$$NO_2 + \frac{1}{2}O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^- \tag{16.50b}$$

Overall,

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \tag{16.51}$$

Both of the aforementioned organisms fix carbon dioxide to be used for biosynthesis. Aerobic nitrification can take place during BOD removal in the presence of these organisms and increases the oxygen requirements in aerobic treatment.

These reactions are energy yielding, and the first step (eq. 16.50a) is the rate-limiting one. Nitrification processes can be accomplished in a single stage with BOD removal or as a two-stage system with separate BOD removal and nitrification units. The choice between the one-stage and two-stage processes typically depends on the ratio of carbon to nitrogen in the feed stream. Typically this ratio is expressed as BOD_5/TKN. The growth yield of nitrifying bacteria is low (0.2 g dry wt per g N) and the fraction of the population that is nitrifying bacteria can be low. For example, at $BOD_5/TKN = 10$ the fraction of nitrifying bacteria is 0.02; at $BOD_5/TKN = 0.5$ the fraction of nitrifying bacteria rises to 0.35. For a single-stage unit with combined BOD removal and nitrification the BOD_5/TKN ratio should be greater than 5. When it is less than 3, the two-stage process is preferred.

Nitrification is best accomplished with suspended cells, typically using a modification of the activated-sludge process. However, fixed-film processes that are well aerated can yield nitrification efficiencies over 90%. In either system DO levels should be high (> 2 mg/l), and slightly alkaline solutions (7.5–8.5) at 20° to 30°C work best.

Under anaerobic conditions, some bacteria utilize nitrate as the final electron acceptor instead of oxygen. This process is known as denitrification. Two types of nitrate reduction are possible: assimilatory and dissimilatory reduction. In assimilatory reduction, nitrate is reduced to ammonia and is incorporated into cell biomass. However, in dissimilatory reduction, nitrate is reduced to nitrite and further to elemental nitrogen. An external carbon source is needed; this source must be inexpensive (e.g., waste starch, methanol, or molasses).

Assimilatory reduction:

$$NO_3^- + H_2O \longrightarrow NH_3 \tag{16.52}$$

Dissimilatory reduction:

$$NO_3^- + \text{C compound} \longrightarrow NO_2^- + CO_2 + \text{cells} \tag{16.53}$$

$$NO_2^- + \text{C compound} \longrightarrow N_2 + CO_2 + \text{cells} \tag{16.54}$$

Using an average biomass composition of $C_5H_7NO_2$ and assuming that methanol is used as the carbon source, the overall balance for denitrification can be written as

$$NO_3^- + 1.08\ CH_3OH + H^+ \longrightarrow 0.065\ C_5H_7NO_2 + 0.47\ N_2 + 0.76\ CO_2 + 2.44\ H_2O \tag{16.55}$$

Clearly, equations such as 16.55 can be used to predict the amount of carbon source (e.g., methanol) required to remove a known amount of NO_3^-. A number of microbes can