CH2407 Process Equipment Design II

www.msubbu.in

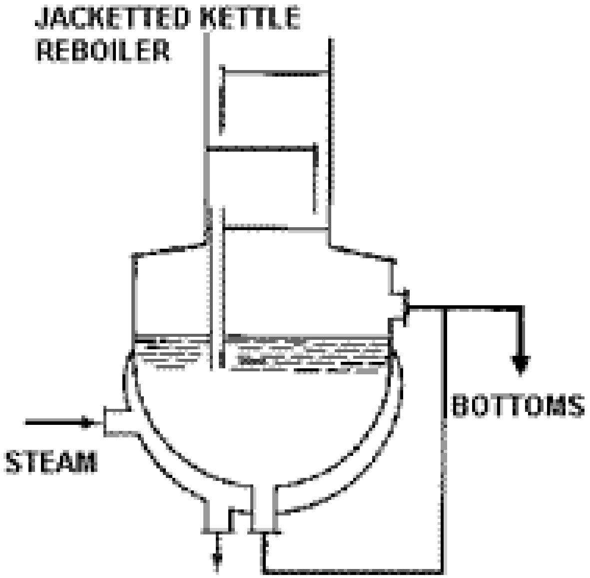
Reboiler Design

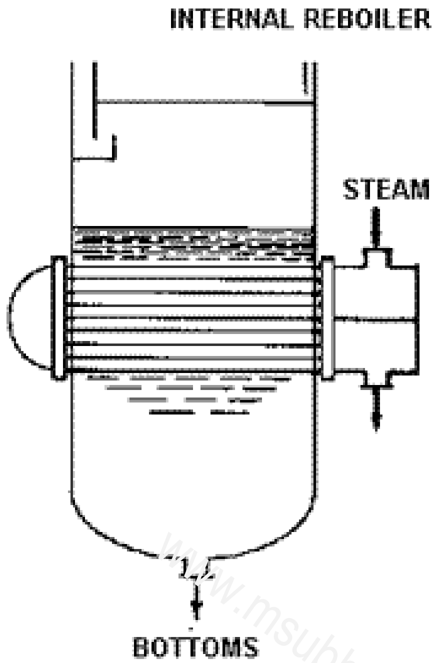
Dr. M. Subramanian

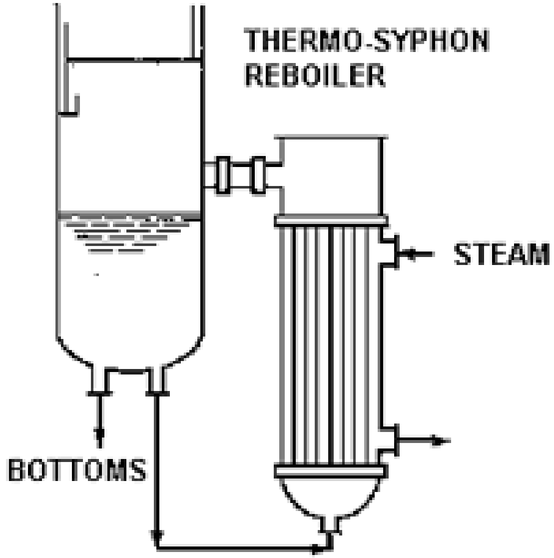
Associate Professor
Department of Chemical Engineering
Sri Sivasubramaniya Nadar College of Engineering
Kalavakkam – 603 110, Kanchipuram (Dist)
Tamil Nadu, India
msubbu.in[AT]gmail.com

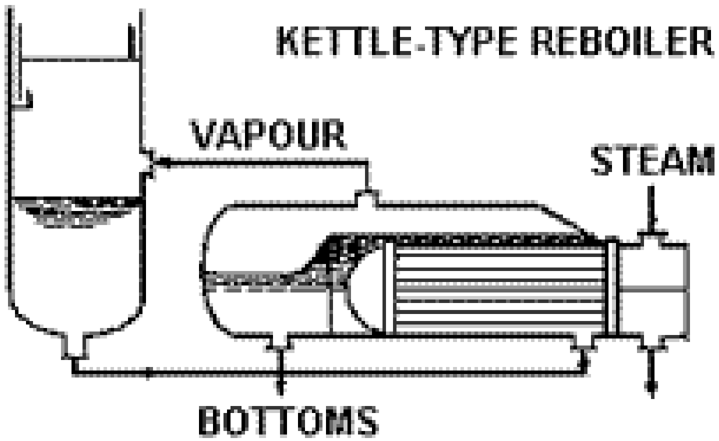
Contents

- Reboiler types, diagrams, and photos
- Kettle type reboiler design considerations
- Example design problem

