

form of calcium phosphate. The effluent water stream would contain less than 1.5 mg/l phosphate in a well-operating PhoStrip process.

Combined nitrogen and phosphate removal processes employ combinations of anaerobic, anoxic, and aerobic zones in different orders which accomplish simultaneous BOD removal also. The most commonly used processes for this purpose are the A<sup>2</sup>/O and the five-stage Bardenpho processes. Among other processes are the UCT (The University of CapeTown) and the VIP (Virginia Initiative Plant) processes.

The A<sup>2</sup>/O process includes an anoxic zone for denitrification in addition to A/O process (Fig. 16.13). Hydraulic residence times in anaerobic and anoxic zones are less than 1.5 h, and in the aerobic zone 4–6 h. The effluent of the aerobic stage is recycled back to the anoxic zone for denitrification purposes. Phosphate release takes place in the anaerobic zone. Denitrification and BOD removal are the major functions of the anoxic zone. Phosphate removal in the form of polyphosphates, nitrification, and some BOD removal take place in aerobic zone. Phosphate is removed from the system in form of waste sludge; nitrogen is released in form of N<sub>2</sub> (gas); and BOD is converted to CO<sub>2</sub> and H<sub>2</sub>O.

The five-stage Bardenpho process includes two additional anoxic and aerobic zones as compared to the A<sup>2</sup>/O process (Fig. 16.13). This process is known as the A<sup>2</sup>/O/A/O process. The effluent of the aerobic zone is partly recycled back to the anoxic zone for denitrification purposes. The last two zones are for additional denitrification and polyphosphate removal to further reduce nitrate and phosphate levels in the effluent. Hydraulic residence times in anaerobic and anoxic zones are less than 4 h and in the first aerobic zone 4–12 h.

The UCT and VIP processes employ similar zones and recycle schemes in different orders, resulting in low nitrogen, phosphate, and BOD levels in the effluent.

In some cases sulfur removal from waste water is needed. Elemental sulfur in waste water can be oxidized to sulfate by *Thiobacillus* species. Sulfate can be further reduced to sulfides by anaerobic sulfate-reducing bacteria, such as *Desulfovibrio*, and sulfides can be precipitated out of waste water in the presence of certain metal ions, such as Fe<sup>2+</sup>, Zn<sup>2+</sup>, and Pb<sup>2+</sup>. Sulfates can also be precipitated with the addition of limestone (CaCO<sub>3</sub>) and Ca(OH)<sub>2</sub> and can be filtered out of waste water.

#### 16.6.4 Conversion of Waste Water to Useful Products

Some waste materials containing starch and cellulose or other easily utilizable carbonaceous compounds can easily be converted to useful products such as high-protein feedstuff or single-cell protein (SCP), ethanol, organic acids (acetic, butyric, propionic), methane, and methanol. Agricultural wastes, waste paper, and waste wood constitute major cellulosic wastes. Major starch-containing wastes are some agricultural wastes (wheat, corn, rice, potato), some domestic solid wastes (vegetable/fruit), and some industrial wastes (food industry).

Cellulosic and starch-containing wastes are first hydrolyzed into sugar molecules, which are further converted to high-protein feedstuff (SCP) under aerobic conditions or ethanol/organic acids under anaerobic conditions. While many organisms can be used, yeasts, particularly *Saccharomyces*, are well suited to protein production, since they already have FDA approval for use in foods. The waste must be free of toxic contaminants.