Growth rate varies nearly linearly with the oxygen transfer rate under oxygen-transfer limitations. Among the various methods used to overcome DO limitations are the use of oxygen-enriched air or pure oxygen and operation under high atmospheric pressure (2 to 3 atm). Oxygen transfer has a big impact on reactor design (see Chapter 10).

The redox potential is an important parameter that affects the rate and extent of many oxidative–reductive reactions. In a fermentation medium, the redox potential is a complex function of DO, pH, and other ion concentrations, such as reducing and oxidizing agents. The electrochemical potential of a fermentation medium can be expressed by the following equation:

$$E_h = E_0' + \frac{2.3RT}{4F}\log P_{O_2} + 2.3\frac{RT}{F}\log\ (H^+) \tag{6.25}$$

where the electrochemical potential is measured in millivolts by a pH/voltmeter and P_{O_2} is in atmospheres.

The redox potential of a fermentation media can be reduced by passing nitrogen gas or by the addition of reducing agents such as cysteine HCl or Na_2S. Oxygen gas can be passed or some oxidizing agents can be added to the fermentation media to increase the redox potential.

Dissolved carbon dioxide (DCO_2) concentration may have a profound effect on performance of organisms. Very high DCO_2 concentrations may be toxic to some cells. On the other hand, cells require a certain DCO_2 level for proper metabolic functions. The dissolved carbon dioxide concentration can be controlled by changing the CO_2 content of the air supply and the agitation speed.

The ionic strength of the fermentation media affects the transport of certain nutrients in and out of cells, the metabolic functions of cells, and the solubility of certain nutrients, such as dissolved oxygen. The ionic strength is given by the following equation:

$$I = \frac{1}{2}\Sigma C_i Z_i^2 \tag{6.26}$$

where C is the concentration of an ion, Z_i is its charge, and I is the ionic strength of the medium.

High substrate concentrations that are significantly above stoichiometric requirements are inhibitory to cellular functions. Inhibitory levels of substrates vary depending on the type of cells and substrate. Glucose may be inhibitory at concentrations above 200 g/l (e.g., ethanol fermentation by yeast), probably due to a reduction in water activity. Certain salts such as NaCl may be inhibitory at concentrations above 40 g/l due to high osmotic pressure. Some refractory compounds, such as phenol, toluene, and methanol, are inhibitory at much lower concentrations (e.g., 1 g/l). Typical maximum noninhibitory concentrations of some nutrients are glucose, 100 g/l; ethanol, 50 g/l for yeast, much less for most organisms; ammonium, 5 g/l; phosphate, 10 g/l; and nitrate, 5 g/l. Substrate inhibition can be overcome by intermittent addition of the substrate to the medium.

6.2.4. Heat Generation by Microbial Growth

About 40% to 50% of the energy stored in a carbon and energy source is converted to biological energy (ATP) during aerobic metabolism, and the rest of the energy is released as heat. For actively growing cells, the maintenance requirement is low, and heat evolution is directly related to growth.