Subject Name: **Heat & Mass Transfer**

Subject Code: **ME-6003**

Semester: **6th**

UNIT –IV
Heat Exchangers
Introduction

"Heat exchanger is process equipment designed for the effective transfer of heat energy between two fluids; a hot fluid and a coolant". The purpose may be either to remove heat from a fluid or to add heat to a fluid.

Examples of heat exchangers:

Intercoolers and pre-heaters

Condensers and boilers in steam plant

Condensers and evaporators in refrigeration unit

Regenerators

Automobile radiators

Oil coolers of heat engine

Evaporator of an ice plant and milk-chiller of a pasteurizing plant

The heat transferred in the heat exchanger may be in the form of latent heat (i.e. in boilers & condensers) or sensible heat (i.e. in heaters & coolers).

Types of Heat Exchangers

Many types of heat exchangers have been developed to meet the widely varying applications. Heat exchangers are typically classified according to:

A. Nature of heat exchange process:

I. Direct contact or open heat exchanger

Complete physical mixing of hot and cold fluid and reach a common temperature.

Simultaneous heat and mass transfer.

Use is restricted, where mixing between two fluids is harmful.

Examples: (i) Water cooling towers - in which a spray of water falling from the top of the tower is directly contacted and cooled by a stream of air flowing upward and (ii) Jet condensers.

II. Regenerators

In a regenerator the hot fluid is passed through a certain medium called "matrix", serves as a heat storage.

The heat is transferred and stored in solid matrix and subsequently transferred to the cold fluid.

The effectiveness of regenerator is depends upon the heat capacity of the regenerating material.

In a fixed matrix configuration, the hot and cold fluids pass alternately through a stationary matrix, and for continuous operation two or more matrices are necessary, as shown in Fig. 1(a). One commonly used arrangement for the matrix is the "packed bed". Another approach is the rotary regenerator in which a circular matrix rotates and alternately exposes a portion of its surface to the hot and then to the cold fluid, as shown in Fig. 1(b).

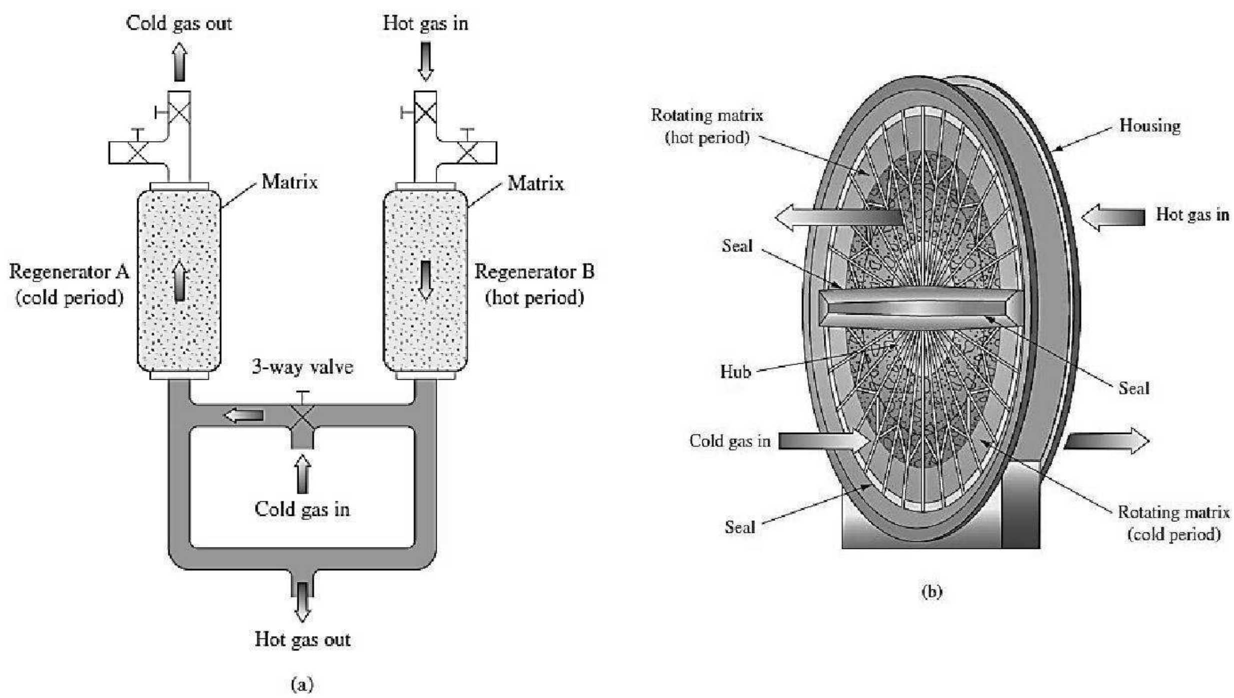


Fig.1 (a) Fixed dual-bed regenerator (b) Rotary regenerator

III. Recuperators

In this type of heat exchanger the hot and cold fluids are separated by a wall and heat is transferred by a combination of convection to and from the wall and conduction through the wall. The wall can include extended surfaces, such as fins.

