Handout: Step-by-step for Heat Exchanger design

Research · September 2015

DOI: 10.13140/RG.2.1.4959.6644

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Steps for design of Heat Exchanger

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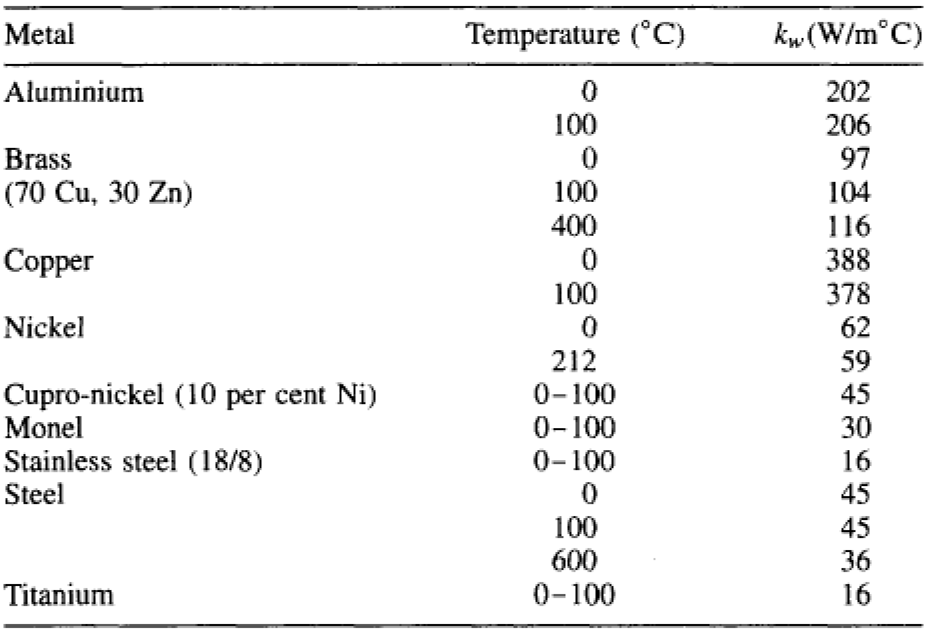
1. Assume tube diameter and BWG, Assume tube length, *L*
2. Assume fouling factor based on inside and outside tubes, h_{di} and h_{do}
3. Assume material of construction for the tubes → thermal conductivity?

Table 12.6. Conductivity of metals



Metal	Temperature (°C)	k_w (W/m°C)
Aluminium	0	202
	100	206
Brass	0	97
(70 Cu, 30 Zn)	100	104
	400	116
Copper	0	388
	100	378
Nickel	0	62
	212	59
Cupro-nickel (10 per cent Ni)	0–100	45
Monel	0–100	30
Stainless steel (18/8)	0–100	16
Steel	0	45
	100	45
	600	36
Titanium	0–100	16

4. You have the option to assume three known temperature and find the fourth one or four temperature values and find one of the shell or tube side flow rate. Use the heat duty equation $q = m_c cp_c (Tc_{ou} - Tc_{in}) = m_h cp_h (T_{h,out} - T_{h,in})$ where subscripts *c* and *h* refer to cold and hot streams. Then obtain the heat duty, *q*.
5. Based on the type of flow, calculate Log Mean Temperature Difference, LMTD.

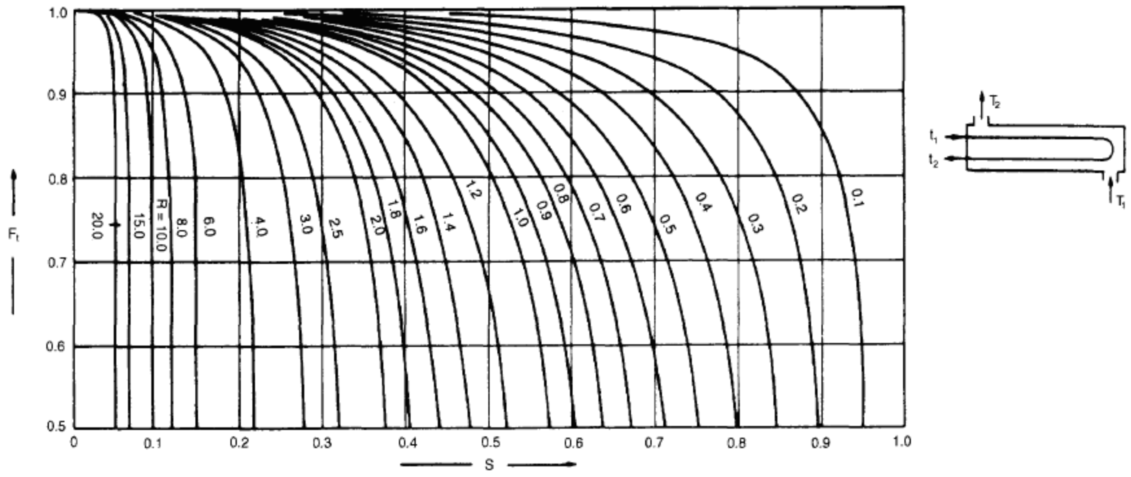
   For counter current $LMTD = \dfrac{(Thi - Tco) - (Tho - Tci)}{\ln \dfrac{(Thi - Tco)}{(Tho - Tci)}}$

