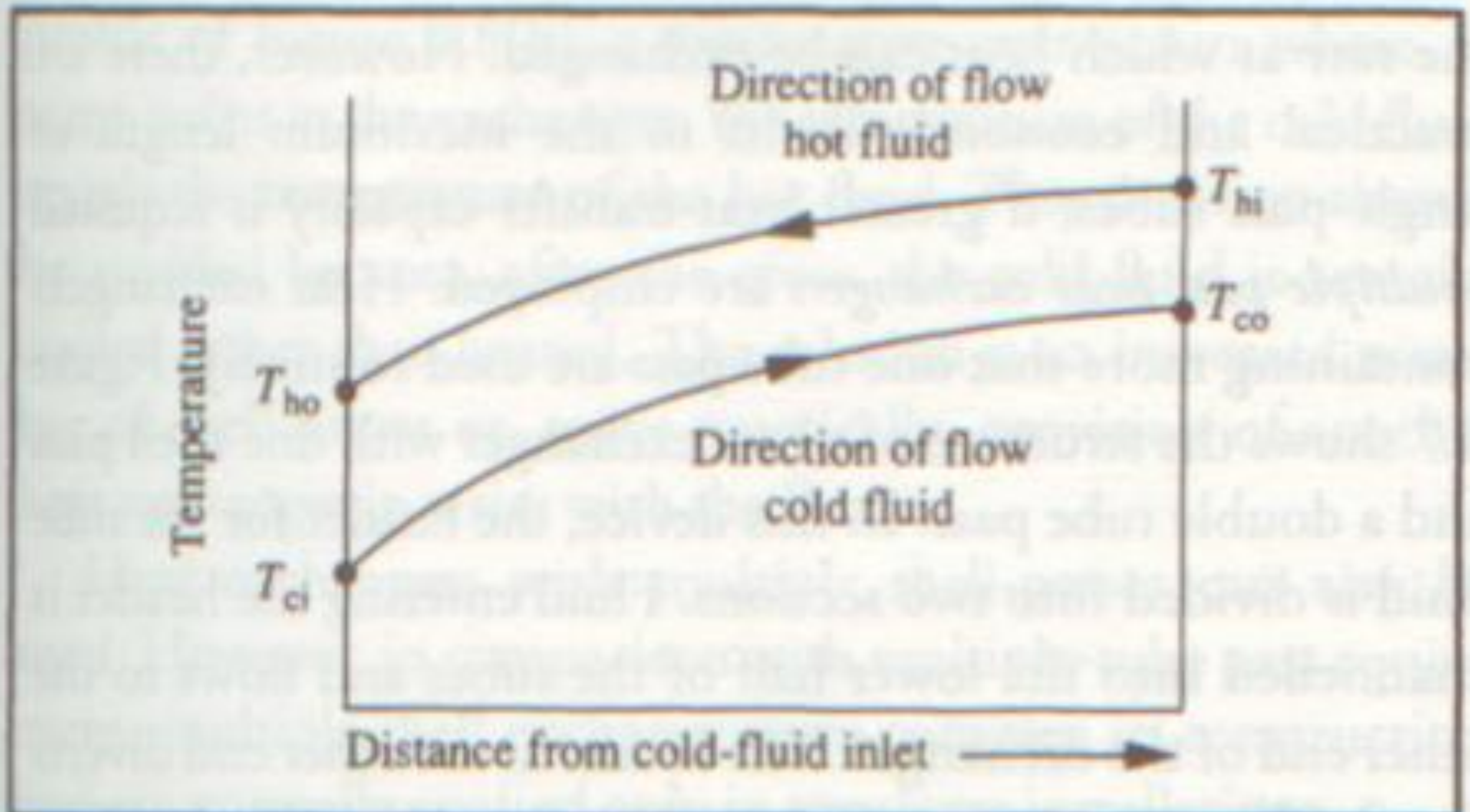
