4.11 Tube-side pressure drop

Two major sources of pressure loss inside the tube: 1- Friction in the tubes 2- Friction due to sudden contraction and expansion

The basic Equation for estimating the friction in the **isothermal** flow in pipes according as follows:

$$\Delta P = 8\, j_f (\frac{(L')}{d_i})(\frac{\rho u_t^2}{2}) \tag{4.17}$$

The flow in the heat exchanger will be **not isothermal**, and the change in the physical properties must be considered. The ΔP can be estimated according to the following equation:

$$\Delta P = 8\, j_f (\frac{(L')}{d_i})\rho(\frac{u_t^2}{2})(\frac{\mu}{\mu_w})^{-m} \tag{4.18}$$

where:

m= 0.25 for laminar flow, Re<2100

m= 0.14 for turbulent flow, Re>2100

The loss in terms of velocity heads can be estimated by counting the number of flow contractions, contraction and reversal, and using the factors for pipe fittings to estimate the number of velocity head lost.

Combining this factor with Equation 4.18

$$\Delta P = N_p[8\, j_f (\frac{(L)}{d_i})(\frac{\mu}{\mu_w})^{-m} + 2.5](\frac{\rho u_t^2}{2}) \tag{4.19}$$

where:

ΔP= tube-side pressure drop (Pa)

N_p= number of tube side passes

u_t= tube-side velocity (m/s)

L= length of one tube

Note: j_h and j_f can be taken from Figure **??** and Figure **??**, respectively.