   For co-current $LMTD = \dfrac{(Thi - Tci) - (Tho - Tco)}{\ln \dfrac{(Thi - Tci)}{(Tho - Tco)}}$
6. Based of the exchanger configuration obtain the Temperature correction factor.

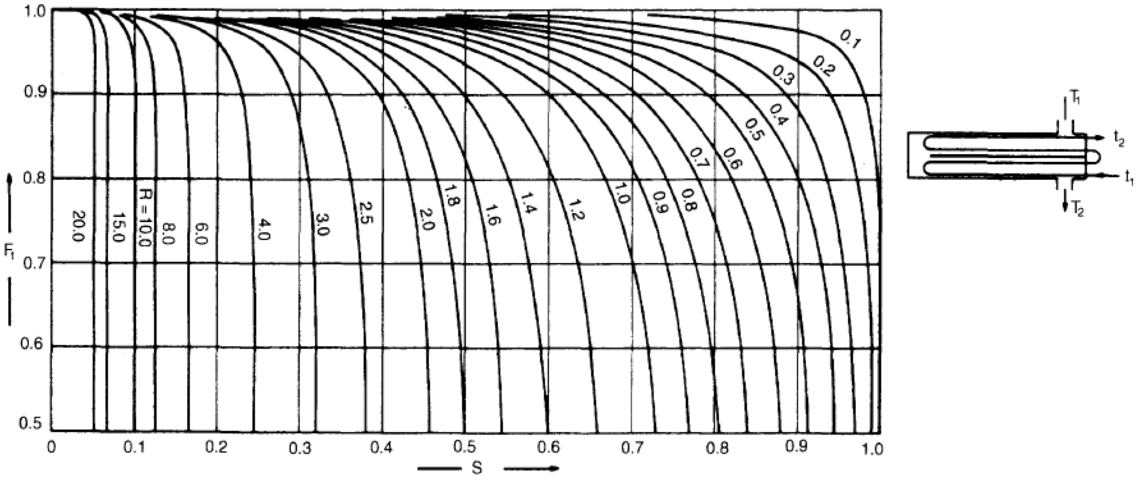
For 1 shell-2 tube pass exchanger

$$F_t = \frac{\sqrt{(R^2+1)}\ln\left[\dfrac{(1-S)}{(1-RS)}\right]}{(R-1)\ln\left[\dfrac{2-S[R+1-\sqrt{(R^2+1)}]}{2-S[R+1+\sqrt{(R^2+1)}]}\right]} \qquad R = \frac{(T_1 - T_2)}{(t_2 - t_1)} \qquad S = \frac{(t_2 - t_1)}{(T_1 - t_1)}$$

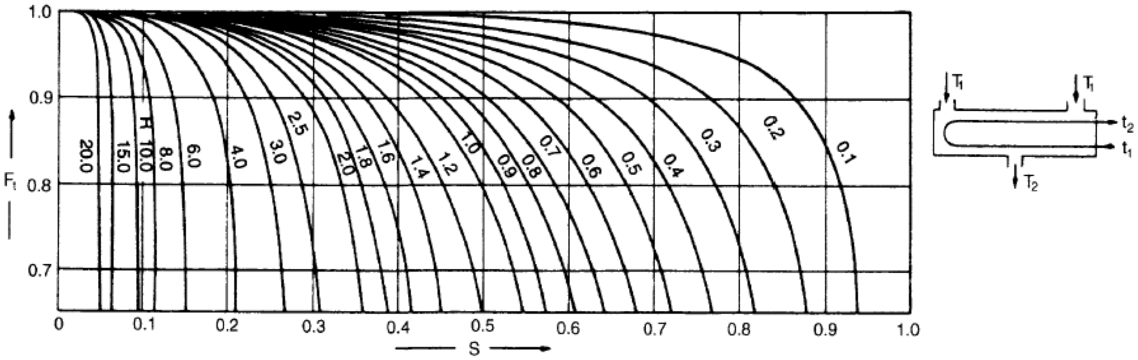
For other configurations use the following charts