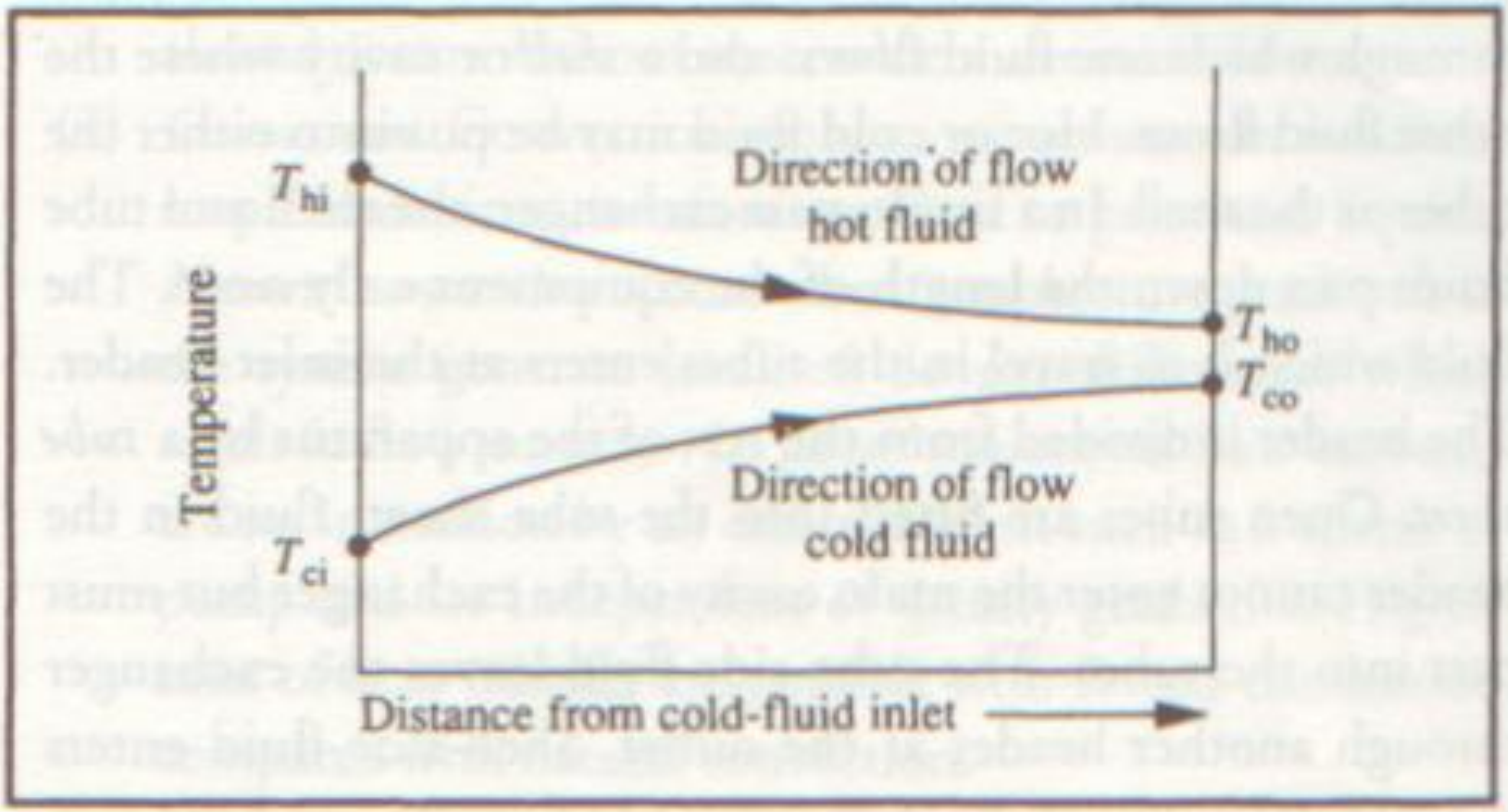


