# Chapter 4

# Heat transfer equipment

The transfer of heat to and from process fluids is an essential part of most chemical processes. The most commonly equipment used type of heat transfer equipment is the ubiquitous shell and tube heat exchanger.

## 4.1 Basic design procedure and theory

The general equation of heat transfer across a surface is:

$$Q = UA\Delta T_m \tag{4.1}$$

where Q is the heat transfer per unit time (W), U is the overall heat transfer coefficient ($W \cdot m^{-2} \cdot {}^{o}C^{-1}$), A is the heat transfer area ($m^2$), and $\Delta T_m$ is the mean temperature difference, the temperature driving force (${}^{o}C$.).

The main point required for the heat exchanger design is the required surface area for the specified duty.

Different heat transfer resistance must be considered when specific heat transfer is required. The over all coefficient is the reciprocal of the over all resistance to heat transfer, which is the sum of the over all resistance to heat transfer.

The relation between the overall coefficient and the individual resistance are as follows:

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o ln(\frac{d_o}{d_i})}{2k_w} + \frac{d_o}{d_i} \times \frac{1}{h_{id}} + \frac{d_o}{d_i} \times \frac{1}{h_i} \tag{4.2}$$

where $U_o$ is the overall coefficient based on the outside area of the tube (W·m$^{-2}$·$^o$C$^{-1}$), h$_o$ is the outside film coefficient (W·m$^{-2}$·$^o$C$^{-1}$), h$_i$ inside fluid film coefficient (W·m$^{-2}$·$^o$C$^{-1}$), h$_{od}$ outside dirt coefficient (W·m$^{-2}$·$^o$C$^{-1}$), h$_{id}$ is the inside dirt coefficient (W·m$^{-2}$·$^o$C$^{-1}$), $k_w$ is the thermal conductivity of the tube wall material (W·m$^{-1}$·$^o$C$^{-1}$), $d_i$ is the tube inside diameter (m), and $d_o$ is the outside diameter (m).

The steps in a typical design procedure are:

**1** Define the duty:heat transfer rate, fluid flow rates, temperatures

**2** Collect together the fluid physical properties required: density, viscosity, thermal conductivity

**3** Decide on the type of heat exchanger to be used

**4** Select a trial value for the overall coefficient (U)

**5** Calculate the mean temperature difference ($\Delta T_m$)

**6** Calculate the area required from Equation 4.1

**7** Calculate the individual coefficient

**8** Calculate the overall coefficient and compare with trial value. If the calculated value differs significantly from the estimated value, substitute the calculated for the estimated value and return to step 6

**9** Calculate the exchanger pressure drop; if unsatisfactory return to steps 7 or 4 or 3 in that order of preference.

**11** Optimise the design: repeat 4 to 10 as necessary to determine the cheapest exchanger that will satisfy the duty. (Note: smallest area is the cheapest)

## 4.2 Over all heat transfer coefficient

Typical values of the overall heat transfer coefficient are given in Figure 4.1. The values estimated from Figure 4.1 can be used for the preliminary sizing of equipment for detailed thermal design.