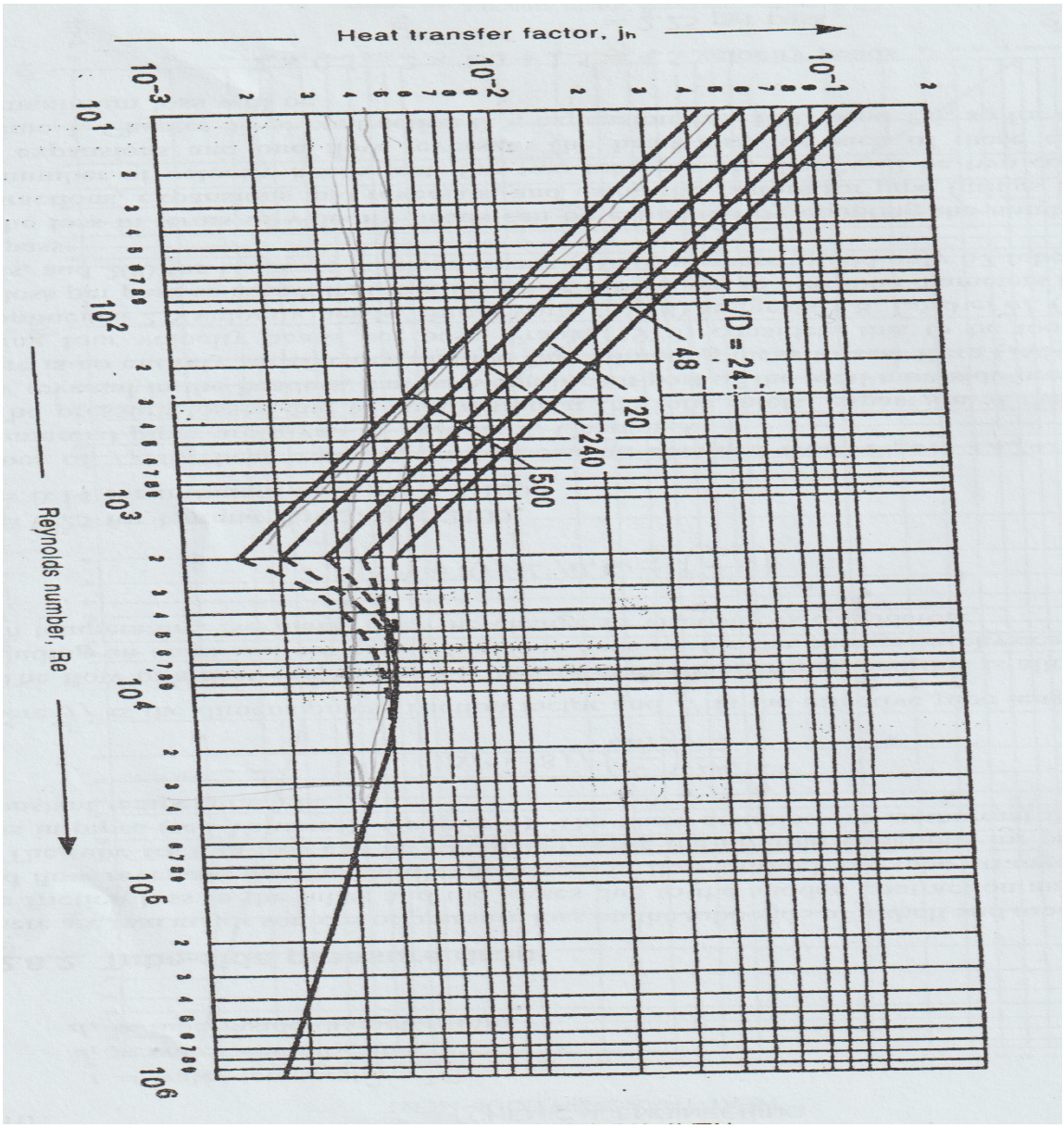

Figure 4.14: Tube side heat transfer factor

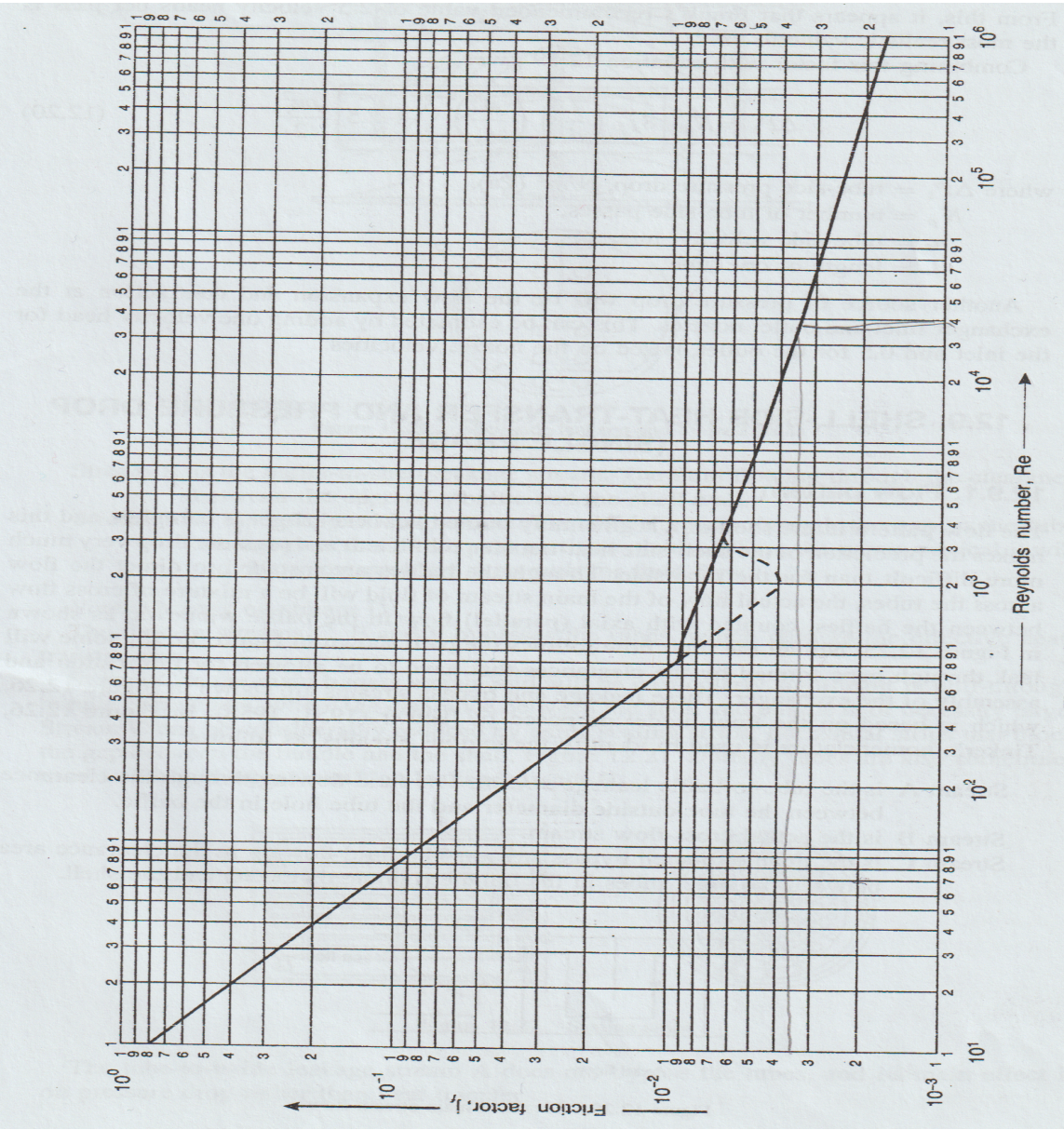

Figure 4.15: Tube side friction factor

4.12 Kern's method

This method was based on experimental work on commercial exchangers with standard tolerance and will give a reasonably satisfactory prediction of the heat transfer

coefficient for standard design.