Figure 8.5 Temperature changes for cocurrent flow in a double-pipe heat exchanger.



- *When large surface areas are needed to achieve the desired rate of heat transfer, the shell-and-tube heat exchanger, is a better and more economical choice.*

Shell and tube Heat exchanger

- If larger flows are involved, a shell and tube exchanger is used, which is the most important type of exchanger in use in the process industries.

- *They have the advantage of containing very large surface areas in a relatively small volume.*

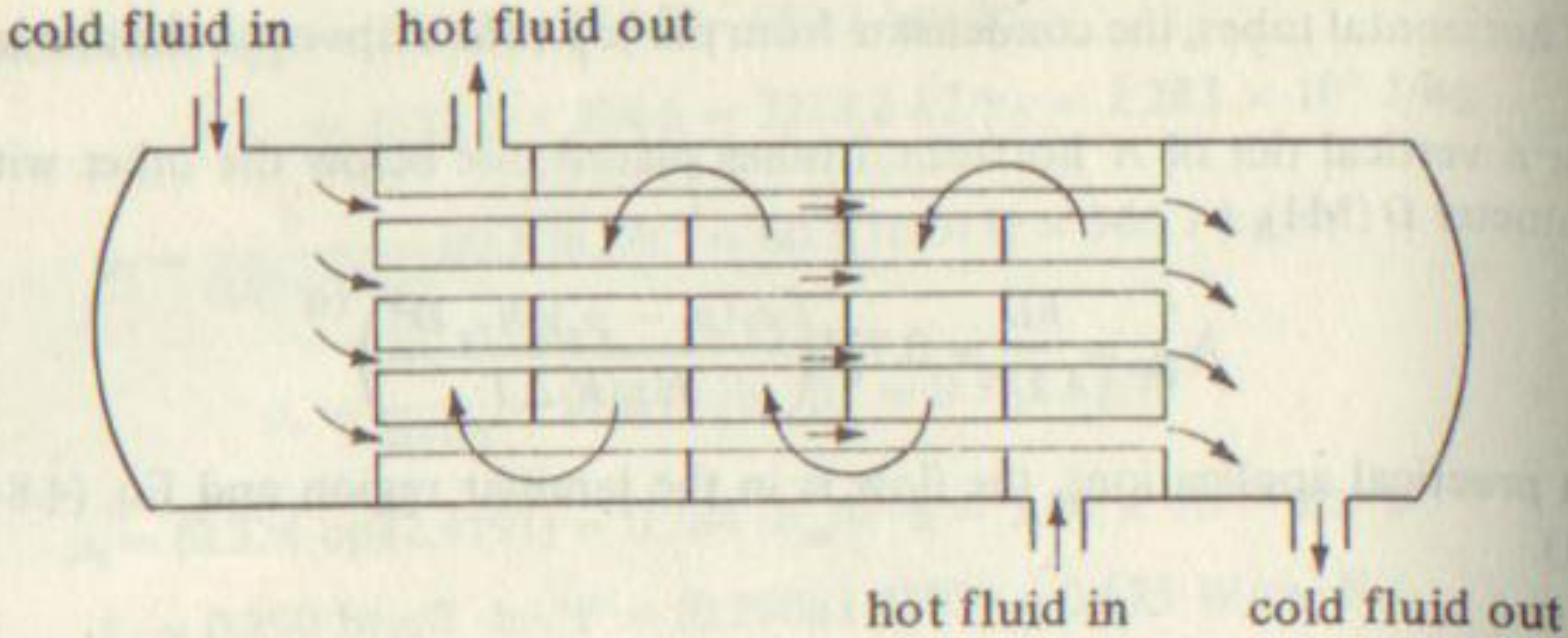
- In these exchangers the flows are continuous many tubes in parallel are used where one fluid flows inside these tubes.

- The tubes, arranged in a bundle, are enclosed in a single shell and the other fluid flow outside the tubes in the shell side.

- The simplest shell and tube exchanger is shown in Fig. a for 1 shell pass and 1 tube pass, or a 1–1 counter flow exchanger.

- The cold fluid enters and flows inside through all the tubes in parallel in one pass.

1 – 1 shell and tube exchanger



(a)

- The hot fluid enters at the other end and flows counter flow across the outside of the tubes.

- The heat-transfer system is divided into two sections: a tube bundle containing pipes through which one fluid flows, and a shell cavity where the other fluid flows.