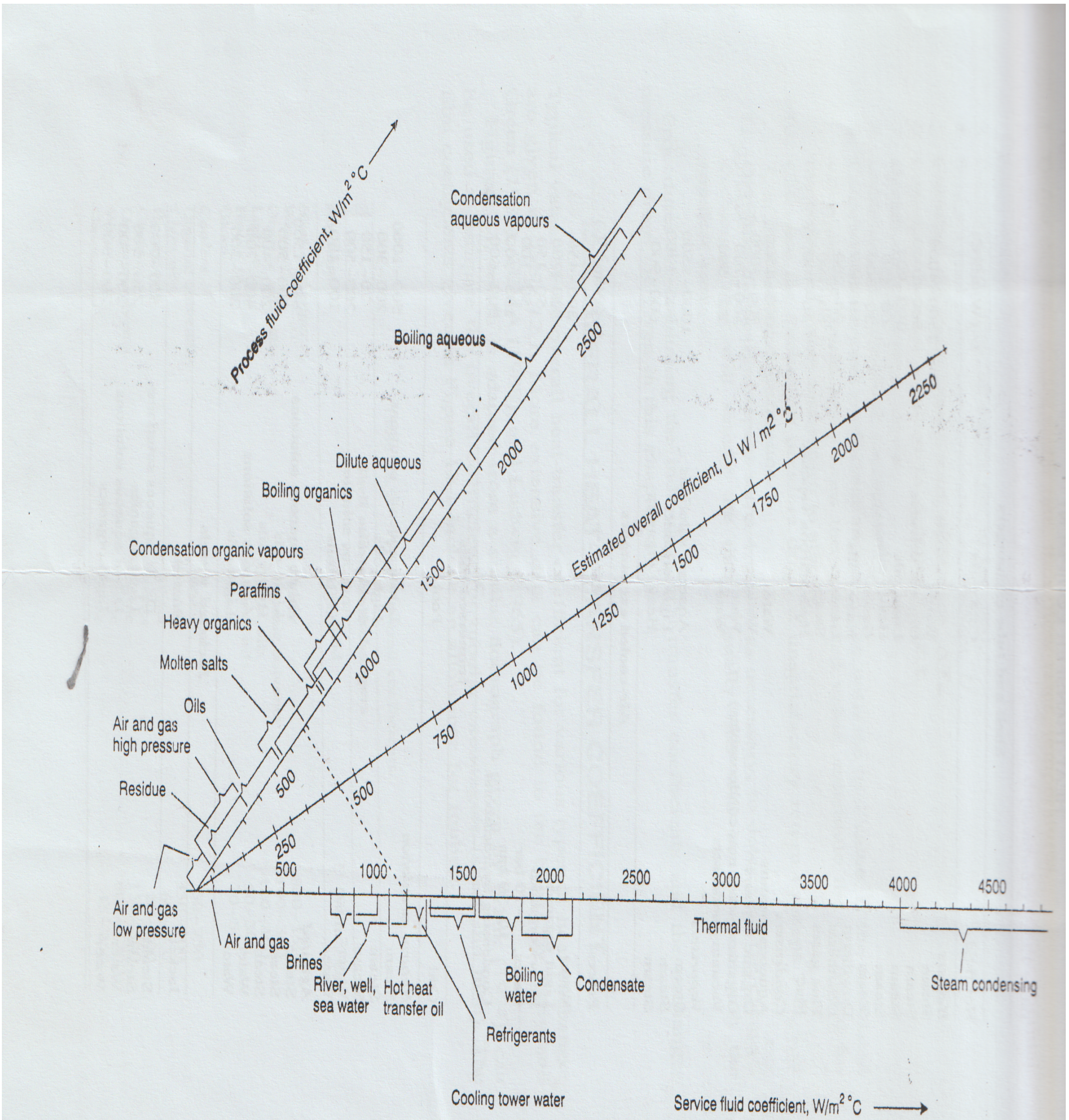


Figure 4.1: Overall coefficient (Join process side duty to service side and read U from centre scale)

## 4.3 Tubes

### 4.3.1 Dimensions

#### 4.3.1.1 Diameter

Selection of tube diameters can be selected according to the duties required. The smaller diameter is 16-25 mm are preferred. Larger tubes are selected for heavily fouling liquid.

Note: Tube diameter, as guide, 19mm is a good trial diameter with which to start design calculation.

#### 4.3.1.2 Thikness

Tube thickness is another consideration in the heat exchanger design. The selection of the thickness is chosen according to internal pressure and adequate corrosion allowance.

#### 4.3.1.3 Materials

The standard of steel tubes of the heat exchangers are covered by the **BS 3606** and the standard applicable for other materials is **BS 3274**.

#### 4.3.1.4 Length

The preferred tubes' length of heat exchanger are 1.83 m, 2.44m, 3.66m, 4.88m, 6.1m, 7.32m. The use of longer tube will reduce the shell diameter, which will result in a lower cost exchanger especially for high shell pressure.

### 4.3.2 Tube arrangments

Different arrangement of tubes are used in the heat exchanger design which are as follows: equilateral triangular, square, or rotated square pattern as shown in Figure 4.2.

The triangular and rotated square patterns gives higher heat transfer but in the expense of high pressure drop than the square pattern.The square or rotated square pattern are used for heavily fouling fluids(**Why?** where it is necessary to mechanically clean the outside of tubes.).

