Lecture 16

Chap.6 HEAT EXCHANGERS

Heat exchange devices are indispensable parts of systems that exchange energy between hot and cold materials. Heat exchange devices are widely used in everyday life, industrial processes, and all situations that employ hot and cold materials to transmit and exchange energy.

Classification of Heat Exchangers

- → ***Heat exchanger*** is an apparatus or an equipment in which effective transfer of heat takes place between a hot fluid & cold fluid.
- → The ***purpose*** of this exchanger is to remove heat from a fluid or to add heat to a fluid.
- → ***Examples:*** Boilers & Condensers in steam plant, heaters & coolers, oil coolers of heat engine, automobile radiators, evaporators & condensers in refrigeration unit, etc.

TYPES OF HEAT EXCHANGERS

The various types of heat exchangers are:

I. Nature of heat exchanger process.
II. Relative direction of fluid motion.
III. Design and constructional features.
IV. No. of Passes
V. Physical state of fluids.

I. NATURE OF HEAT EXCHANGER PROCESS.

Heat exchangers are further classified as:
1) DIRECT CONTACT (OR OPEN) HEAT EXCHANGER.
2) INDIRECT CONTACT HEAT EXCHANGERS.

1) **DIRECT CONTACT (OR OPEN) HEAT EXCHANGERS.**

2) **INDIRECT CONTACT HEAT EXCHANGERS.**

- **i. REGENERATORS**
- ii. **RECUPERATERS**

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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II. RELATIVE DIRECTION OF FLUID MOTION

According to the relative direction of two fluids, the exchangers are further classified as

1) PARALLEL / COCURRENT/ UNIDIRECTIONAL FLOW HEAT EXCHANGER.
2) COUNTER FLOW HEAT EXCHANGER.
3) CROSS FLOW HEAT EXCHANGER.

1) **PARALLEL / UNIDIRECTIONAL FLOW HEAT EXCHANGERS**.
2) **COUNTER FLOW HEAT EXCHANGERS**.
3) **CROSS FLOW EXCHANGERS**.

→ In these exchangers, the two fluids flow at right angles to each other.
→ Two different arrangements are commonly used.
→ In one case, each of the fluids is unmixed as it flows through the heat exchanger. Due to this, temperatures of the fluids leaving the exchanger are not uniform.

III PHYSICAL STATE OF FLUIDS

They are further divided in to

1) CONDENSERS
2) EVAPORATERS

1) CONDENSERS

→ In condensers, the condensing fluid remains at constant temperature throughout the exchanger while cold fluid temperature gradually increases from inlet to exit.
→ The hot fluid looses latent heat which is taken up by cold fluid.
→ The temperature distribution is shown in the **FIGURE** below.

2) EVAPORATERS

→ In evaporators, the boiling fluid (cold fluid) remains at constant temperature while the hot fluid temperature gradually decreases.
→ The temperature distribution is shown in the **FIGURE** above.
→ In both exchangers, since the temperature of one of the fluid remains constant, it is immaterial whether the fluids flow in same direction or opposite.

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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DESIGN & CONSTURUCTIONAL FEATURES

On the basis of design & constructional features, the heat exchangers are classified as:

1) DOUBLE PIPE HEAT EXCHANGER
2) SHELL AND TUBE HEAT EXCHANGER
3) MULTIPLE SHELL AND TUBE HEAT EXCHANGER
4) COMPACT HEAT EXCHANGERS
    a) FINNED HEAT EXCHANGER / EXTENDED HEAT EXCHANGERS
    b) PLATE TYPE HEAT EXCHANGER
    c) SPIRAL HEAT EXCHANGER

ADVANTAGES

DISADVANTAGES

OTHER TYPES OF SHELL AND TUBE HEAT EXCHANGER

They are classified as:

A. Fixed tube heat exchanger
B. Floating head heat exchanger
C. U-tube heat exchanger
D. Reboiler / Kettle type heat exchanger
    a) With internal floating head
    b) With U tube (hair pin)

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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Heat Exchanger Performance:

For designing or predicting the performance of a heat exchanger it is necessary that the total heat transfer may be related with its governing parameters: (i) U (overall heat transfer coefficient) due to various modes of heat transfer, (ii) A total surface area of the heat transfer, and (iii) t_1, t_2 (the inlet and outlet fluid temperatures).