Majority of the industrial applications have recuperator type heat exchangers.

B. Relative direction of motion of fluids

I. Parallel flow

- Hot and cold both the fluids flow in the same direction

II. Counter flow

- Flow of fluids is opposite in direction to each other
- Gives maximum heat transfer rate

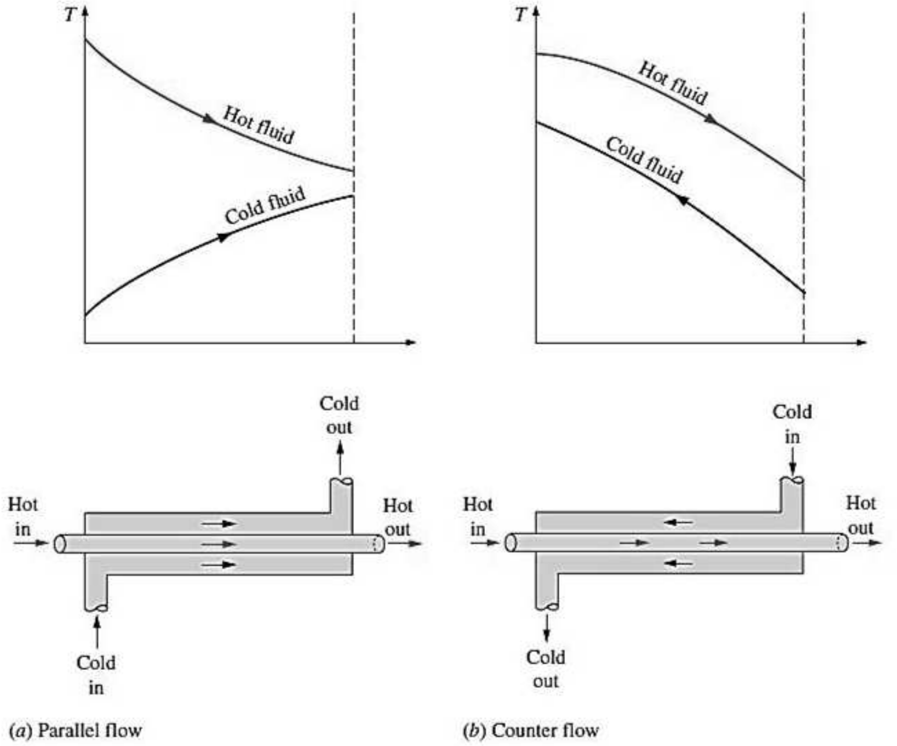


Fig.2 Different flow regimes and temperature profiles in a double-pipe heat exchanger

III. Cross flow arrangement

- Two fluids are directed perpendicular to each other.
- **Examples:** Automobile radiator and cooling unit of air-conditioning duct.
- The flow of the exterior fluid may be by forced or by natural convection.
- Fig.3 shows different configurations used in cross-flow heat exchangers.

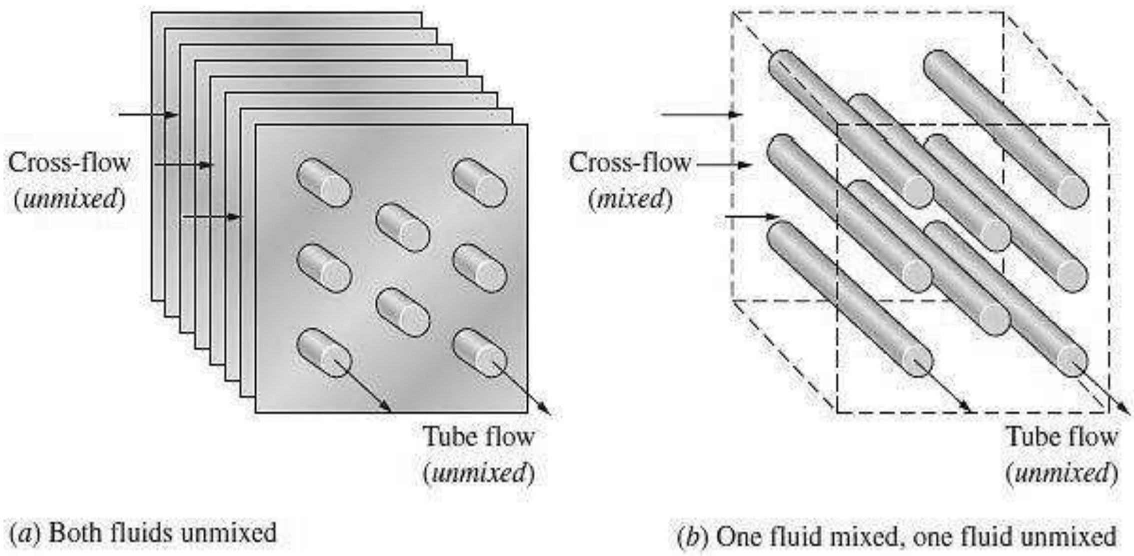


Fig.3 Different flow configurations in cross-flow heat exchangers

C. Mechanical design of heat exchange surface

I. Concentric tube heat exchanger

- Two concentric pipes.
- Each carrying one of the fluids.
- The direction of flow may correspond to parallel or counter flow arrangement as shown in Fig.2.