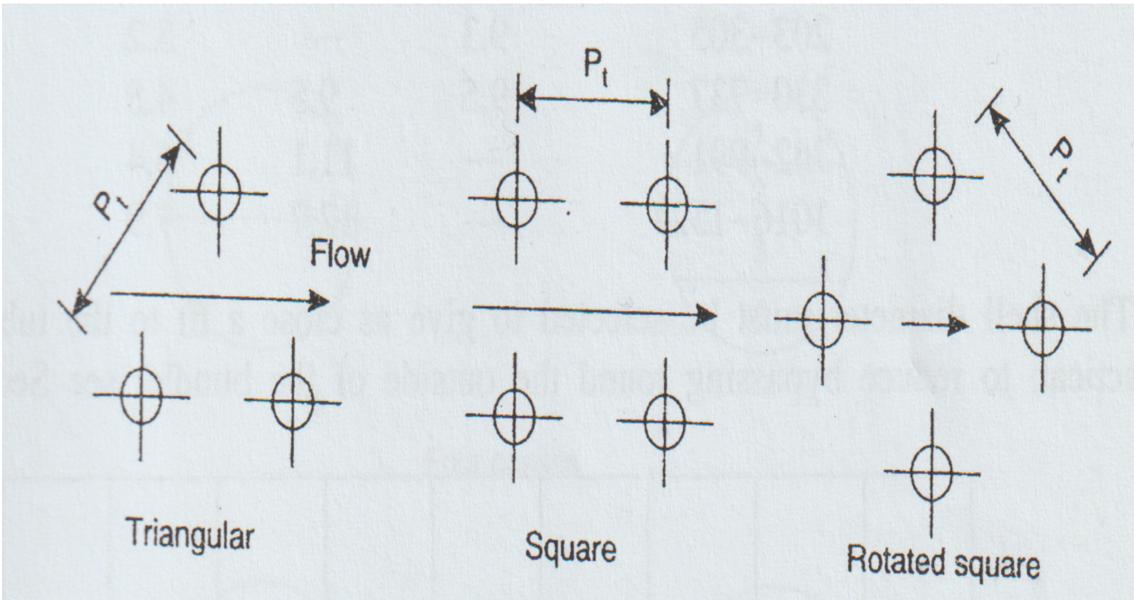


Figure 4.2: Tube patterns

Tube pitch is recommended to be 1.25 times the tube outside diameter. The square pattern recommended minimum clearance between the tubes to be 6.4 mm. The square pattern is used for ease of cleaning, the recommended clearance between the tubes is 6.4mm

### 4.3.3 Tube-side passes

In order to increase the tube length, number of passes are used. The fluid is usually directed back and forth for a number of passes. The arrangement of pass partitions for 2,4,and 6 tubes passes are shown in Figure 4.3

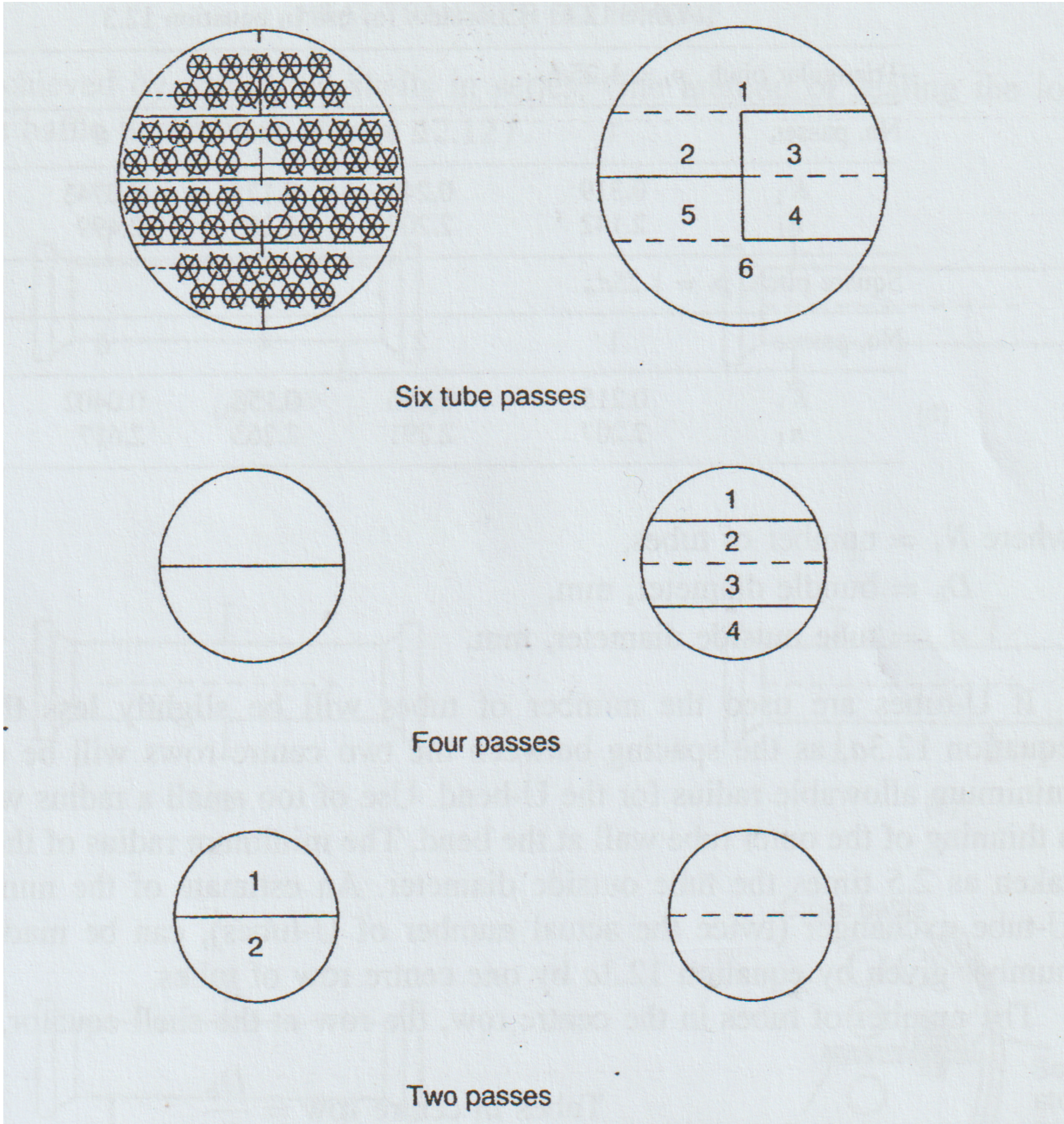


Figure 4.3: Tube arrangements, showing pass-partitions in headers