The prediction of pressure drop is less satisfactory, as pressure drop is more affected by leakage and bypassing than heat transfer.

The shell-side heat transfer coefficient and friction factors are correlated in a similar manner to those for tube-side flow by using a hypothetical shell velocity and shell diameter. The shell equivalent diameter is calculated using the flow area between the tubes taken in the axial direction(parallel to the tubes)and wetted perimeter of the tubes(see Figure **??**)

Procedure :

1- Calculate the area for cross-flow (A_s) for the hypothetical row of tubes at the shell equator, given by:

$$A_s = \frac{(P_t - d_o)D_s l_b}{P_t} \tag{4.20}$$

where:

P_t= tube pitch

d_o= tube outside diameter

D_s= shell inside diameter

l_B= baffle spacing

2- Calculate the shell-side mass velocity (G_S) and the linear velocity (u_s):

$$G_s = \frac{W_s}{A_s} \tag{4.21}$$

$$u_s = \frac{G_s}{\rho} \tag{4.22}$$

where:

W_s= fluid-flow rate on the shell side (kg/s)

ρ= shell-side fluid density (kg/m^3)

3- Calculate the shell-side equivalent diameter according to the tube patterns arrangements (Figure **??**)

a- Square pitch arrangements:

$$d_e = \frac{1.27}{d_o}(P_t^2 - 0.785 d_o^2) \tag{4.23}$$

b- Equilateral triangular pitch arrangements:

$$d_e = \frac{1.10}{d_o}(P_t^2 - 0.917 d_o^2) \tag{4.24}$$

where d_e equivalent diameter (m).

4- Calculate the shell side Reynolds number which is given by:

$$Re = \frac{G_s d_e}{\mu} = \frac{u_s d_e \rho}{\mu} \tag{4.25}$$

5- Read the value of j_h from Figure **??** for the selected baffle cut and tube arrangements, and calculate the shell-side heat transfer coefficient h_s from:

$$Nu = \frac{h_s d_e}{k_f} = j_h Re Pr^{\frac{1}{3}} (\frac{\mu}{\mu_w})^{-0.14} \tag{4.26}$$

The heat transfer coefficient for **water** can be estimated according to the following Equation 4.27. The physical properties are incorporated into the correlation. This equation has been adopted and given by Eagle and Ferguson:

$$h_i = \frac{4200(1.35 + 0.02 \times t) u_t^{0.8}}{d_i^{0.2}} \tag{4.27}$$

where h_i inside coefficient for water ($\mathrm{W{\cdot}m^{-2}{\cdot}^o C^{-1}}$)

6- Read the friction factor from Figure **??**, and calculate the pressure drop according to the following:

$$\Delta P = 8\, j_f (\frac{(D_s)}{d_e})(\frac{L}{l_B})(\frac{\rho u_s^2}{2})(\frac{\mu}{\mu_w})^{-0.14} \tag{4.28}$$

where:

L= Tube length

l_B Baffle spacing

Example:

Design an exchanger to sub-cool condense from a methanol condenser from 95^{o}C to 40^{o}C. Flow rate of methanol 100,000 kg/h. Brackish water will be used as the coolant, with temperature rise from 25^{o}C to 40^{o}C.

Solution:

Coolant is corrosive, so assign to tube-side.

Note:

- Decide which fluid in the shell or tubes. In our case, methanol will pass through the shell and water through the tube since the effect of water will appear on the inside diameter. - Physical properties of fluids can be found in the appendices of Volume 6.

Heat capacity methanol=2.84 kJ$\cdot$kg$^{-1}\cdot^o$C.

1- Heat load can be estimated from mass flow rate, heat capacity of methanol, and temperature difference of methanol according to the following:

2- Estimate the mean temperature difference after choosing the type of heat exchanger: In our case we will choose heat exchanger with one shell and two tube passes, The mean temperature difference will be estimated according to the following:

3- Correct the mean temperature difference according to the following procedure: a- estimate R and S according to the following:

b- Find the correction factor according to the type of heat exchanger, R, and S