II. Shell & tube heat exchanger

- One of the fluids is carried through a bundle of tubes enclosed by a shell and other fluid is forced through shell and flows over the outside surface of tubes.
- The direction of flow for either or both fluids may change during its passage through the heat exchanger.

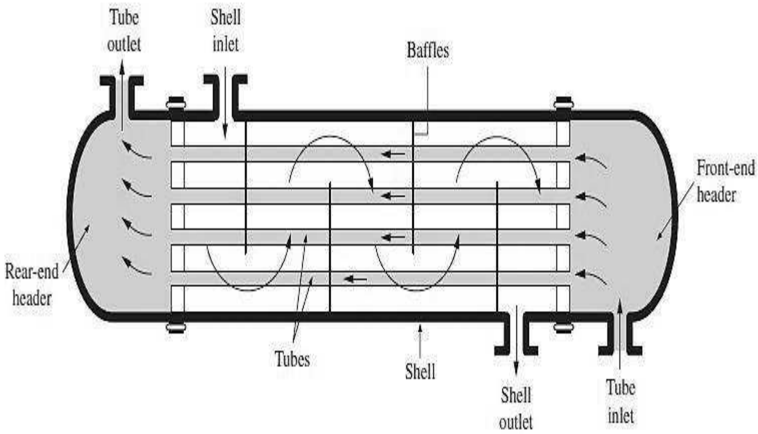


Fig.4 Shell & tube heat exchanger with one shell pass and one tube pass (1-1 exchanger)

III. Multiple shell & tube passes

- **Single-pass:** Two fluids may flow through the exchanger only once as shown in Fig.4.
- **Multi-pass:** One or both fluids may traverse the exchanger more than once as shown in Fig.5.
- Baffles are provided within a shell which cause the fluid surrounding the tubes (shell side fluid) to travel the length of shell a no. of times.
- An exchanger having n – shell passes and m – tubes passes is designed as n-m exchanger.
- A multiple shell & tube exchanger is preferred to ordinary counter flow design due to its low cost of manufacture, easy dismantling for cleaning and repair and reduced thermal stresses due to expansion.

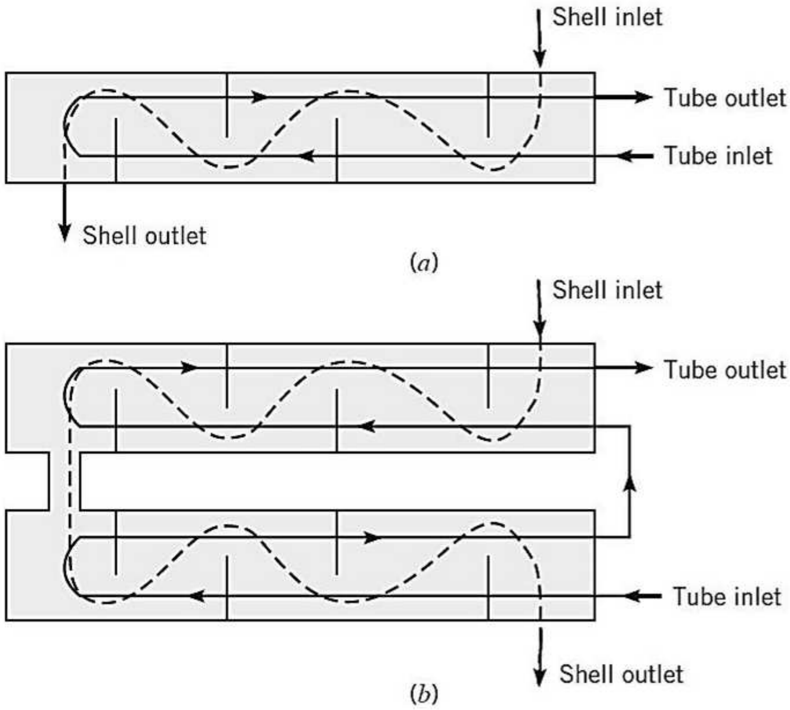


Fig. 5 Shell & tube heat exchangers. (a) One shell pass and two tube passes. (b) Two shell passes and four tube passes.

D. Physical state of heat exchanging fluids

The direction of flow is immaterial in these cases and the LMTD will be the same for both parallel flow, counter flow and other flow types. Refer Fig. 6.

