6.5.2 Pool Boiling on a Horizontal Surface

Perhaps the most common configuration, known as *pool boiling*, occurs when a pool of liquid is heated from below through a horizontal surface. For present purposes it will be assumed that the heat flux, $\dot{q}$, is uniform. A uniform bulk temperature far from the wall is maintained because the mixing motions generated by natural convection (and, in boiling, by the motions of the bubbles) mean that most of the liquid is at a fairly uniform time-averaged temperature. In other words, the time-averaged temperature difference, ΔT, occurs within a thin layer next to the wall.

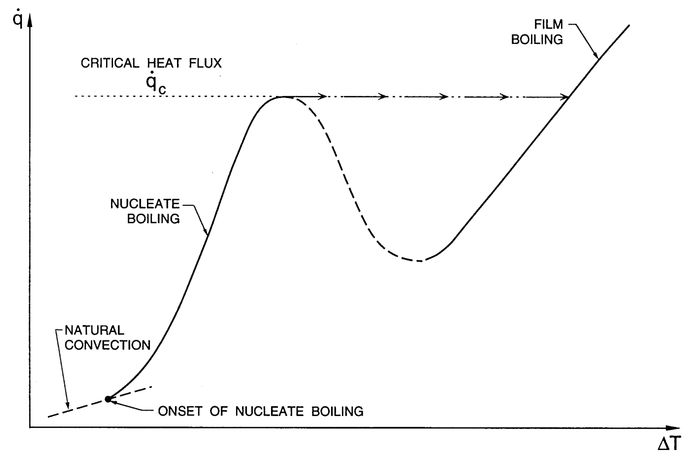

Figure 1: Pool boiling characteristics.

In pool boiling the relation between the heat flux, $\dot{q}$, and ΔT is as sketched in figure 1 and events develop with increasing ΔT as follows. When the pool as a whole has been heated to a temperature close to T_e, the onset of nucleate boiling occurs. Bubbles form at nucleation sites on the wall and grow to a size at which the buoyancy force overcomes the surface tension forces acting at the line of attachment of the bubble to the wall. The bubbles then break away and rise through the liquid.

In a steady state process, the vertically-upward heat flux, $\dot{q}$, should be the same at all elevations above the wall. Close to the wall the situation is complex for several mechanisms increase the heat flux above that for pure conduction through the liquid. First the upward flux of vapor away from the wall must be balanced by an equal downward mass flux of liquid and this brings cooler liquid into closer proximity to the wall. Second, the formation and movement of the bubbles enhances mixing in the liquid near the wall and thus increases heat transfer from the wall to the liquid. Third, the flux of heat to provide the latent heat of vaporization that supplies vapor to the bubbles increases the total heat flux. While a bubble is still attached to the wall, vapor may be formed at the surface of the bubble closest to the wall and then condense on the surface furthest from the wall thus creating a heat pipe effect. This last mode of heat transfer is sketched in figure 2 and requires the presence of a thin layer of liquid under the bubble known as the *microlayer*.

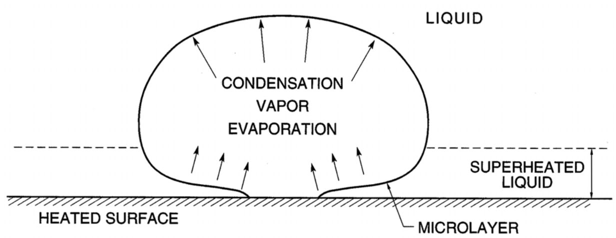

Figure 2: Sketch of nucleate boiling bubble with microlayer.

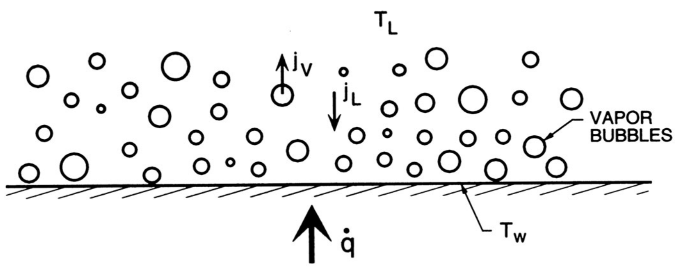

Figure 3: Nucleate boiling.

At distances further from the wall (figure 3) the dominant component of $\dot{q}$ is simply the enthalpy flux difference between the upward flux of vapor and the downward flux of liquid. Assuming this enthalpy difference is given approximately by the latent heat, $\mathcal{L}$, it follows that the upward volume flux of vapor, j_V, is given by $\dot{q}/\rho_V\mathcal{L}$, where ρ_V is the saturated vapor density at the prevailing pressure. Since mass must be conserved the downward mass flux of liquid must be equal to the upward mass flux of vapor and it follows that the downward liquid volume flux should be $\dot{q}/\rho_L\mathcal{L}$, where ρ_L is the saturated liquid density at the prevailing pressure.

To complete the analysis, estimates are needed for the number of nucleation sites per unit area of the wall ($N^*\ m^{-2}$), the frequency (f) with which bubbles leave each site and the equivalent volumetric radius (R) upon departure. Given the upward velocity of the bubbles (u_V) this allows evaluation of the volume fraction and volume flux of vapor bubbles from:

$$\alpha = \frac{4\pi R^3 N^* f}{3u_V} \quad ; \quad j_V = \frac{4}{3}\pi R^3 N^* f \tag{1}$$

and it then follows that

$$\dot{q} = \frac{4}{3}\pi R^3 N^* f \rho_V \mathcal{L} \tag{2}$$

As ΔT is increased both the site density N^* and the bubble frequency f increase until, at a certain critical heat flux, $\dot{q}_c$, a complete film of vapor blankets the wall. This is termed *boiling crisis* and the heat flux at which it occurs is termed the *critical heat flux (CHF)* . Normally one is concerned with systems in which the heat flux rather than the wall temperature is controlled, and, because the vapor film provides a substantial barrier to heat transfer, such systems experience a large increase in the wall temperature when the boiling crisis occurs. This development is sketched in figure 1. The large increase in wall temperature can be very hazardous and it is therefore important to be able to predict the boiling crisis and the heat flux at which this occurs. There are a number of detailed analyses of the boiling crisis and for such detail the reader is referred to Zuber *et al.* (1959, 1961), Rohsenow and Hartnett (1973), Hsu and Graham (1976), Whalley (1987) or Collier and Thome (1994). This important fundamental process is discussed below in section 6.5.4.