6.5.3 Nucleate Boiling

As equation 2, section 6.5.2, illustrates, quantitative understanding and prediction of nucleate boiling requires detailed information on the quantities N^*, f, R and u_V and thus knowledge not only of the number of nucleation sites per unit area, but also of the cyclic sequence of events as each bubble grows and detaches from a particular site. Though detailed discussion of the nucleation sites is beyond the scope of this book, it is well-established that increasing ΔT activates increasingly smaller (and therefore more numerous) sites (Griffith and Wallis 1960) so that N^* increases rapidly with ΔT. The cycle of events at each nucleation site as bubbles are created, grow and detach is termed the *ebullition cycle* and consists of

1. a period of bubble growth during which the bubble growth rate is directly related to the rate of heat supply to each site, $\dot{q}/N^*$. In the absence of inertial effects and assuming that all this heat is used for evaporation (in a more precise analysis some fraction is used to heat the liquid), the bubble growth rate is then given by

$$\frac{dR}{dt} = CR^{-2}\frac{\dot{q}}{4\pi\rho_V\mathcal{L}N^*} \tag{1}$$

   where C is some constant that will be influenced by complicating factors such as the geometry of the bubble attachment to the wall and the magnitude of the temperature gradient in the liquid normal to the wall (see, for example, Hsu and Graham 1976).

2. the moment of detachment when the upward buoyancy forces exceed the surface tension forces at the bubble-wall contact line. This leads to a bubble size, R_d, upon detachment given qualitatively by

$$R_d = C^*\left[\frac{\mathcal{S}}{g(\rho_L-\rho_V)}\right]^{\frac{1}{2}} \tag{2}$$

   where the constant C^* will depend on surface properties such as the contact angle but is of the order of 0.005 (Fritz 1935). With the growth rate from the growth phase analysis this fixes the time for growth.

3. the waiting period during which the local cooling of the wall in the vicinity of the nucleation site is diminished by conduction within the wall surface and after which the growth of another bubble is initiated.

Obviously the sum of the growth time and the waiting period leads to the bubble frequency, f. In addition, the rate of rise of the bubbles, u_V, must be estimated using the methods such as those described in Brennen (2005); note that the downward flow of liquid must also be taken into account in evaluating u_V.

These are the basic elements involved in characterizing nucleate boiling though there are many details for which the reader is referred to the texts by Rohsenow and Hartnett (1973), Hsu and Graham (1976), Whalley (1987) or Collier and Thome (1994). Note that the concepts involved in the analysis of nucleate boiling on an inclined or vertical surface do not differ greatly. The addition of an imposed flow velocity parallel to the wall will alter some details since, for example, the analysis of the conditions governing bubble detachment must include consideration of the resulting drag on the bubble.