I. Condenser

The temperature of hot fluid will remain constant throughout the heat exchanger. (only latent heat is transferred)

II. Evaporator

The temperature of cold fluid will remain constant throughout the heat exchanger. (only latent heat is transferred)

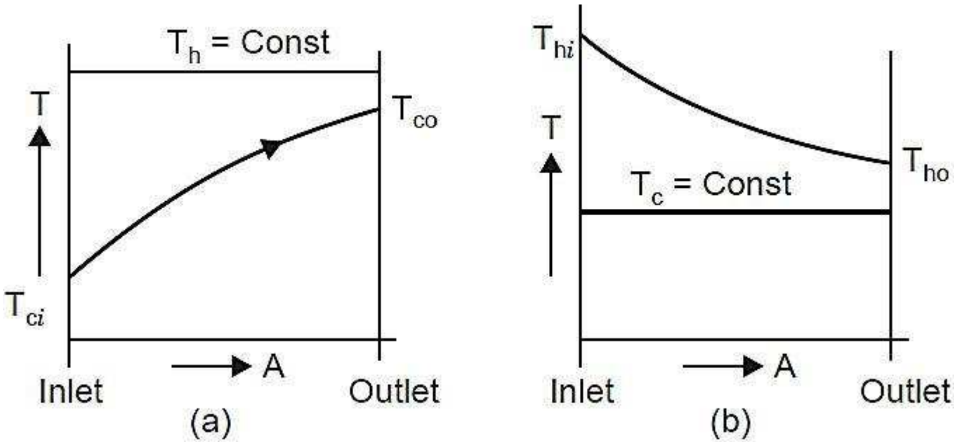


Fig. 6 (a) Condensing (b) Evaporating

Heat Exchanger Analysis

- Fig. 7 represents the block diagram of a heat exchanger.
- The governing parameters are:

