properties among individuals in a population. With a narrow distribution, cell death will occur nearly simultaneously; with a broad distribution, a subfraction of the population may survive for an extended period. It is this subfraction that would dominate the reestablishment of a culture from inoculum derived from stationary or death-phase cultures. Thus, using an old inoculum may select for variants of the original strain having altered metabolic capabilities.

To better describe growth kinetics, we define some stoichiometrically related parameters. Yield coefficients are defined based on the amount of consumption of another material. For example, the growth yield in a fermentation is

$$Y_{X/S} \equiv -\frac{\Delta X}{\Delta S} \tag{6.11}$$

At the end of the batch growth period, we have an *apparent growth yield* (or observed growth yield). Because culture conditions can alter patterns of substrate utilization, the apparent growth yield is not a true constant. For example, with a compound (such as glucose) that is both a carbon and energy source, substrate may be consumed as:

$$\Delta S = \Delta S_{\substack{\text{assimilation}\\ \text{into biomass}}} + \Delta S_{\substack{\text{assimilated}\\ \text{into an}\\ \text{extracellular}\\ \text{product}}} + \Delta S_{\text{growth energy}} + \Delta S_{\substack{\text{maintenance}\\ \text{energy}}} \tag{6.12}$$

In the section on continuous culture, we will differentiate between the true growth yield (which is constant) and the apparent yield. Yield coefficients based on other substrates or product formation may be defined; for example,

$$Y_{X/O_2} = -\frac{\Delta X}{\Delta O_2} \tag{6.13}$$

$$Y_{P/S} = -\frac{\Delta P}{\Delta S} \tag{6.14}$$

For organisms growing aerobically on glucose, $Y_{X/S}$ is typically 0.4 to 0.6 g/g for most yeast and bacteria, while Y_{X/O_2} is 0.9 to 1.4 g/g. Anaerobic growth is less efficient, and the yield coefficient is reduced substantially (see Fig. 6.5). With substrates that are more or less reduced than glucose, the value of the apparent yield coefficient will change. For methane, $Y_{X/S}$ would assume values of 0.6 to 1.0 g/g, with the corresponding Y_{X/O_2} decreasing to about 0.2 g/g. In most cases the yield of biomass on a carbon-energy source is 1.0 ± 0.4 g biomass per g of carbon consumed. Table 6.1 lists some examples of $Y_{X/S}$ and Y_{X/O_2} for a variety of substrates and organisms.

A *maintenance coefficient* is used to describe the specific rate of substrate uptake for cellular maintenance, or

$$m \equiv -\frac{[dS/dt]_m}{X} \tag{6.15}$$

However, during the stationary phase where little external substrate is available, endogeneous metabolism of biomass components is used for maintenance energy.