- Hot or cold fluid may be put into either the tubes or the shell.

- In a single-pass exchanger, the shell and tube fluids pass down the length of the equipment only once.

- The fluid which is to travel in the tubes enters at the inlet header. The header is divided from the rest of the apparatus by a tube sheet. Open tubes are fitted into the tube sheet; fluid in the header cannot enter the main cavity of the exchanger but must pass into the tubes.

- The tube-side fluid leaves the exchanger through another header at the outlet.

- Shell-side fluid enters the internal cavity of the exchanger and flows around the outside of the tubes in a direction which is largely countercurrent to the tube fluid.

- Heat is exchanged across the tube walls from hot fluid to cold fluid.

- Cross baffles are used so that the fluid is forced to flow perpendicular across the tube bank rather than parallel with it.

- *This added turbulence generated by this cross flow increases the shell-side heat-transfer coefficient.*

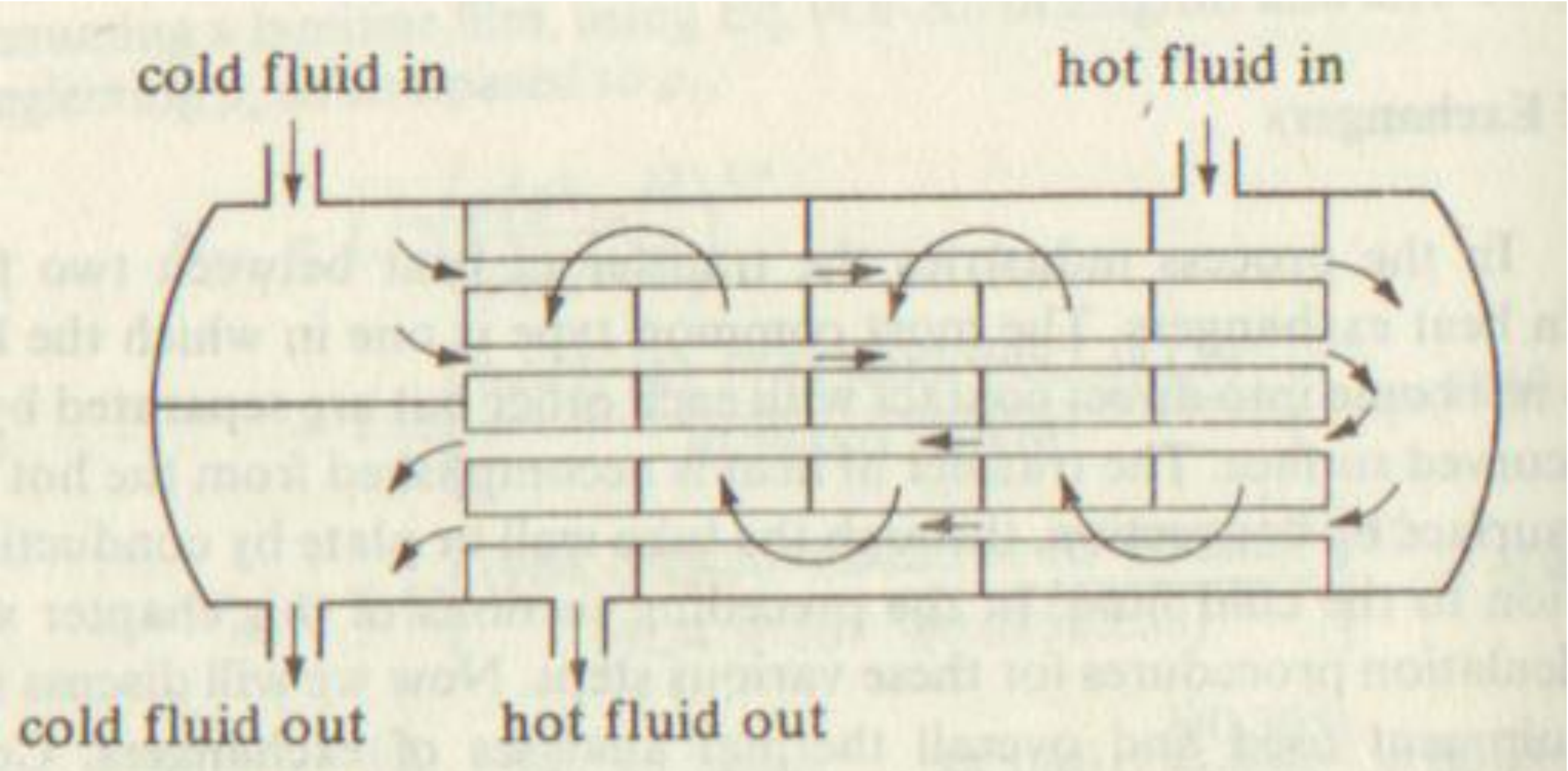
- Baffles also support the tube bundle and keep the tubes from sagging