I. Overall heat transfer co-efficient (U) due to various modes of heat transfer

II. Heat transfer surface area

III. Inlet and outlet fluid temperatures

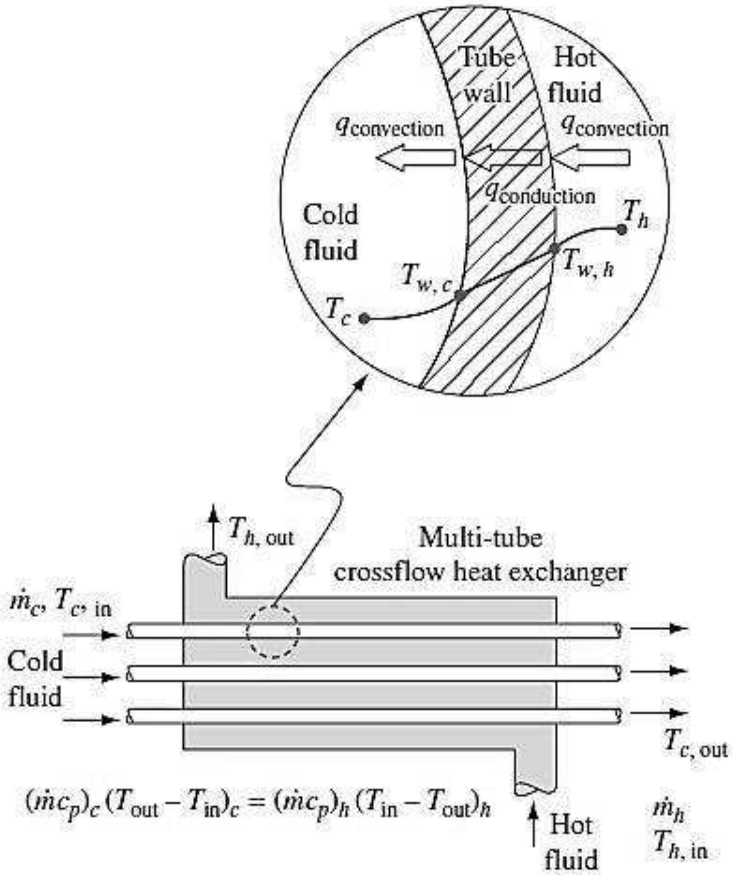


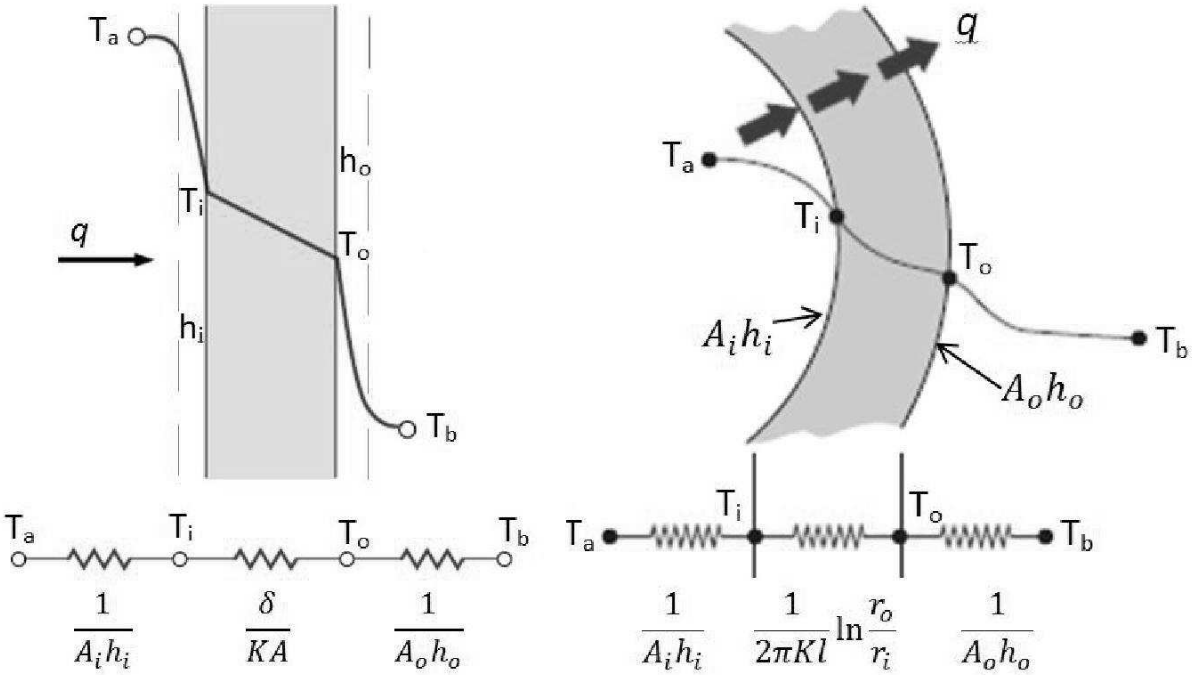
Fig. 7 Overall energy balance in heat exchanger

Overall Heat Transfer Co-efficient

- A heat exchanger is essentially a device in which energy is transferred from one fluid to another across a good conducting solid wall.
- The rate of heat transfer between two fluids is given by,

Wall

Wall



(a) Plane Wall (b) Cylindrical Wall

Fig. 8 Thermal resistance network for (a) plane and (b) cylindrical separating wall

When the two fluids of the heat exchanger are separated by a plane wall as shown in Fig. 8 (a), the thermal resistance comprises:

(i) Convection resistance due to the fluid film at the inner surface

(ii) Wall conduction resistance

(iii) Convection resistance due to fluid film at the outer surface

Fouling Factor

- Equations are essentially valid only for clean and un-corroded surface.
- However during normal operation the tube surfaces get covered by deposits of ash, soot (smoke), dirt and scale etc. This phenomenon of rust formation and deposition of fluid impurities is called **Fouling**.
- The surface deposits increase thermal resistance with a corresponding drop in the performance of the heat exchange equipment.
- Since the thickness and thermal conductivity of the scale deposits are difficult to determine, the effect of scale on heat flow is considered by specifying an **"Equivalent Scale Heat Transfer Co-efficient",**
- If and denote the heat transfer co-efficient for the scale formed on the inside and outside surfaces respectively, then the thermal resistance due to scale formation on the inside surface is,

Important Points

- The overall heat transfer co-efficient (U) depends upon the flow rate and properties of the fluid, the material thickness and surface condition of tubes and the geometrical configuration of the heat exchanger.
- High conducting liquids such as water and liquid metals give higher values of heat transfer co-efficient (h) and overall heat transfer co-efficient (U).
- For an efficient and effective design, there should be no high thermal resistance in the heat flow path; all the resistance in the heat exchanger must be low.

Logarithmic Mean Temperature Difference (LMTD)

- During heat exchange between two fluids, the temperature of the fluids, change in the direction of flow and consequently there occurs a change in the thermal head causing the flow of heat.
- In a parallel flow system, the thermal head (temperature potential) causing the flow of heat is maximum at inlet and it goes on diminishing along the flow path and becomes minimum at the outlet.
- In a counter flow system, both the fluids are in their coldest state at the exit.
- To calculate the rate of heat transfer by the expression, an average value of the temperature difference (i.e. LMTD) between the fluids has to be determined.

Assumptions made to derive expression for LMTD:

1. The overall heat transfer co-efficient, U is constant.
2. The flow conditions are steady.
3. The specific heats and mass flow rate of both fluids are constant.
4. There is no loss of heat to surrounding i.e. the heat exchanger is perfectly insulated.
5. There is no change of phase either of the fluid during the heat transfer.
6. The changes in potential and kinetic energies are negligible.
7. Axial conduction along the tubes of the heat exchanger is negligible.