OVERALL HEAT TRANSFER COEFFICIENT (U):

$$\therefore \; UA = \frac{1}{\frac{1}{A_i h_i} + \frac{\ln(r_o/r_i)}{2\pi L k_w} + \frac{1}{A_o h_o}}$$

$$\Rightarrow U_i = \frac{1}{\frac{1}{h_i} + \frac{A_i \ln(r_o/r_i)}{2\pi L k_w} + \left(\frac{A_i}{A_o}\right)\frac{1}{h_o}} \quad \text{.......................... (iii)}$$

$$\Rightarrow U_o = \frac{1}{\left(\frac{A_o}{A_i}\right)\frac{1}{h_i} + \frac{A_o \ln(r_o/r_i)}{2\pi L k_w} + \frac{1}{h_o}} \quad \text{.............................. (iv)}$$

$$U_i = \frac{1}{\frac{1}{h_i} + \left(\frac{r_i}{k_w}\right)\ln(r_o/r_i) + \left(\frac{r_i}{r_o}\right)\frac{1}{h_o}} \quad \text{.............................. (v)}$$

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

SCALE FORMATION / FOULING ON SURFACES OF TUBES

FOULING FACTOR (R_s):

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

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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LOGARITHMIC MEAN TEMPERATURE DIFFERENCE (LMTD):

In a heat exchanger the temperatures of the hot and cold fluids keep on changing from point to point along the length of exchanger. In such cases mean temperature difference when multiplied by U and appropriate A will give the correct heat flow rate.

Logarithmic Mean Temperature Difference (LMTD) is the temp – difference, which if constant, gives the same rate of heat transfer as actually occurs under different temperature differences.

CASE I: PARALLEL FLOW ARRANGEMENT

$$\Delta t_m = \frac{\left[\left(t_{h_2} - t_{c_2}\right) - \left(t_{h_1} - t_{c_1}\right)\right]}{\ln \frac{\left(t_{h_2} - t_{c_2}\right)}{\left(t_{h_1} - t_{c_1}\right)}} \quad \text{OR} \quad \Delta t_m = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

Where Δt_2 & Δt_1 denote the difference between the temperatures of hot and cold fluids at A = A and A = 0 respectively.

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CASE (2) (COUNTER FLOW ARRANGEMENT)

$$\Delta t_m = \frac{\left[\left(t_{h_2} - t_{c_2}\right) - \left(t_{h_1} - t_{c_1}\right)\right]}{\ln \frac{\left(t_{h_2} - t_{c_2}\right)}{\left(t_{h_1} - t_{c_1}\right)}} \quad \text{OR} \quad \Delta t_m = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

Where Δt_2 & Δt_1 denote the difference between the temperatures of hot and cold fluids at A = A and A = 0 respectively.

- Examples based on LMTD

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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- **LMTD CORRECTION FACTORS**

The mean temperature difference is strictly applicable only to parallel flow and counter flow exchangers in which the two fluids flow only once across the exchanger i.e. single pass heat exchangers.

For multipass parallel and counter flow exchangers or with cross flow exchangers, first of all LMTD is to be calculated for single pass exchanger and then this LMTD is multiplied with correction factor F. This LMTD correction factor F, which takes into account the actual flow arrangement of the exchanger

Thus Q = U A ΔT_m ; (for single pass exchanger)

Q = U A F $\left[(\Delta t)_m\right]_{counterflow}$ (for multipass or cross flow exchanger)

The correction factor F is calculated from charts.
The factor F is a function of two dimensionless variables.

1. Capacity ratio R
2. Temperature ratio θ

The capacity ratio, R is defined as follows:

$$R = \frac{\text{Heat capacity of the fluid passing through tube}}{\text{Heat capacity of the fluid passing through shell}}$$

$$= \frac{m_t c_t}{m_s c_s}$$

Where suffices t and s denotes the fluid flowing through the tube or shell resp.

