5.4. Falling Film Heat Transfer

Falling film vaporizers are characterized by having thin films in contact with the heat transfer surfaces; therefore, the heat transfer equations are basically the same as the condensation equations, the only difference being the direction of heat flow. Hence, we give below only a few basic equations and refer you to section 3 for the influence of shear, mass transfer, etc. The above statements assume no nucleate boiling occurs. Due to the high coefficients and low ΔT used in these units, nucleation is normally not experienced; however, the effect of nucleation is to increase the rate of heat transfer, hence, this is a conservative assumption. There is one special characteristic that appears in the vaporizers and that is the dry patch phenomenon. A dry patch can form due to (1) insufficient liquid to wet the surface, and (2) too high a surface temperature and heat flux causing the liquid to form rivulets thus resulting in dry spots. The dry spots have very low heat fluxes and thus reduces capacity and should be avoided. We will discuss the dry spot effects later.

5.4.1. Vertical In-Tube Vaporizer

Uniformity of liquid distribution to all tubes is essential for in-tube falling films. The type of distributor, Figure 5.16, used on each tube affects the allowable hydraulic gradient for the flow across the tube sheet; e.g., a simple overflow weir is very sensitive to the hydraulic gradient while a slotted tube is less sensitive. Distributors are not a commercially available item and are engineered for each application.

Although the feed to the vaporizers may be at or very close to the saturation temperature, nevertheless, a preheat section is required to establish the temperature gradient within the film. In the laminar region the coefficient is (47)

$$h = 4.71\, k/(3\Gamma\, \mu/g\, \rho^2)^{1/3} \tag{5.39}$$

and for the turbulent region the recommended (48) equation is

$$h\left(\frac{\mu^2}{k^3\rho^2 g}\right)^{1/3} = 5.7(10^{-3})\left(\frac{4\Gamma}{\mu}\right)^{0.4}\left(\frac{c\mu}{k}\right)^{0.34} \tag{5.40}$$

For surface evaporation the respective equations for local heat transfer coefficients are (48):

Laminar flow

$$h = 0.821\left(\frac{\mu^2}{k^3\rho^2 g}\right)^{-1/3}\left(\frac{4\Gamma}{\mu}\right)^{-0.22} \tag{5.41}$$

Turbulent flow

$$h = 3.8\left(10^{-3}\right)\left(\frac{\mu^2}{k^3\rho^2 g}\right)^{-1/3}\left(\frac{4\Gamma}{\mu}\right)^{0.4}\left(\frac{c\mu}{k}\right)^{0.65} \tag{5.42}$$

The laminar equation 5.41 included the effect of waves and ripples. The transition Reynolds number is just the value from the intersection of these equations, not the transition of flow regimes, and is

$$\left(\frac{4\Gamma}{\mu}\right)_{trans} = 5800\left(\frac{c\mu}{k}\right)^{-1.06} \quad (5.43)$$

The above equations provide the local heat transfer coefficients which are used in stepping through the vaporizer. All the fluid properties are evaluated for the liquid phase. This stepping process will also account for the temperature changes and thus give an integrated UΔT value. For mixtures there may be additional mass transfer resistances in the liquid and gas films and techniques of handling these complications are the same as for condensation, therefore, refer to section 3 for further information.

5.4.2. Horizontal Shell-Side Vaporizer

Distribution is less critical with horizontal units since drippage between tube rows soon overpowers the initial distribution. While there is still much to be resolved regarding the effect of tube spacing on the effect of drippage and vapor velocities on the motion of drops within the tube bundles, the following equations can be used for approximating the heat transfer, where all the fluid properties are evaluated for the liquid phase. For the preheat zone:

$$h\left(\frac{\mu^2}{k^3\rho^2 g}\right)^{1/3} = 0.39\left(\frac{4\Gamma}{\mu}\right)^{.21}\left(\frac{c\mu}{k}\right)^{.36}\left(\frac{g d_o^3 \rho^2}{\mu^2}\right)^{-.12}\left(\frac{\mathrm{Pr}}{\mathrm{Pr}_w}\right)^{.25} \quad (5.44)$$

For the evaporation zone (50):

$$h\left(\frac{\mu^2}{k^3\rho^2 g}\right)^{1/3} = 0.18\left(\frac{4\Gamma}{\mu}\right)^{0.24}\left(\frac{c\mu}{k}\right)^{0.66} \quad (5.45)$$

Horizontal units are used with finned tubes or enhancements on both inside and outside of the tubes to improve heat transfer. See the government literature associated with the development of sea water desalinization and ocean thermal energy conversion for further information.

5.4.3. Dry Spots - Film Breakdown

Although theories have been developed to explain the dry spot or film breakdown due to either minimum flows or high fluxes, the agreement with experimental data is only fair, see (9, 47) for further references. The best suggestion is to have a minimum flow at the bottom of the tube or bundle, for water, above 150 lb/hr ft and to not exceed a film ΔT of 18°F (10°C)

The requirement for minimum wetting rate means a minimum amount of recirculation may be necessary and it is best to assure the recirculation is sufficient for adequate wetting. When handling mixtures this recirculated liquid can affect the concentrations and boiling points of the feed.