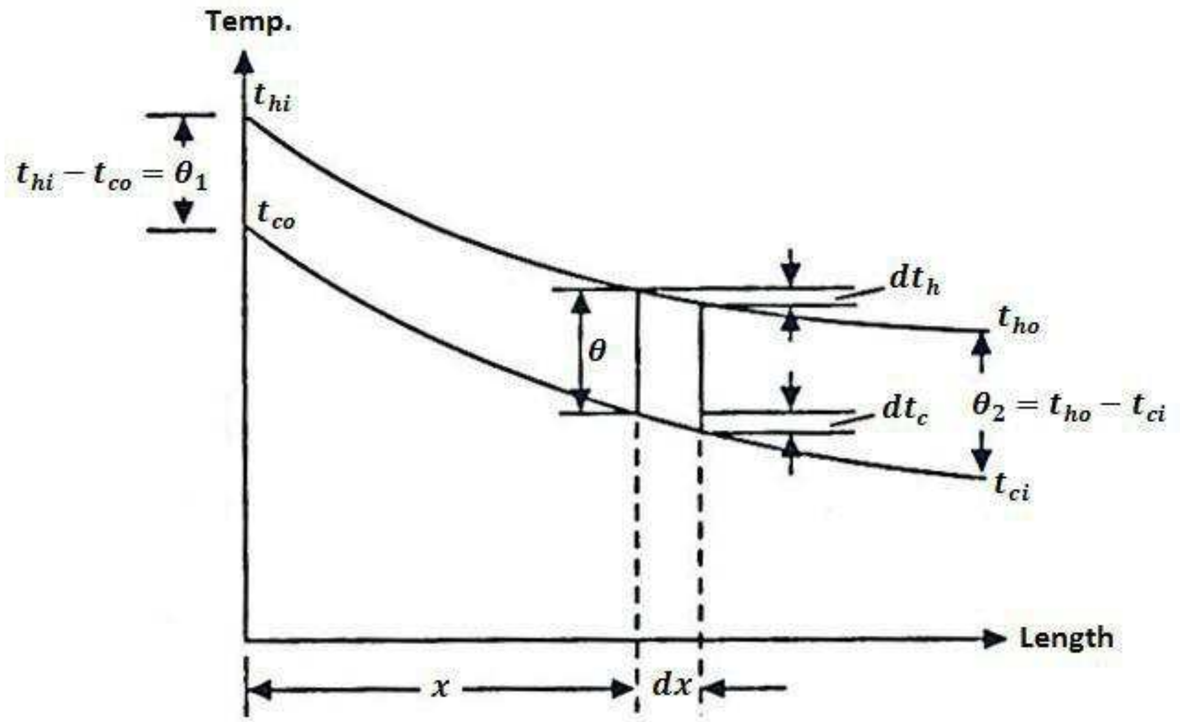


Fig. 9 Temperature changes of fluids during counter flow arrangement

- **LMTD for Counter Flow Heat Exchanger**
- **LMTD for Parallel Flow Heat Exchanger**
- **Arithmetic Mean Temperature Difference (AMTD)**
  When the temperature variation of the fluids is relatively small, then temperature variation curves are approximately straight lines (as in condenser and evaporator) and sufficiently accurate results are obtained by taking the arithmetic mean temperature difference (AMTD).

Correction Factors for Multi-pass Arrangements

- The relation for LMTD is essentially applicable for the single pass heat exchangers.
- The effect of multi-tubes, several shell passes or cross flow in an actual flow arrangement is considered by identifying a correction factor F such that depends on geometry of the heat exchanger and the inlet and outlet temperatures of hot and cold fluid streams.

Correction factors for several common arrangements have been given in Figs. 10 to 13.

- The data is presented as a function of two non-dimensional temperature ratios P and R. the parameter P is the ratio of the rise in temperature of the cold fluid to the difference in the inlet temperatures of the two fluids and the parameter R defines the ratio of the temperature drop of the hot fluid to temperature rise in the cold fluid.
- Since no arrangement can be more effective than the conventional counter flow, the correction factor F is always less than unity for shell and tube heat exchanger.
- Its value is an indication of the performance level of a given arrangement for the given terminal fluid temperatures.
- When a phase change is involved, as in condensation or boiling, the fluid normally remains at essentially constant temperature. For these conditions, P or R becomes zero and we obtain