- The length of tubes in a single-pass heat exchanger determines the surface area available for heat transfer, and therefore the rate at which heat can be exchanged.

- However, there are practical and economic limits to the maximum length of single-pass tubes; *if greater heat-transfer capacity is required multiple-pass heat exchangers are employed*.

- Heat exchangers containing more that one tube pass are used routinely

1 – 2 shell and tube exchanger



(b)

- In Fig. a 1 – 2 parallel – counter flow exchanger is shown.
- The liquid on the tube side flows in two passes as shown and the shell-side liquid flows in one pass.
- Figure shows the structure of a heat exchanger with one shell pass and a double tube pass.
- In this device, the header for the tube fluid is divided into two sections.
- Fluid entering the header is channeled into the lower half of the tubes and flows to the other end of the exchanger.
- The header at the other end diverts the fluid into the upper tubes; the tube-side fluid therefore leaves the exchanger at the same end it entered.

- On the shell side, the configuration is the same as for the single-pass structure; fluid enters one end of the shell and flows around several baffles to the other end.

- *In the first pass of the tube side the cold fluid is flowing counter flow to the hot shell-side fluid and in the second pass of the tube side the cold fluid flows in parallel (co-current) with the hot fluid.*

- Another type of exchanger has 2 shell-side passes and 4 tube passes.

- Other combinations of number of passes are also used sometimes, with the 1 – 2 and 2 – 4 types being the most common.

Design Equations For Heat-Transfer Systems

- The basic equation for design of heat exchangers is Eq. $Q = U A \Delta T$

- If Q, U and ΔT are known, this equation allows us to calculate A.

- Specification of A is a major objective of heat-exchanger design; the surface area required dictates the configuration and size of the equipment and its cost.

- In the following sections, we will consider procedures for determining Q, U and ΔT for use in the above Eq.

Energy Balance in heat exchangers

- In heat-exchanger design, energy balances are applied to determine Q and all inlet and outlet temperatures used to specify ΔT.
- At steady state, the energy balance eqn is given by,

$$\boxed{\dot{m}_h C_{ph}(T_{hi} - T_{ho}) = \dot{m}_c C_{pc}(\mathbf{T_{co}} - \mathbf{T_{ci}}) = Q}$$

(1)

- In heat-exchanger design, this Eqn is used to determine Q and the inlet and outlet conditions of the fluid streams.

Cross-flow exchanger

- When a gas such as air is being heated or cooled, a device used is the cross-flow heat exchanger shown in Fig. 4.9-3a.
- One of the which is a liquid, flows inside through the tubes and the exterior gas flows across the bundle by forced or sometimes natural convection.
- The fluid inside the tubes is considered to be unmixed since it is confined and cannot mix with any other stream.
- If flow outside the tubes is mixed since it can move about freely between the tubes any will be a tendency for the gas temperature to equalize in the direction normal to For the unmixed fluid inside the tubes there will be a temperature gradient both 1a
- and normal to the direction of flow. allY ifl
- A second type of cross-flow heat exchanger shown in Fig. 4.9-3b is used tYP' air-conditioning and space-heating applications. In this type the gas flows across a finned-tube bundle and is unmixed since it is confined in separate flow channels between the fins as it passes over the tubes. The fluid in the tubes is unmixed.
- DIscussjon% of other types of specialized heat-transfer equipment is deferred to Section 413. The remainder of this section deals primarily with a shell-andtube and cross-flow heat exchangers.