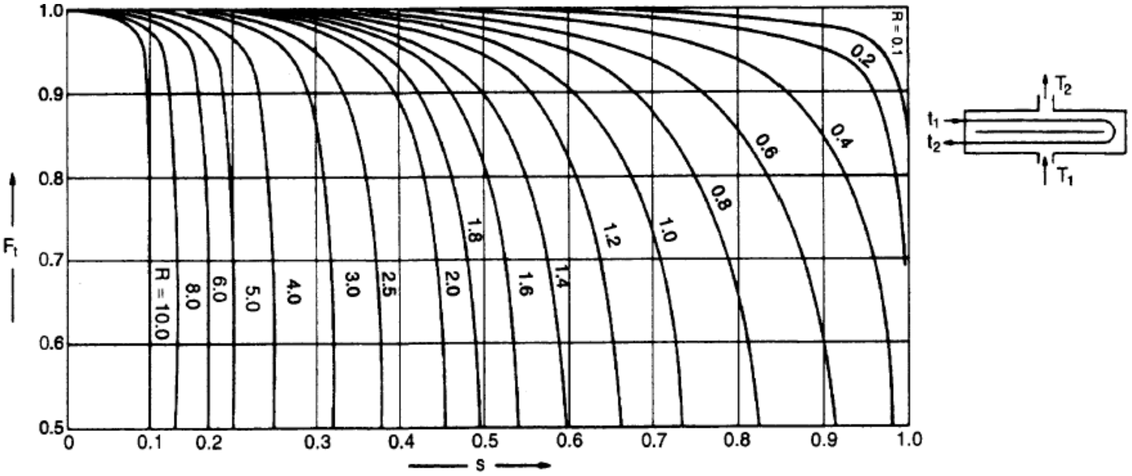
Temperature correction factor: one shell pass; two or more even tube 'passes



Temperature correction factor: two shell passes; four or multiples of four tube passes



Temperature correction factor: divided-flow shell; two or more even-tube passes



Temperature correction factor, split flow shell, 2 tube pass

7. Calculate the mean temperature difference using $DT_m = Ft \times LMTD$
8. Assume overall heat transfer coefficient as initial guess from the table bellow:

Table 12.1. Typical overall coefficients

Shell and tube exchangers

Hot fluid	Cold fluid	U (W/m^2°C)
Heat exchangers		
Water	Water	800–1500
Organic solvents	Organic solvents	100–300
Light oils	Light oils	100–400
Heavy oils	Heavy oils	50–300
Gases	Gases	10–50
Coolers		
Organic solvents	Water	250–750
Light oils	Water	350–900
Heavy oils	Water	60–300
Gases	Water	20–300
Organic solvents	Brine	150–500
Water	Brine	600–1200
Gases	Brine	15–250
Heaters		
Steam	Water	1500–4000
Steam	Organic solvents	500–1000
Steam	Light oils	300–900
Steam	Heavy oils	60–450
Steam	Gases	30–300
Dowtherm	Heavy oils	50–300
Dowtherm	Gases	20–200
Flue gases	Steam	30–100
Flue	Hydrocarbon vapours	30–100
Condensers		
Aqueous vapours	Water	1000–1500
Organic vapours	Water	700–1000
Organics (some non-condensables)	Water	500–700
Vacuum condensers	Water	200–500
Vaporisers		
Steam	Aqueous solutions	1000–1500
Steam	Light organics	900–1200
Steam	Heavy organics	600–900

