act as denitrifiers; among these are species of the genera *Pseudomonas, Acaligenes, Arthobacter,* and *Corynebacter.* Such bacteria grow slowly with $\mu_g = 0.5\ d^{-1}$ and with a yield coefficient of 0.8 g biomass per g nitrogen removed. Saturation constants are low (e.g., 0.1 mg/l < K_5 < 1 mg/l) for both nitrification and denitrification, so these reactions can be approximated as zero order for nitrogen concentrations above about 2 mg/l.

Activated-sludge or packed-bed biofilm type reactors may be used for anaerobic denitrification. Upflow packed-bed reactors utilizing biofilms on porous support material are reported to result in high nitrate removal rates.

A typical two-stage nitrification/denitrification process is depicted in Figure 16.11. Optimal pH and temperature values for denitrification are pH = 6.5–7 and T = 20°–30°C.

Phosphate removal from waste waters by biological means can be realized either by assimilation or by "luxury" phosphate uptake. Assimilation of phosphate occurs in all aerobic/anaerobic processes since nearly 3% of cell mass is made of phosphorus. Luxury phosphate uptake is accomplished by organisms belonging to the genera *Acinetobacter,* among which *Acinetobacter calcoaceticus* is the most widely known. *Acinetobacter* species utilize carbohydrates as carbon and energy source by the Entner–Doudoroff pathway. Those organisms utilize acetate and fatty acids under anaerobic conditions to synthesize polyhydroxybutyrate (PHB). Energy required for PHB synthesis is obtained from ATP molecules generated by breakdown of polyphosphates. Under aerobic conditions in the absence of carbon source, the organisms utilize PHB molecules as carbon/energy source to synthesize polyphosphates and store them in form of polyphosphate granules inside the cell.

Aerobic polyphosphate synthesis:

$$(PO_4)_n + ATP \longrightarrow (PO_4)_{n+1} + ADP \tag{16.56}$$

Anaerobic polyphosphate depolymerization:

$$(PO_4)_n + H_2O \longrightarrow (PO_4)_{n-1} + H_2PO_4^{-1} \tag{16.57}$$

Consequently, the organisms remove phosphate from liquid media to synthesize and store polyphosphates under aerobic conditions and release phosphate into the media under anaerobic/anoxic conditions. *Acinetobacter* species can store polyphosphates up to 30% of their dry weight.

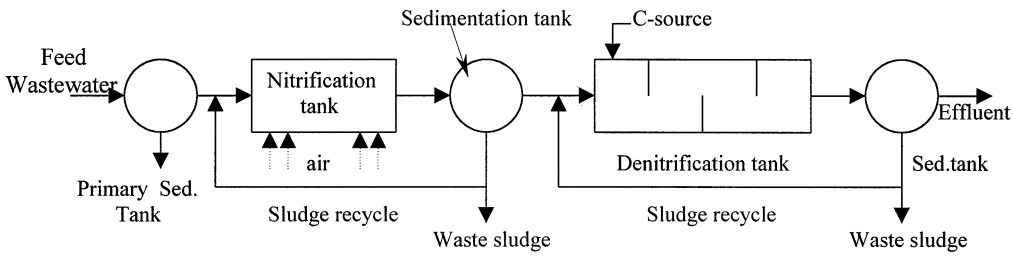

Figure 16.11 A schematic of the two-stage nitrification–denitrification process.