For competitive substrate inhibition: $$\mu_g = \frac{\mu_m S}{K_s\left(1+\frac{S}{K_I}\right)+S} \quad (6.41)$$

Note that eq. 6.41 differs from 6.39 and 6.40, and K_I in 6.40 and 6.41 differ. Substrate inhibition may be alleviated by slow, intermittent addition of the substrate to the growth medium.

2. *Product inhibition:* High concentrations of product can be inhibitory for microbial growth. Product inhibition may be competitive or noncompetitive, and in some cases when the underlying mechanism is not known, the inhibited growth rate is approximated to exponential or linear decay expressions.

Important examples of the product inhibition rate expression are as follows:

Competitive product inhibition: $$\mu_g = \frac{\mu_m S}{K_s\left(1+\frac{P}{K_p}\right)+S} \quad (6.42)$$

Noncompetitive product inhibition: $$\mu_g = \frac{\mu_m}{\left(1+\frac{K_s}{S}\right)\left(1+\frac{P}{K_p}\right)} \quad (6.43)$$

Ethanol fermentation from glucose by yeasts is a good example of noncompetitive product inhibition, and ethanol is the inhibitor at concentrations above about 5%. Other rate expressions used for ethanol inhibition are

$$\mu_g = \frac{\mu_m}{\left(1+\frac{K_s}{S}\right)}\left(1-\frac{P}{P_m}\right)^n \quad (6.44)$$

where P_m is the product concentration at which growth stops, or

$$\mu_g = \frac{\mu_m}{\left(1+\frac{K_s}{S}\right)} e^{-P/K_p} \quad (6.45)$$

where K_p is the product inhibition constant.

3. *Inhibition by toxic compounds:* The following rate expressions are used for competitive, noncompetitive, and uncompetitive inhibition of growth in analogy to enzyme inhibition.

Competitive inhibition: $$\mu_g = \frac{\mu_m S}{K_s\left(1+\frac{I}{K_I}\right)+S} \quad (6.46)$$

Noncompetitive inhibition: $$\mu_g = \frac{\mu_m}{\left(1+\frac{K_s}{S}\right)\left(1+\frac{I}{K_I}\right)} \quad (6.47)$$