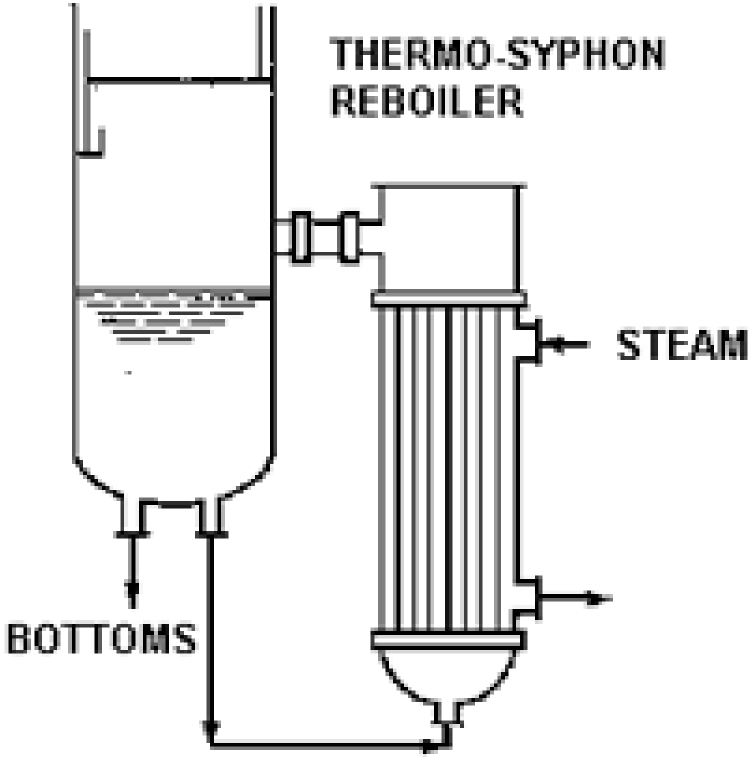

JACKETTED KETTLE
REBOILER
BOTTOMS
STEAM


INTERNAL REBOILER
STEAM
BOTTOMS


THERMO-SYPHON
REBOILER
STEAM
BOTTOMS


