6.2.3. How Environmental Conditions Affect Growth Kinetics

The patterns of microbial growth and product formation we have just discussed are influenced by environmental conditions such as temperature, pH, and dissolved-oxygen concentration.

Temperature is an important factor affecting the performance of cells. According to their temperature optima, organisms can be classified in three groups: (1) psychrophiles ($T_{opt} < 20°C$), (2) mesophiles (T_{opt} = from 20° to 50°C), and (3) thermophiles ($T_{opt} > 50°C$). As the temperature is increased toward optimal growth temperature, the growth rate approximately doubles for every 10°C increase in temperature. Above the optimal temperature range, the growth rate decreases and thermal death may occur. The net specific replication rate can be expressed by the following equation for temperature above optimal level:

$$\frac{dN}{dt} = (\mu'_R - k'_d)N \tag{6.19}$$

At high temperatures, the thermal death rate exceeds the growth rate, which causes a net decrease in the concentration of viable cells.

Both μ'_R and k'_d vary with temperature according to the Arrhenius equation:

$$\mu'_R = Ae^{-E_a/RT}, \quad k'_d = A'e^{-E_d/RT} \tag{6.20}$$

where E_a and E_d are activation energies for growth and thermal death. The activation energy for growth is typically 10 to 20 kcal/mol, and for thermal death 60 to 80 kcal/mol. That is, thermal death is more sensitive to temperature changes than microbial growth.

Temperature also affects product formation. However, the temperature optimum for growth and product formation may be different. The yield coefficient is also affected by temperature. In some cases, such as single-cell protein production, temperature optimization to maximize the yield coefficient ($Y_{X/S}$) is critical. When temperature is increased above the optimum temperature, the maintenance requirements of cells increase. That is, the maintenance coefficient (see eq. 6.15) increases with increasing temperature with an activation energy of 15 to 20 kcal/mol, resulting in a decrease in the yield coefficient.

Temperature also may affect the rate-limiting step in a fermentation process. At high temperatures, the rate of bioreaction might become higher than the diffusion rate, and diffusion would then become the rate-limiting step (for example, in an immobilized cell system). The activation energy of molecular diffusion is about 6 kcal/mol. The activation energy for most bioreactions is more than 10 kcal/mol, so diffusional limitations must be carefully considered at high temperatures. Figure 6.7 depicts a typical variation of growth rate with temperature.

Hydrogen-ion concentration (pH) affects the activity of enzymes and therefore the microbial growth rate. The optimal pH for growth may be different from that for product formation. Generally, the acceptable pH range varies about the optimum by ±1 to 2 pH units. Different organisms have different pH optima: the pH optimum for many bacteria ranges from pH = 3 to 8; for yeast, pH = 3 to 6; for molds, pH = 3 to 7; for plant cells, pH = 5 to 6; and for animal cells, pH = 6.5 to 7.5. Many organisms have mechanisms to