Since $m_t c_t\left(t_{t_2} - t_{t_1}\right) = m_s c_s\left(t_{s_1} - t_{s_2}\right)$

$$R = \frac{m_t c_t}{m_s c_s} = \frac{\left(t_{s_1} - t_{s_2}\right)}{\left(t_{t_2} - t_{t_1}\right)} = \frac{\Delta t_{shell}}{\Delta t_{tube}}$$

The temperature ratio, θ is defined as;

$$\theta = \frac{t_{t_2} - t_{t_1}}{t_{s_1} - t_{t_1}} = \frac{\Delta t_{tube}}{\Delta t_{inlet}}$$

- Examples based on LMTD and Heat Exchanger Design

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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- **HEAT EXCHANGER EFFECTIVENESS**

The effectiveness of a heat exchanger or temperature effectiveness is denoted by ε. It is defined as:

$$\varepsilon = \frac{\text{The actual heat transfer rate}}{\text{The maximum possible heat transfer rate}}$$

Theoretically, maximum heat transfer rate will occur with a counter flow heat exchanger if very large area when either of the following conditions is attained :

(a.) The exit temp. of the cold fluid equals the entry temp. of the hot fluid i.e. $t_{c_2} = t_{h_1}$

(b.) The exit temp. of hot fluid equals the entry temp. of the cold fluid i.e. $t_{h_2} = t_{c_1}$

$$\varepsilon = \frac{C_c\left(t_{c_2} - t_{c_1}\right)}{C_{\min}\left(t_{h_1} - t_{c_1}\right)} \text{ .... (vii)}$$

OR

$$\varepsilon = \frac{C_h\left(t_{h_1} - t_{h_2}\right)}{C_{\min}\left(t_{h_1} - t_{c_1}\right)}$$

Calculation Steps:

1. Draw Temperature Profile
2. Tabulate all given data
3. Calculate Q by Q = mCpΔt (either for cold or hot fluid)
4. Find missing temperature of any one fluid
5. Find Δt_m
6. Find U.
7. Find A by $Q = UA\Delta t_m$
8. Find diameter or no. of tubes etc.

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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Shell and Tube Heat Exchanger:

Construction Details of Heat Exchangers:

SHELL
TUBES
TUBE PITCH
CLEARANCE
TUBE ARRANGEMENT
The tubes are commonly laid on either
1) SQUARE PITCH
2) TRIANGULAR PITCH
TUBE SHEET

BAFFLES **Classification of Transverse Baffles:**

BAFFLE SPACERS

ALLOCATION OF FLUIDS: SHELL OR TUBES

DIFFERENT TYPES OF SHELL AND TUBE HEAT EXCHANGER

A. FIXED TUBE HEAT EXCHANGER
- → This is the simplest type of heat exchanger.
- → In fixed tube sheet heat exchanger, the tube sheets are welded to the shell at both ends so that the shell & tube sheet material must be weld able to each other.
- → The shell is equipped with two nozzles for entry and exit of shell side fluid.

FLOATING HEAD HEAT EXCHANGER

U – TUBE HEAT EXCHANGER

KETTLE REBOILERS / REBOILER EXCHANGER
Kettle reboilers are of two types:
1) Internal floating head arrangement
2) U-tube arrangement.

FINNED TUBE HEAT EXCHANGER / EXTENDED SURFACE EXCHANGER

TYPES OF FINS
i. LONGITUDINAL FINS
ii. TRANSVERSE FINS

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta

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PLATE TYPE HEAT EXCHANGER

- Plate type heat exchanger consists of series of rectangular parallel plates held firmly together between substantial head frames.
- The plates have corner ports which permit the entry & exit of hot & cold fluid.
- The corner ports are sealed by gaskets & the plate edges are also sealed.
- The plates serve as heat transfer surfaces.

SPIRAL-PLATE HEAT EXCHANGER

- The plates are frequently of stainless steel & have corrugated faces which in turn gives a high degree of turbulence even at low flow rates.
- The gap between the plates is 1.3 to 1.5mm & is provided with inlet & outlet nozzles for fluids at ends.
- The hot fluid passes through alternate gaps i.e. between alternate pairs of plates, transferring heat to cold fluid in the adjacent spaces.
- These exchangers are successfully used in dairy & brewery industries.
- Moreover they are relatively effective with viscous fluids with viscosities up to about 300 poise.

ADVANTAGES

1. They are very compact and requires very small floor space & provides large heat transfer area in small volume.
2. It gives low pressure drop.
3. There is an absence of inter leakage of fluids.
4. Easy in dismantling for inspection & cleaning.
5. High heat transfer coefficient than shell & tube heat exchanger.
6. It is mostly used when close control of temperature is required & in case of heat sensitive materials.
7. Heat transfer area can be increased by adding more plates.

DISADVANTAGES

1. The maximum operating pressure is limited to 30 bar.
2. The operating temperature of any fluid used is limited to 250 C due to gasket material.

Reference: Engineering Heat Transfer By R.Prakash & C.D.Gupta