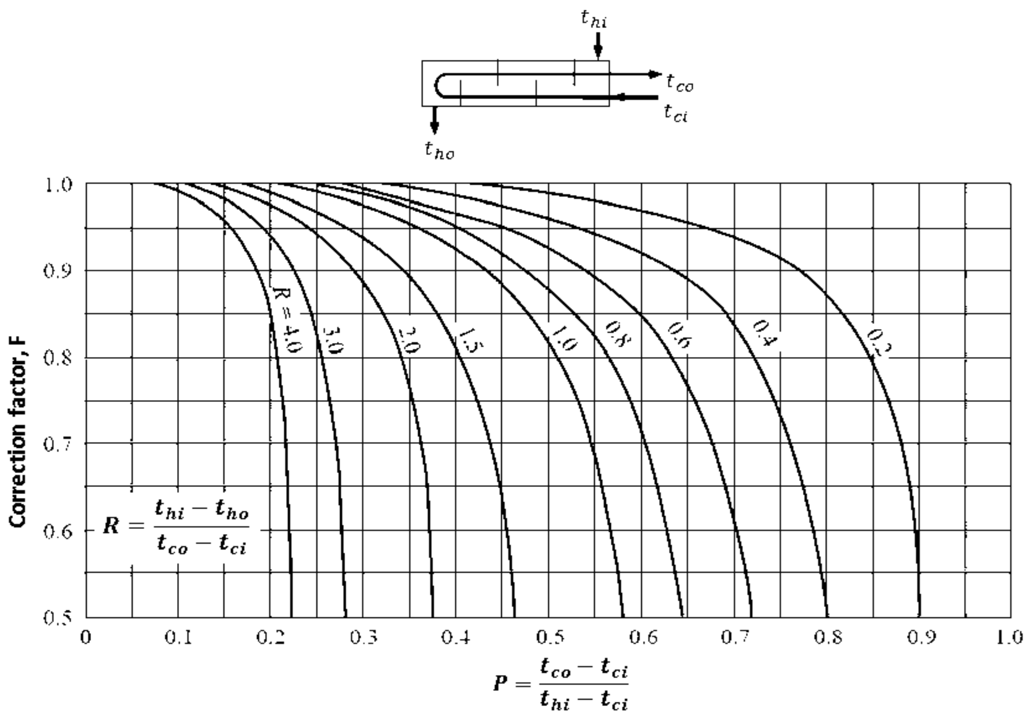


Fig. 10 Correction-factor plot for exchanger with one shell pass and two, four, or any multiple of tube passes

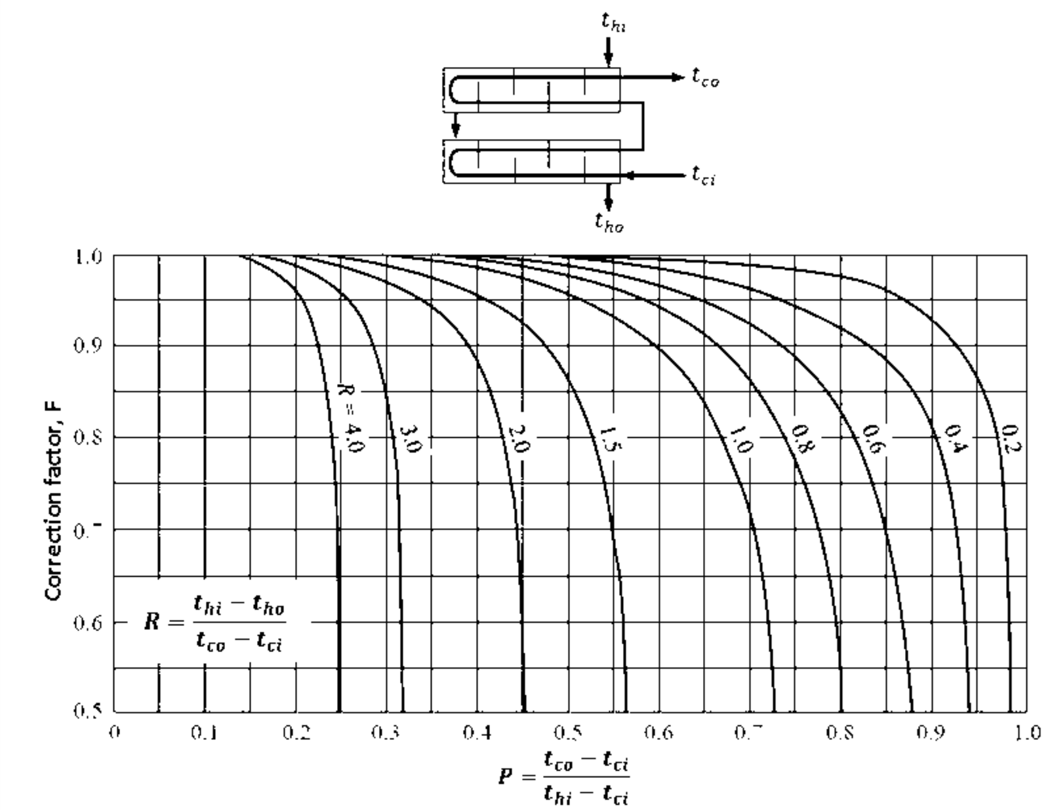


Fig. 11 Correction-factor plot for exchanger with two shell passes and four eight or any multiple of tube passes