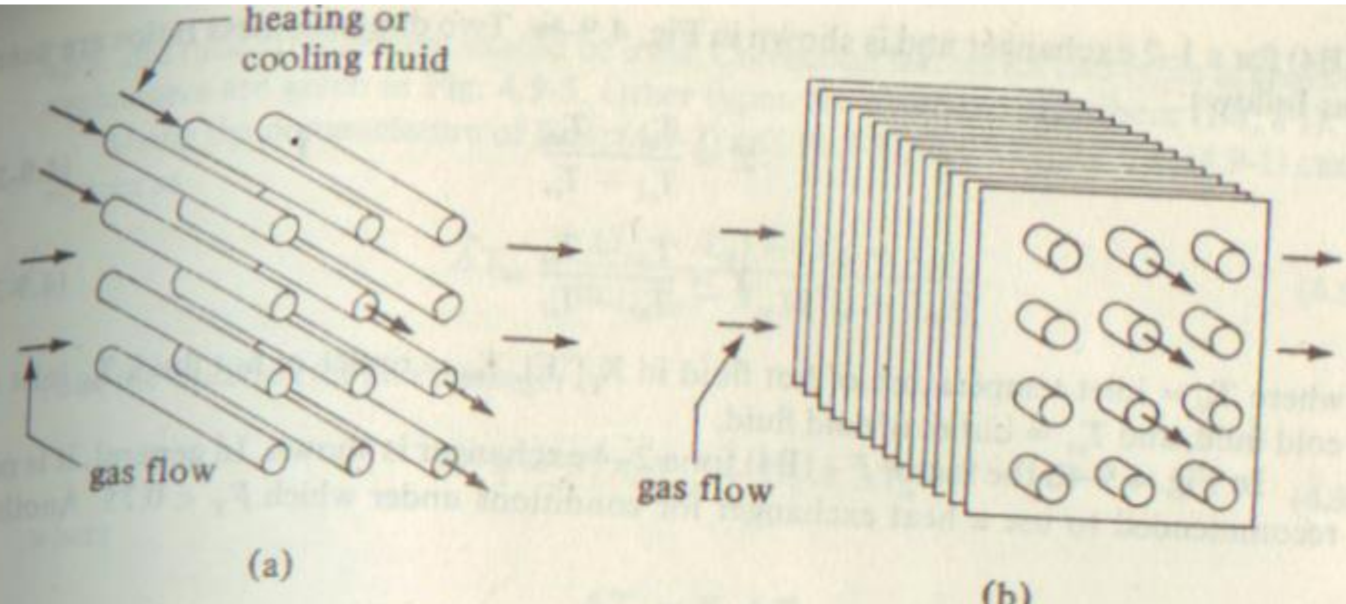


FIGURE 4.9-3. *Flow patterns of cross-flow heat exchangers: (a) one fluid mixed (gas) and one fluid unmixed; (b) both fluids unmixed.*

Logarithmic Temperature Differences

- We know the heat-exchanger design equation, $Q = U A \Delta T$
- which requires knowledge of the temperature-difference driving force for heat transfer, ΔT is equal to the difference in temperature between hot and cold fluids.
- But, fluid temperatures vary with position in heat exchangers
- for example, the temperature difference between hot and cold fluids at one end of the exchanger may be more or less than at the other end.
- The driving force for heat transfer therefore varies from point to point in the system.
- This difficulty is overcome by use of an average T.
- If the temperature varies in both fluids in either countercurrent or co-current flow, *the logarithmic-mean temperature difference is used*:

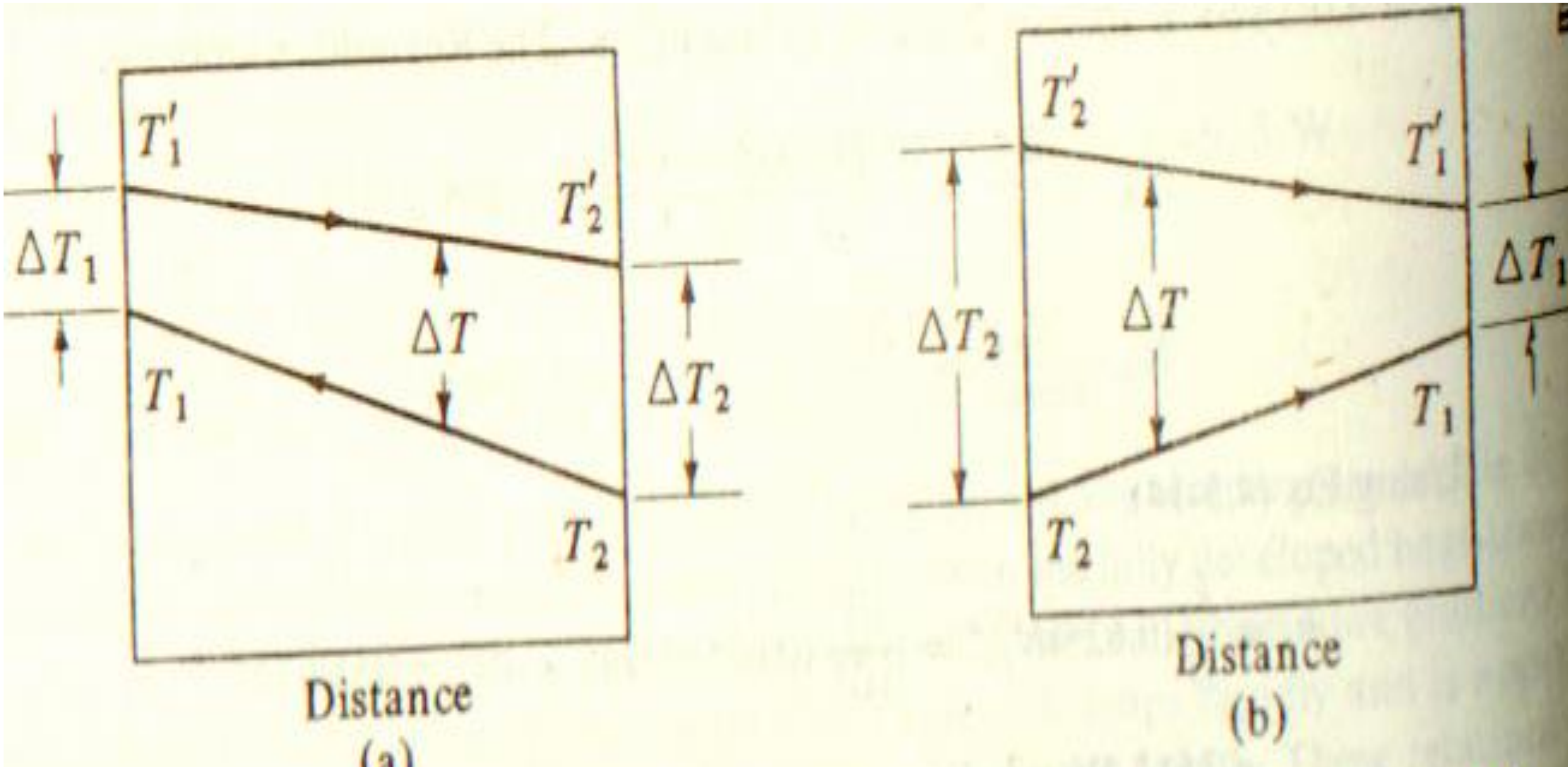


FIGURE 4.5-3. *Temperature profiles for one-pass double-pipe heat exchangers: (a) countercurrent flow; (b) cocurrent or parallel flow.*

- Hence, in the case where the overall heat-transfer coefficient U is constant throughout the equipment and the heat capacity of each fluid is constant, the proper temperature driving force to use over the entire apparatus is the *log mean driving force*, $Q = U\,A\,\Delta T_{lm}$

$$\boxed{where,\ \Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}}$$

- *So, whenever u solve the problem in HEAT EX.. …*
  - *first find out parallel/counter flow…..*
  - *draw the temp profile……*
  - *find ΔT_1 and ΔT_2 and then find out ΔT_{lm}*