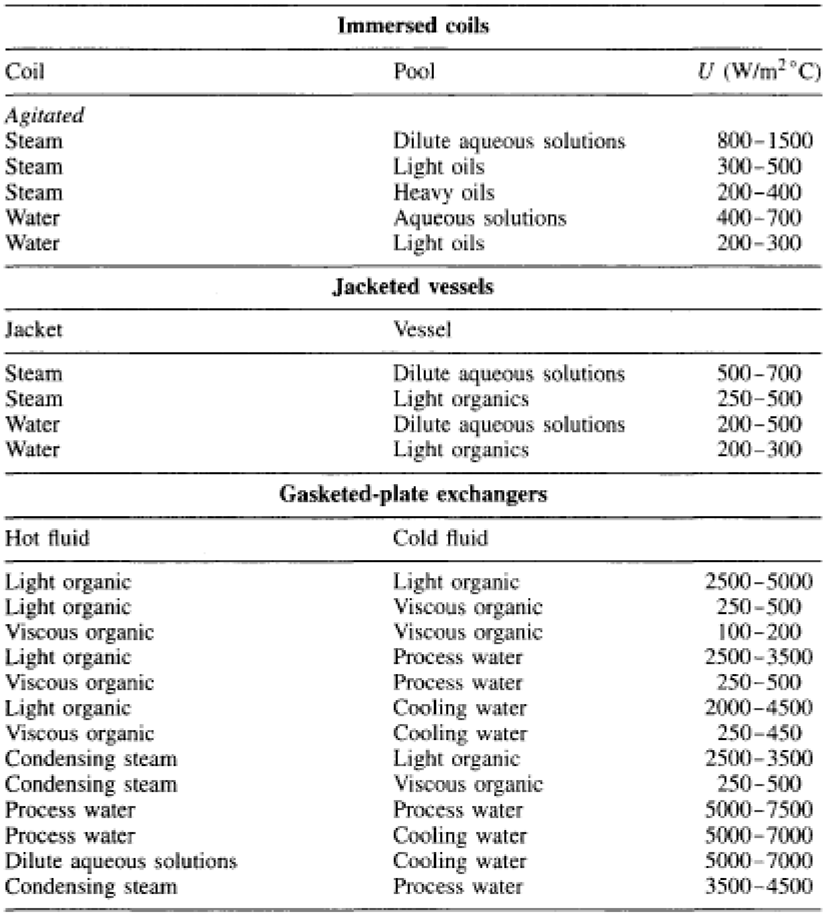
Air-cooled exchangers

Process fluid	
Water	300–450
Light organics	300–700
Heavy organics	50–150
Gases, 5–10 bar	50–100
10–30 bar	100–300
Condensing hydrocarbons	300–600

Immersed coils

Coil	Pool	
Natural circulation		
Steam	Dilute aqueous solutions	500–1000
Steam	Light oils	200–300
Steam	Heavy oils	70–150
Water	Aqueous solutions	200–500
Water	Light oils	100–150

Table 12.1. *(continued)*



Immersed coils		
Coil	Pool	U (W/m^2 °C)
Agitated		
Steam	Dilute aqueous solutions	800–1500
Steam	Light oils	300–500
Steam	Heavy oils	200–400
Water	Aqueous solutions	400–700
Water	Light oils	200–300
	Jacketed vessels	
Jacket	Vessel	
Steam	Dilute aqueous solutions	500–700
Steam	Light organics	250–500
Water	Dilute aqueous solutions	200–500
Water	Light organics	200–300
	Gasketed-plate exchangers	
Hot fluid	Cold fluid	
Light organic	Light organic	2500–5000
Light organic	Viscous organic	250–500
Viscous organic	Viscous organic	100–200
Light organic	Process water	2500–3500
Viscous organic	Process water	250–500
Light organic	Cooling water	2000–4500
Viscous organic	Cooling water	250–450
Condensing steam	Light organic	2500–3500
Condensing steam	Viscous organic	250–500
Process water	Process water	5000–7500
Process water	Cooling water	5000–7000
Dilute aqueous solutions	Cooling water	5000–7000
Condensing steam	Process water	3500–4500

9. Calculate the provisional area $A = \dfrac{q}{U.DT_m}$
10. Based on the assumed tube diameter (ID and OD at a given BWG) and tube length, *L*, calculate number of tubes: $N_t = \dfrac{A}{\pi.d_o.L}$
11. Calculate tube pitch and the bundle diameter

$$p_t = 1.25 d_o \qquad D_b = d_o \left(\frac{N_t}{K_1}\right)^{1/n_1},$$

where N_t = number of tubes,
D_b = bundle diameter, mm,
d_o = tube outside diameter, mm.