KETTLE-TYPE REBOILER
VAPOUR
STEAM
BOTTOMS

Thermosyphon Reboiler



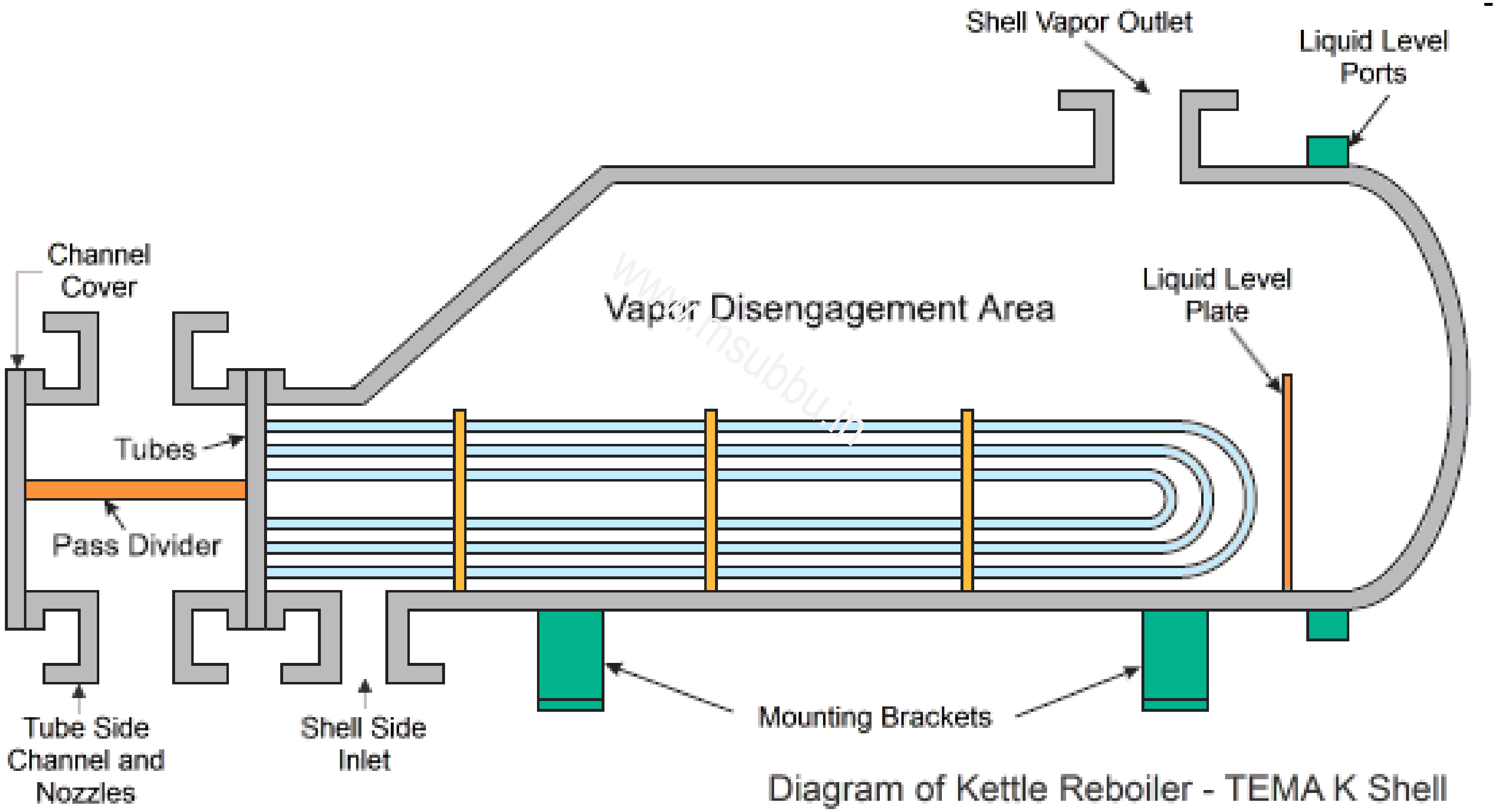
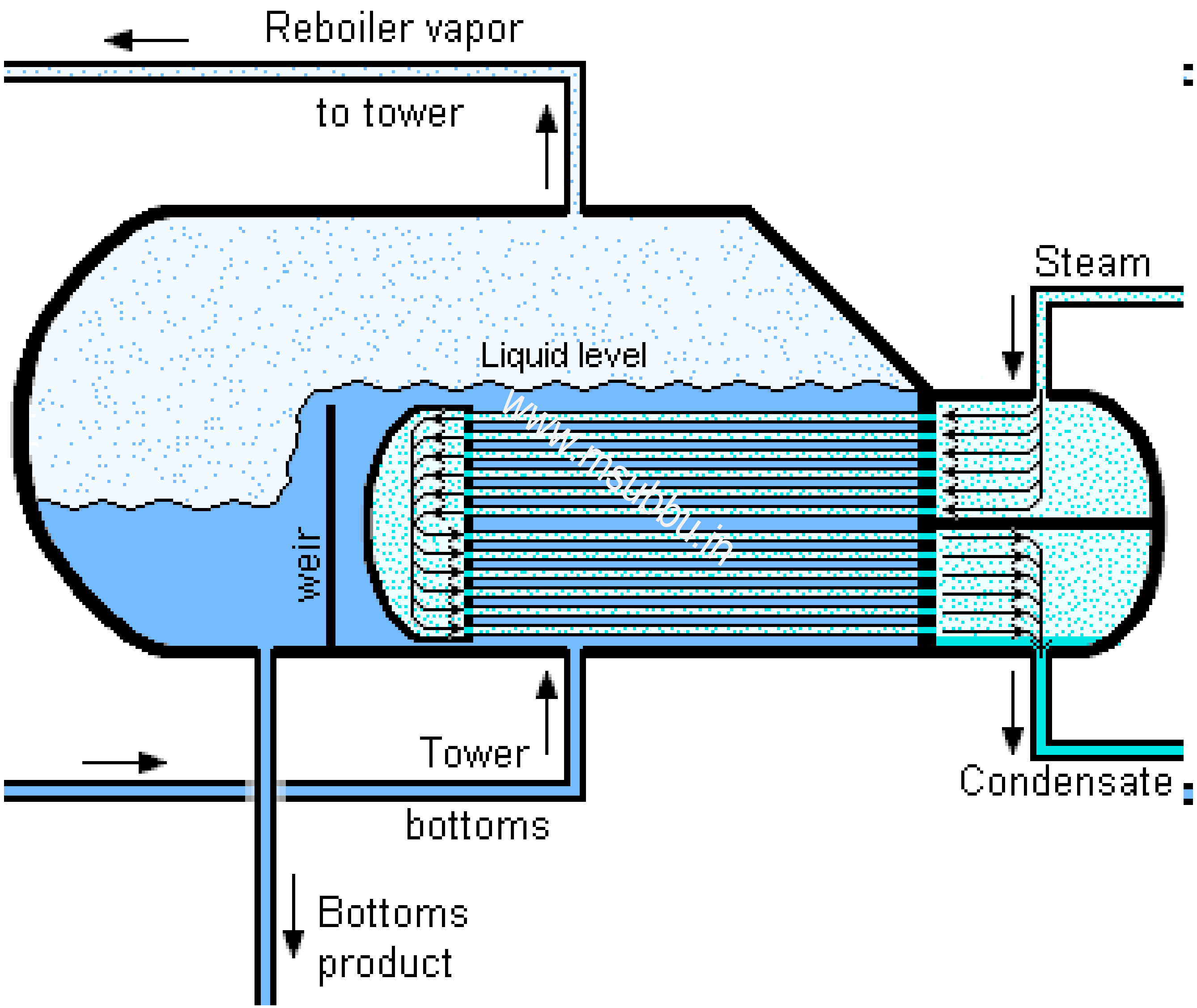