Prob 3. LMTD

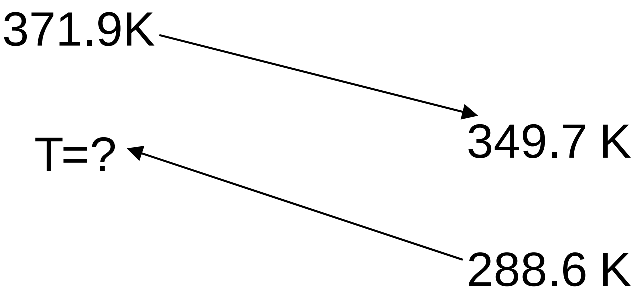
- A liquid stream is cooled from 70°C to 32°C in a double-pipe heat exchanger. Fluid flowing counter currently with this stream is heated from 20°C to 44°C. Calculate the log-mean temperature difference.
- Solution:
- Counter current flow…..
- 70°C → 32°C
  44°C ← 20°C
- $\Delta T_1 = (70 - 44)°C = 26°C$
- $\Delta T_2 = (32 - 20)°C = 12\ °C$
- By using LMTD,
- $\Delta T_{lm} = 18.1\ °C$

$$\therefore \Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\dfrac{\Delta T_2}{\Delta T_1}\right)}$$

Prob 4. Heat-Transfer Area and LMTD

- A heavy hydro carbon oil which has a C_{pm} = 2.30 kJ/kg. K is being cooled in a heat exchanger from 371.9 K to 349.7K and flows inside the tube at a rate of 3630 kg/h. A flow of 1450 kg water/h enters at 288.6 K for cooling and flows outside the tube. Assume a C_{pm} = 4.187 kJ/kg.K for water.
- (a) Calculate the water outlet temperature and heat-transfer area if the overall U_i = 340 W/m^2.K and the streams are countercurrent
- (b) Repeat for parallel flow.

- ***First for Counter current:***



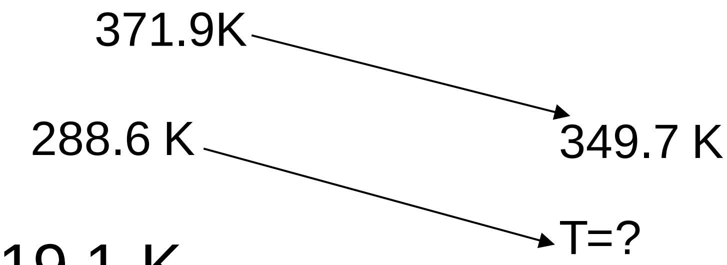
- Water outlet temp, T_{exit}= ?
- First calculate the ***heat lost by the oil***,
- $Q = mcp\Delta T = 3630(2.3)(371.9 – 349.7)$
- Therefore, Q= 185 400 kJ/h (51 490 W)
- By a heat balance, the q must be equal to the heat gained by water:
- ➔ $Q = 185\ 400 = (1450)4.187(T_{exit} – 288.6)$
- Solving, $T_{exit} = 319.1\ K$

- ***To find AREA:***
- First find out LMTD,
- $\Delta T_1 = (371.9 - 319.1) = 52.8$ K
- $\Delta T_2 = (349.7 - 288.6) = 61.1$ K

- Therefore, $\Delta T_{lm} = 56.9$ K

- $\Rightarrow Q = U_i A_i \Delta T_{lm} = \Rightarrow A_i = 2.66\ m^2$

- *For parallel flow:*



- Water exit temp is still…. T_{exit} = 319.1 K
- But, ΔT_1= (349.7 – 319.1) = 83.3 K
- ΔT_2 = (371.9– 288.6) = 30.6 K
- Therefore, ΔT_{lm} = 52.7 K
- ==➔ Ai = 2.87 m^2
- *This is a larger area than for counter flow*
- *This occurs because counter flow gives larger temp driving forces, and it is usually preferred over parallel flow for this reason*