Where K_1 and n_1 are obtained from the table bellow based on the type of tube arrangement (Triangular or square pitch):

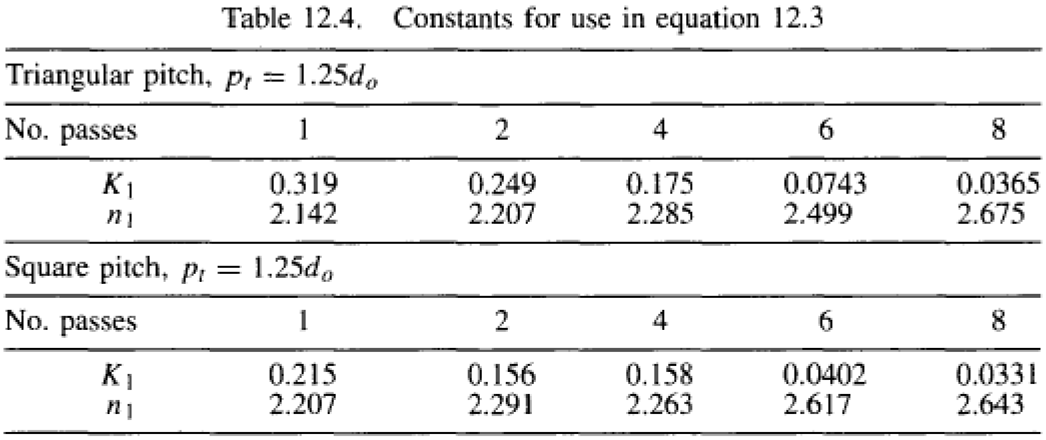
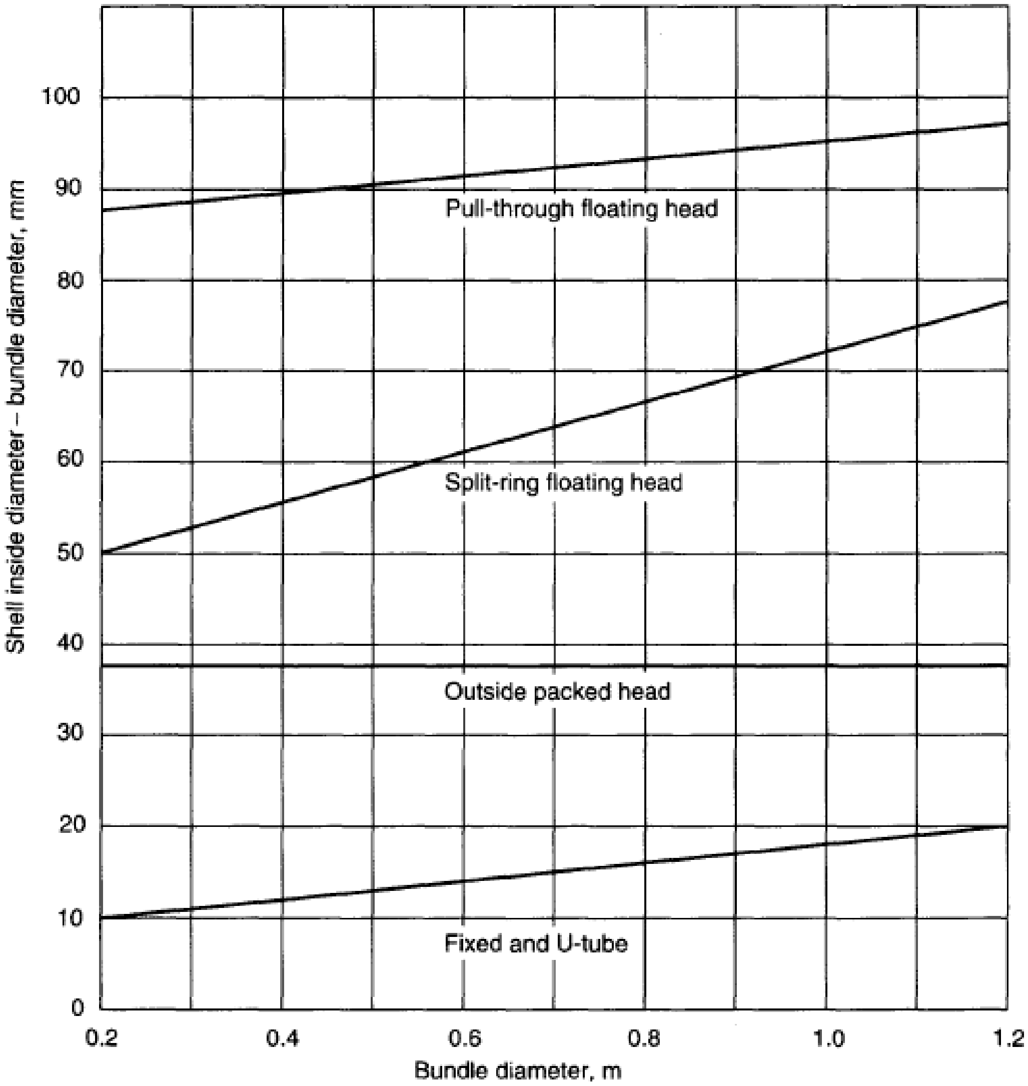