Diagram of Kettle Reboiler - TEMA K Shell



Reboiler vapor
to tower
Steam
Liquid level
weir
Tower
bottoms
Condensate
Bottoms
product


www.msubbu.in
27 7:54 AM

Kettle Type Reboilers

- Kettle reboilers, and other submerged bundle equipment, are essentially pool boiling devices, and their design is based on data for nucleate boiling.

- The tube arrangement, triangular or square pitch, will not have a significant effect on the heat-transfer coefficient. A tube pitch of between 1.5 to 2.0 times the tube outside diameter should be used to avoid vapour blanketing.

- Long thin bundles will be more efficient than short fat bundles

Disengagement of Vapor and Liquid

The shell should be sized to give adequate space for the disengagement of the vapour and liquid. The shell diameter required will depend on the heat flux. The following values can be used as a guide:

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.

Check for Maximum Vapor Velocity

- To avoid excessive entrainment, the maximum vapour velocity $\hat{u}_v$ (m/s) at the liquid surface should be less than that given by the expression:

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

Boiling Heat Transfer Coefficients

- In the design of vaporisers and reboilers the designer will be concerned with two types of boiling: pool boiling and convective boiling.
- Pool boiling is the name given to nucleate boiling in a pool of liquid; such as in a kettle-type reboiler or a jacketed vessel.
- Convective boiling occurs where the vaporising fluid is flowing over the heated surface, and heat transfer takes place both by forced convection and nucleate boiling; as in forced circulation or thermosyphon reboilers.
- Boiling is a complex phenomenon, and boiling heat-transfer coefficients are difficult to predict with any certainty. Whenever possible experimental values obtained for the system being considered should be used, or values for a closely related system.

Critical Heat Flux

- It is important to check that the design, and operating, heat flux is well below the critical flux.
- The maximum heat flux achievable with nucleate boiling is known as the critical heat flux.
- In a system where the surface temperature is not self-limiting, such as a nuclear reactor fuel element, operation above the critical flux will result in a rapid increase in the surface temperature, and in the extreme situation the surface will melt. This phenomenon is known as “burn-out”.
- The heating media used for process plant are normally self-limiting; for example, with steam the surface temperature can never exceed the saturation temperature.
- Care must be taken in the design of electrically heated vaporisers to ensure that the critical flux can never be exceeded.

