agitated fermenter (1500 m^3) ever built (by ICI) is an airlift design for the production of single-cell protein. With very large fermenters (> 200 m^3) the use of nonmechanically agitated designs is preferred, as high oxygen transfer rates and better cooling can be attained. With an airlift design the interchange of material between fluid elements is small, so the transient time to circulate from the bottom of the draft tube to the top and back again is important. In the ICI design, multiple injection points for the substrate were used to prevent the cells from becoming substrate starved during circulation. The addition of mechanical stirring to a loop reactor increases flexibility (the operating range).

Although we focus our attention on agitated tanks, the reader should realize that most fermentations (in terms of total volume) are conducted in nonstirred and nonaerated vessels. Such vessels are used often in food fermentations, such as for beer, wine, and dairy products (e.g., cheese). In anaerobic fermentations, gas evolution by the fermenting organisms can provide some mixing, but gases are not normally sparged into the vessel. However, agitated and/or aerated vessels are used on a wider variety of fermentations (in terms of number of processes), are more difficult to scale, and are more likely to be chosen for the production of new products.

10.2.3. Some Considerations in Aeration, Agitation, and Heat Transfer

The basic equations describing oxygen transfer, carbon dioxide evolution, and heat generation by microbial growth are given in Chapter 6. For industrial-scale fermenters, oxygen supply and heat removal are the key design limitations.

The severity of the oxygen requirements depends on the choice of organism. Equation 6.24 can be rewritten as

$$\mathrm{OUR} = X \cdot q_{\mathrm{O}_2} = k_L a(C^* - C_L) \tag{10.1}$$

where q_{O_2} is the specific uptake rate of oxygen (mol O_2/g-h). Typical values of q_{O_2} are given in Table 10.1. The value of q_{O_2} (or OUR or oxygen uptake rate) is the demand side of the equation; typical requirements in large-scale systems are 40 to 200 mmol O_2/l-h, with most systems in the 40- to 60-mmol O_2/l-h range.

On the supply side, the critical parameter is $k_L a$ (h^{-1}), the volumetric transfer coefficient. A wide range of equations has been suggested for the estimation of $k_L a$. References at the end of this chapter detail some of these correlations. A typical correlation is of the form

$$k_L a = k(P_g/V_R)^{0.4}(v_S)^{0.5}(N)^{0.5} \tag{10.2a}$$

where k is an empirical constant, P_g is the power requirement in an aerated (gassed) bioreactor, V_R is bioreactor volume, v_S is the superficial gas exit speed, and N is the rotational speed of the agitator. With equations of the form of 10.2a, all the parameters must be in the units used in fitting the equation to a data set. An example of one of the original correlations of this type (when partial pressures are used) is

$$k_L a\ (\mathrm{mmol/l\text{-}h\text{-}atm}) = 0.6[P_g/V_R(hp/1000\ \mathrm{l})]^{0.4}[v_S(\mathrm{cm/min})\ ]^{0.5}[N(\mathrm{rpm})]^{0.5} \tag{10.2b}$$