Table 12.4. Constants for use in equation 12.3

Triangular pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.319	0.249	0.175	0.0743	0.0365
n_1	2.142	2.207	2.285	2.499	2.675
Square pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.215	0.156	0.158	0.0402	0.0331
n_1	2.207	2.291	2.263	2.617	2.643

12. Provide/Assume the type of floating head of the exchanger and obtain the bundle diameter clearance, BDC. Use the chart bellow:



13. Calculate the shell diameter. $Ds = Db + BDC$
14. Calculate the baffle spacing. $Bs = 0.4Ds$
15. Calculate the are for cross-flow, $As = \dfrac{(p_t - d_o)Ds.Bs}{p_t}$
16. Calculate the shell-side mass velocity, $Gs = \dfrac{\text{shell - side flowrate [kg/s]}}{\text{As}}$
17. Calculate the shell equivalent diameter

a square pitch arrangement:

$$d_e = \frac{4\left(\dfrac{p_t^2 - \pi d_o^2}{4}\right)}{\pi d_o} = \frac{1.27}{d_o}(p_t^2 - 0.785 d_o^2)$$

For an equilateral triangular pitch arrangement:

$$d_e = \frac{4\left(\dfrac{p_t}{2} \times 0.87 p_t - \frac{1}{2}\pi \dfrac{d_o^2}{4}\right)}{\dfrac{\pi d_o}{2}} = \frac{1.10}{d_o}(p_t^2 - 0.917 d_o^2)$$

where d_e = equivalent diameter, m.

18. Calculate the shell-side Reynolds number

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

19. Calculate Prandtle number. $\Pr = \dfrac{\mu.Cp}{k}$
20. Obtain the shell-side heat transfer coefficient

$$Nu = \frac{h_s d_e}{k_f} = j_h Re Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