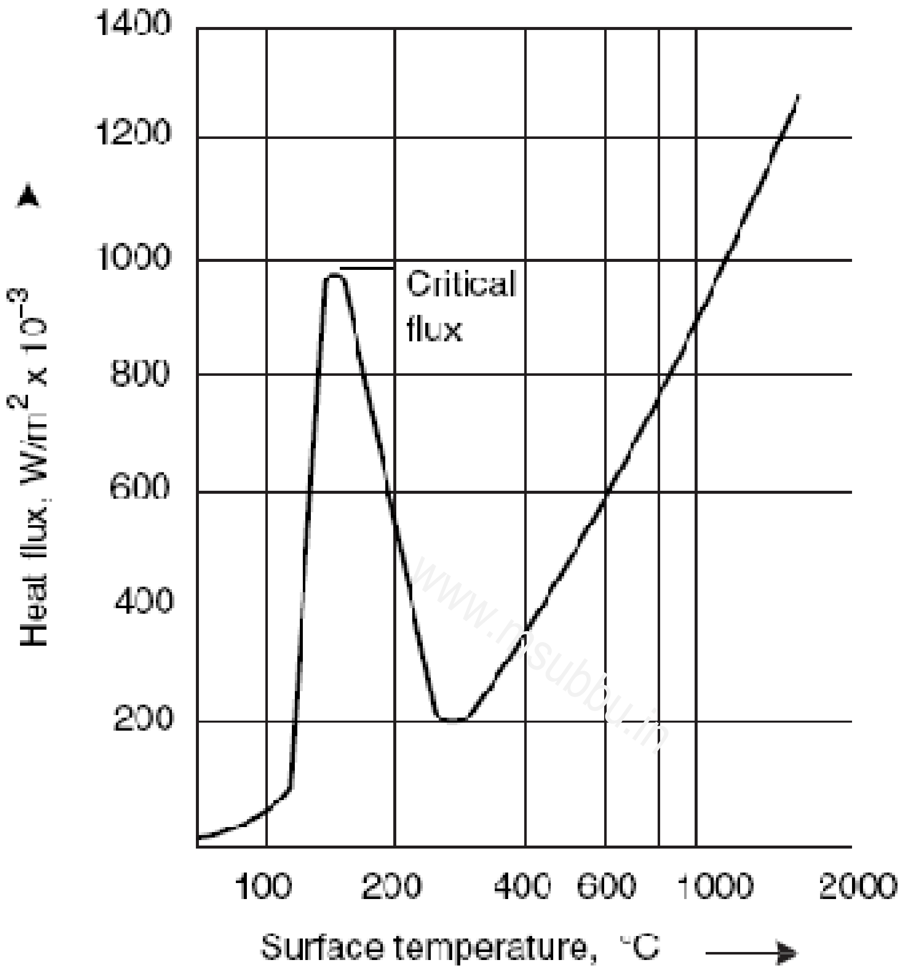


Figure 12.54. Typical pool boiling curve (water at 1 bar)

The critical flux is reached at surprisingly low temperature differences; around 20 to 30^{o}C for water, and 20 to 50^{o}C for light organics

Boiling Heat Transfer Coefficient Estimation

- 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.

Boiling Heat Transfer Coefficient Estimation (contd.)

- 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.

Check for Critical Heat Flux

- In SI units, Zuber's (1961) equation can be written as:

$$q_c = 0.131\lambda[\sigma g(\rho_L - \rho_v)\rho_v^2]^{1/4}$$

where q_c = maximum, critical, heat flux, W/m^2,
g = gravitational acceleration, 9.81 m/s^2.

- Mostinski also gives a reduced pressure equation for predicting the maximum critical heat flux:

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

Check for Critical Heat Flux (contd.)

- 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,

- Palen and Small (1964) suggest that a factor of safety of 0.7 be applied to the maximum flux estimated from equation

Heat Transfer Coefficient of Condensing Steam

- Steam is frequently used as a heating medium.
- The film coefficient for condensing steam can be calculated using the methods given in the previous sections; but, as the coefficient will be high and will rarely be the limiting coefficient, it is customary to assume a typical, conservative, value for design purposes. For air-free steam a coefficient of 8000 $W/m2\ ^{o}C$ can be used.