Reboiler Design Guidelines

(Reference: R.K.Sinnot, Coulson & Richardson's Chemical Engineering, Volume 6, Edition 3, Butterworth-Heinemann, 1999)

Heat Transfer rate:

$$Q = UA\Delta T_m$$

where Q = heat transferred per unit time, W,
U = the overall heat transfer coefficient, $W/m^2\,^\circ C$,
A = heat-transfer area, m^2,
ΔT_m = the mean temperature difference, the temperature driving force, °C.

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

where U_o = the overall coefficient based on the outside area of the tube, $W/m^2\,^\circ C$,
h_o = outside fluid film coefficient, $W/m^2\,^\circ C$,
h_i = inside fluid film coefficient, $W/m^2\,^\circ C$,
h_{od} = outside dirt coefficient (fouling factor), $W/m^2\,^\circ C$,
h_{id} = inside dirt coefficient, $W/m^2\,^\circ C$,
k_w = thermal conductivity of the tube wall material, $W/m^\circ C$,
d_i = tube inside diameter, m,
d_o = tube outside diameter, m.

Temperature Difference:

ΔT_m = Temperature of condensing steam – temperature of boiling fluid

Procedure:

1. Assume a value of over all heat transfer coefficient, and estimate heat transfer area A from the equation, $Q = UA\Delta T_m$
2. Allocate this A by choosing a tube dimension, and calculate the number of tubes, and tube bundle diameter.
3. Calculate the boiling fluid's heat transfer coefficient.
4. Calculate the heat flux and check whether, it is less than the critical heat flux.
5. Calculate the shell diameter based on the heat flux in the reboiler.
6. Check whether the vapor velocity is less than the allowable vapor velocity
7. If step 4 or 6, is not met with then go to step 1 and redo the entire steps; else stop the calculations, and the dimensions as arrived in step 2 will meet the required heat transfer duty.

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

Table 12.2. Fouling factors (coefficients), typical values

Fluid	Coefficient (W/m^2°C)	Factor (resistance) (m^2°C/W)
River water	3000–12,000	0.0003–0.0001
Sea water	1000–3000	0.001–0.0003
Cooling water (towers)	3000–6000	0.0003–0.00017
Towns water (soft)	3000–5000	0.0003–0.0002
Towns water (hard)	1000–2000	0.001–0.0005
Steam condensate	1500–5000	0.00067–0.0002
Steam (oil free)	4000–10,000	0.0025–0.0001
Steam (oil traces)	2000–5000	0.0005–0.0002
Refrigerated brine	3000–5000	0.0003–0.0002
Air and industrial gases	5000–10,000	0.0002–0.0001
Flue gases	2000–5000	0.0005–0.0002
Organic vapours	5000	0.0002
Organic liquids	5000	0.0002
Light hydrocarbons	5000	0.0002
Heavy hydrocarbons	2000	0.0005
Boiling organics	2500	0.0004
Condensing organics	5000	0.0002
Heat transfer fluids	5000	0.0002
Aqueous salt solutions	3000–5000	0.0003–0.0002

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

3. **Heat Transfer Coefficient Estimations**

Tube side heat transfer coefficient:

Tube side fluid is generally the condensing steam, and the heat transfer coefficient for the same can be taken to be constant as 8000 W/m^2.K.

Shell side Heat Transfer coefficient:

Boiling Heat Transfer Coefficient Estimation (i). The correlation given by **Forster and Zuber (1955)** can be used to estimate pool boiling coefficients:

$$h_{nb} = 0.00122 \left[\frac{k_L^{0.79} C_{pL}^{0.45} \rho_L^{0.49}}{\sigma^{0.5} \mu_L^{0.29} \lambda^{0.24} \rho_v^{0.24}} \right] (T_w - T_s)^{0.24} (p_w - p_s)^{0.75}$$

where h_{nb} = nucleate, pool, boiling coefficient, W/m^2°C,
k_L = liquid thermal conductivity, W/m°C,
C_{pL} = liquid heat capacity, J/kg°C,
ρ_L = liquid density, kg/m^3,
μ_L = liquid viscosity, Ns/m^2,
λ = latent heat, J/kg,
ρ_v = vapour density, kg/m^3,
T_w = wall, surface temperature, °C,
T_s = saturation temperature of boiling liquid °C,
p_w = saturation pressure corresponding to the wall temperature, T_w, N/m^2,
p_s = saturation pressure corresponding to T_s, N/m^2,
σ = surface tension, N/m.