Where j_h is obtained from the chart bellow

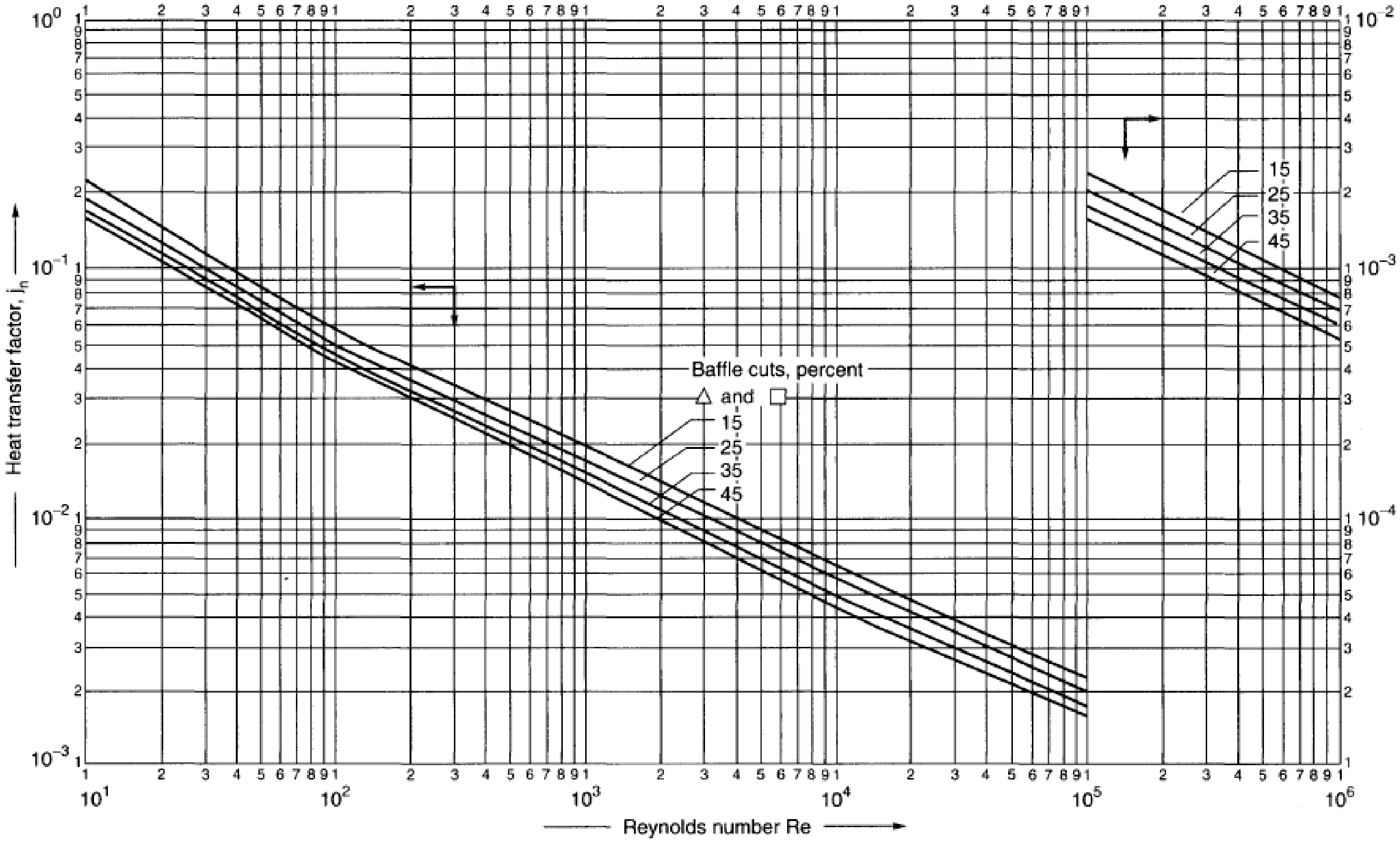


Figure 12.29. Shell-side heat-transfer factors, segmental baffles

21. Calculate the pressure drop in the shell

$$\Delta P_s = 8 j_f \left(\frac{D_s}{d_e}\right)\left(\frac{L}{l_B}\right)\frac{\rho u_s^2}{2}\left(\frac{\mu}{\mu_w}\right)^{-0.14}$$

where L = tube length,
l_B = baffle spacing.