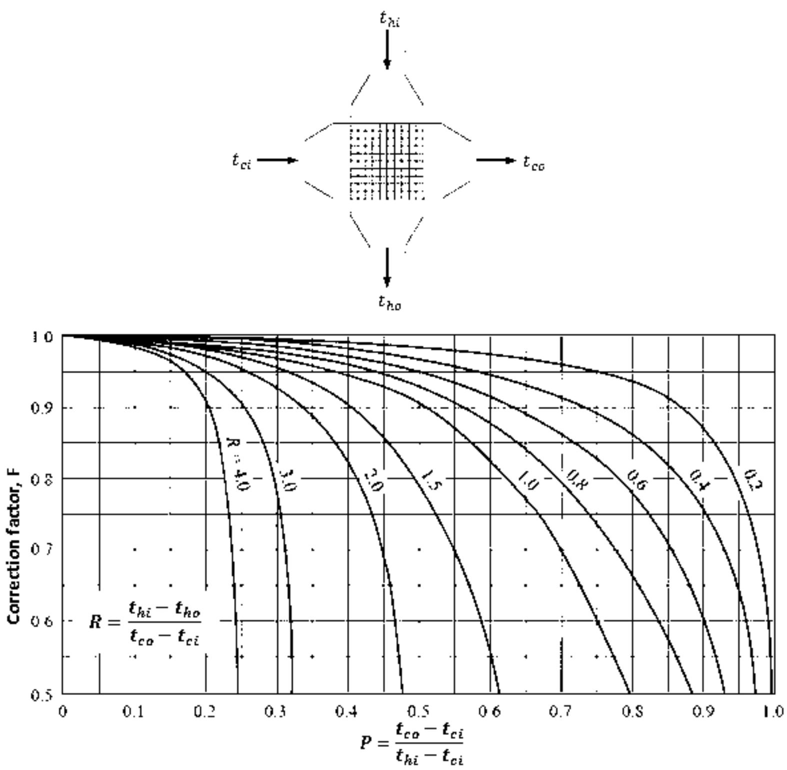


Fig. 12 Correction factor plot for single pass cross-flow heat exchanger with both fluids unmixed

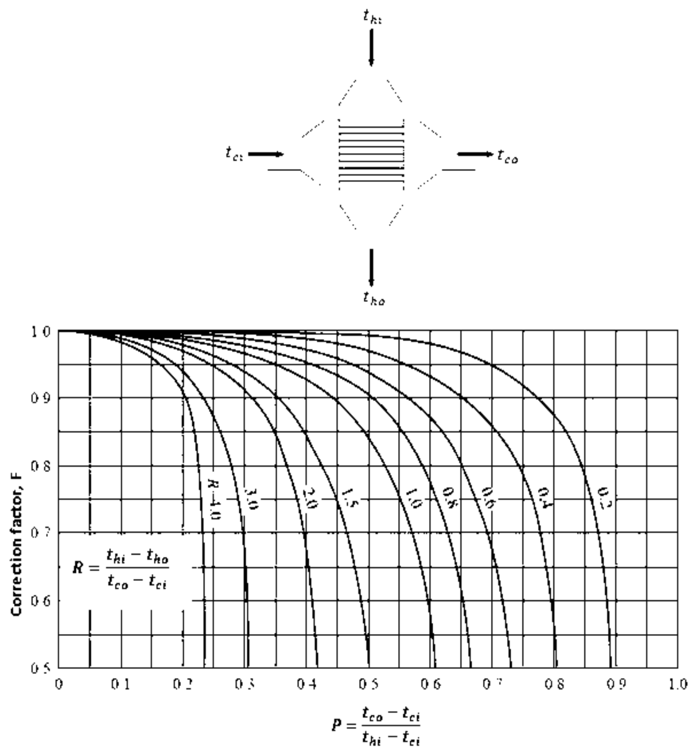


Fig. 13 Correction factor plot for single-pass flow heat exchanger, one fluid mixed and the other unmixed

Effectiveness and Number of Transfer Units (NTU)

- The concept of LMTD for estimating/analysing the performance of a heat exchanger unit is quite useful only when the inlet and outlet temperature of the fluids are either known or can be determined easily from the relevant data.
- In normal practice the useful design is however based on known fluid inlet temperatures and estimated heat transfer co-efficient. The unknown parameters may be the outlet conditions and heat transfer or the surface area required for a specified heat transfer.
- An analysis/estimate of the heat exchanger can be made more conveniently by the NTU approach, which is based on the capacity ratio, effectiveness and number of transfer units.

Capacity Ratio (C):

The product of mass and specific heat ( ) of a fluid flowing in a heat exchanger is termed as the **Capacity rate**. It indicates the capacity of the fluid to store energy at a given rate. "The ratio of minimum to maximum capacity rate is defined as **Capacity ratio** (C).

Capacity rate of the hot fluid,

Capacity rate of the cold fluid,

Number of Transfer Units (NTU):

- NTU is a dimensionless parameter.
- It is a measure of the (heat transfer) size of the heat exchanger.
- The larger the value of NTU, the closer the heat exchanger reaches its thermodynamic limit of operation.