(ii). The reduced pressure correlation given by **Mostinski** (1963) is simple to use and gives values that are as reliable as those given by more complex equations.

$$h_{nb} = 0.104 (P_c)^{0.69} (q)^{0.7} \left[1.8 \left(\frac{P}{P_c} \right)^{0.17} + 4 \left(\frac{P}{P_c} \right)^{1.2} + 10 \left(\frac{P}{P_c} \right)^{10} \right]$$

where P = operating pressure, bar,
P_c = liquid critical pressure, bar,
q = heat flux, W/m^2.

Note. $q = h_{nb}(T_w - T_s)$.

Mostinski's equation is convenient to use when data on the fluid physical properties are not available.

After estimating the boiling heat transfer coefficient from any of the above equations, and using the heat transfer coefficient for the condensing steam as 8000 W/m^2.K, calculate overall heat transfer coefficient U.

4. Check for prevailing heat flux:

It is to be ensured that the heat flux prevailing in the reboiler is below the critical value. This is done by using any of the equations as given below:

(i). Mostinski also gives a reduced pressure equation for predicting the maximum critical heat flux:

$$q_c = 3.67 \times 10^4 P_c \left(\frac{P}{P_c}\right)^{0.35} \left[1 - \left(\frac{P}{P_c}\right)\right]^{0.9}$$

(ii) The modified Zuber equation can be written as:

$$q_{cb} = K_b \left(\frac{p_t}{d_o}\right) \left(\frac{\lambda}{\sqrt{N_t}}\right) [\sigma g(\rho_L - \rho_v)\rho_v^2]^{0.25}$$

where q_{cb} = maximum (critical) heat flux for the tube bundle, W/m^2,
K_b = 0.44 for square pitch arrangements,
= 0.41 for equilateral triangular pitch arrangements,
p_t = tube pitch,
d_o = tube outside diameter,
N_t = total number of tubes in the bundle,

(iii). Palen and Small (1964) suggested that a factor of safety of 0.7 be applied to the maximum flux estimated from equations.

5. Shell Diameter Calculations:

If the heat flux prevailing in the reboiler is below that of critical heat flux, then proceed as below:

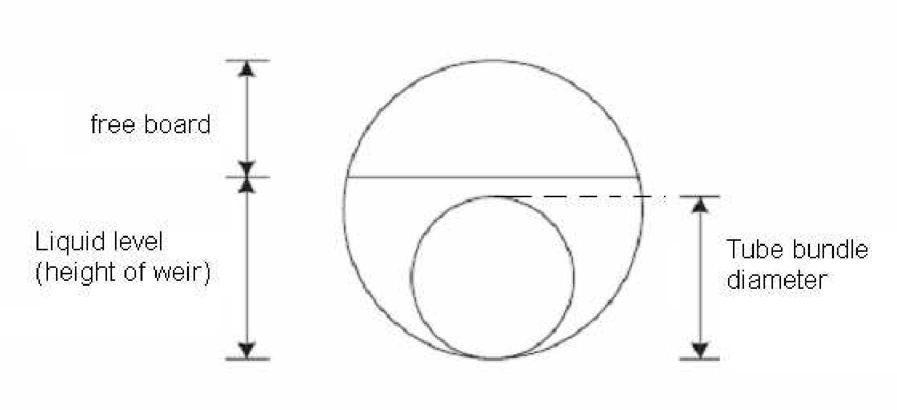
For the heat flux prevailing in the reboiler, choose the shell dia to tube bundle dia ratio from the guidelines as given below:

Heat flux W/m^2	Shell dia./Bundle dia.
25,000	1.2 to 1.5
25,000 to 40,000	1.4 to 1.8
40,000	1.7 to 2.0

The freeboard between the liquid level and shell should be at least 0.25 m.

Calculate the shell diameter and freeboard based on the above guidelines.

Calculate the vapor velocity at the liquid surface, based on the surface area of liquid and rate of vaporization of liquid.



6. Check for Maximum Vapor Velocity

To avoid excessive entrainment, the maximum vapour velocity (m/s) at the liquid surface should be less than that given by the expression:

$$\hat{u}_v < 0.2\left[\frac{\rho_L - \rho_v}{\rho_v}\right]^{1/2}$$