Where j_f may be obtained from the chart bellow

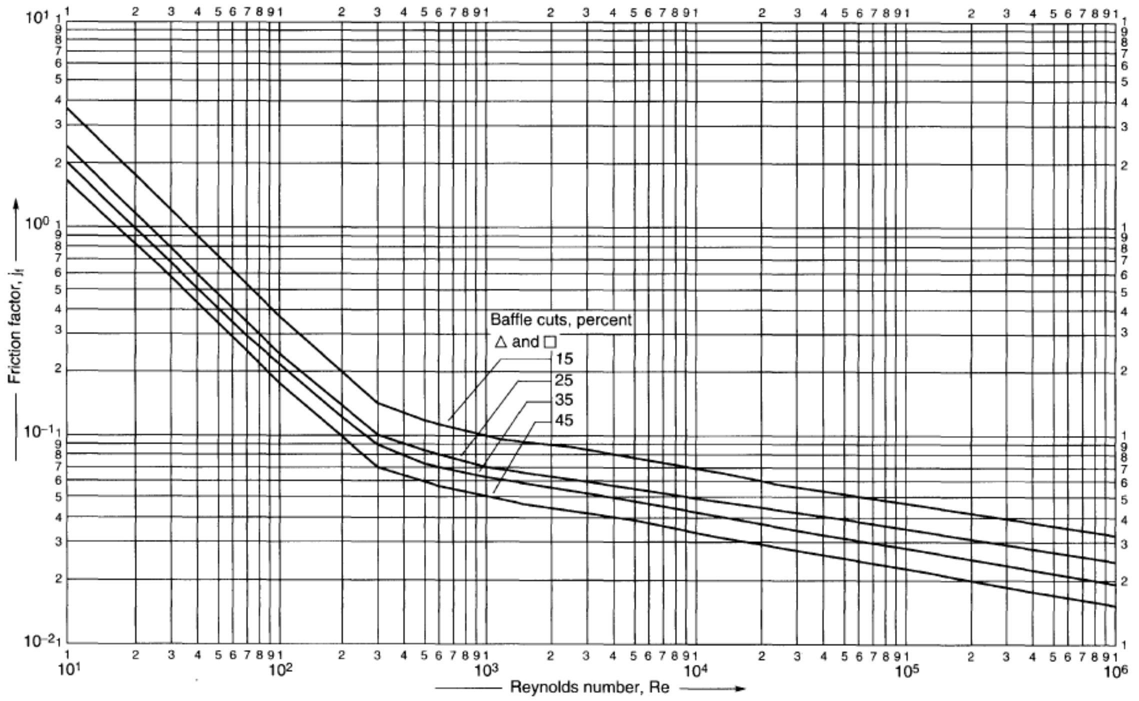


Figure 12.30. Shell-side friction factors, segmental baffles

22. Calculate the number of tubes per pass; $Ntpp = N_t / \text{number of passes}$

23. Calculate tube-side mass velocity, $Gm = \dfrac{\text{tube-side flowrate [kg/s]}}{\mathrm{N_{tpp}} \times \pi d_i^2 / 4}$

24. Calculate tube-side velocity $v = \dfrac{Gm}{\rho_i}$ where ρ_i is the density of fluid inside tubes.

25. Calculate Prandtle and Reynolds numbers for fluids inside tubes

$\Pr = \dfrac{\mu.Cp}{k}$, $\mathrm{Re} = \dfrac{\rho_i d_i v}{\mu_i}$ where subscript i refers to fluid inside tubes.

26. Calculate heat transfer coefficient h_i by using either the following relations

If $\mathrm{Re} < 2100$ (Laminar flow) then $h_i = 1.86 \dfrac{k_f}{d_i} (\mathrm{Re}.\Pr)^{0.33} \left(\dfrac{d_i}{L}\right)^{0.33} \left(\dfrac{\mu}{\mu_w}\right)^{0.14}$

If $\mathrm{Re} > 2100$ (Transition and Turbulent) $h_i = 0.023 \dfrac{k_f}{d_i} \mathrm{Re}^{0.8} \Pr^{0.33} \left(1 + \dfrac{d_i}{L}\right)^{0.7}$

Or by analogy $h_i = j_h \dfrac{k_f}{d_i} \mathrm{Re}.\Pr^{0.33} \left(\dfrac{\mu}{\mu_w}\right)^{0.14}$

27. Calculate the overall heat transfer factor

Based on *"inside tubes flow"* $U_i = \dfrac{1}{\dfrac{1}{h_i} + \dfrac{1}{h_{di}} + \dfrac{d_i \ln(d_o / d_i)}{2k_w} + \dfrac{d_i}{d_o h_{do}} + \dfrac{d_i}{d_o h_o}}$

Or based on *"outside tubes flow"* $U_o = \dfrac{1}{\dfrac{1}{h_o} + \dfrac{1}{h_{do}} + \dfrac{d_o \ln(d_o / d_i)}{2k_w} + \dfrac{d_o}{d_i h_o} + \dfrac{d_o}{d_i h_{di}}}$

Where h_{di} and h_{do} are the heat transfer coefficients for the scales (dirt) inside and outside tubes, respectively.

28. Compare the calculated overall heat transfer coefficient you obtained from the previous step with that you assumed in step 8. if it is close to what you assumed, then you had a valid assumption, then tabulate your results such as total surface area of tubes, number of tubes, exchanger length and diameter, heat duty and other design specification. Otherwise, use the calculated value in step 8 and do loop until the difference between the calculated *U* between two consecutive iterations is small.
29. The tube-side pressure drop may be calculated using the relation

$$\Delta P = \left(1.5 + N_t \left[2.5 + \frac{8 j_f L}{d_i} + \left(\frac{\mu}{\mu_w}\right)^{-m}\right]\right) \frac{\rho_i v^2}{2}$$