4.3.1 Conditions for denitrification

The necessary conditions for the denitrification process to develop in an activated sludge process can be summarised as:

(1) Presence of a facultative bacterial mass;
(2) Presence of nitrate and absence of DO in the mixed liquor (i.e. an anoxic environment);
(3) Suitable environmental conditions for bacterial growth;
(4) Presence of an electron donor (nitrate reductor).

1) Presence of a facultative bacterial mass

Facultative bacteria are characterised by the fact that they can use both oxygen and nitrate as an oxidant for organic matter. A large fraction of the bacterial mass that develops in an activated sludge process is facultative. It has been established experimentally that activated sludge generated under aerobic conditions will use nitrate immediately when it is placed in an anoxic environment (Heidman, 1979). The rate of nitrate utilisation continues without change, as long as the anoxic condition and the availability of organic matter persist. However, anoxic oxidation of organic matter occurs at a lower rate than aerobic oxidation under otherwise comparable conditions.

2) Presence of nitrate and absence of dissolved oxygen in the mixed liquor

The presence of dissolved oxygen in mixed liquor inhibits the development of denitrification. It is difficult to quantify this influence because concentration gradients of dissolved oxygen will develop in the flocs so that the micro-environment in a floc may be very different from the bulk of the liquid phase (see also Fig. 4.7). In effect, efficient (though irregular) nitrate removal has been observed in aerobic activated sludge processes (Pasveer, 1965 and Maatsche, 1971), mainly those of the carrousel type. This can be explained only if it is accepted that anoxic micro regions are formed within the flocs.

In general it has been observed that a dissolved oxygen concentration of more than 0.2 to 0.5 mg $O_2.l^{-1}$ reduces the rate of denitrification significantly. In general, nitrogen in waste water is present in the form of ammonium or organic nitrogen. Thus, the necessity to have nitrate present in an anoxic environment normally implies the need for nitrification as a prerequisite for denitrification. The magnitude of the nitrate concentration has little influence on the denitrification rate: when the nitrate concentration is higher than 0.5 mg $N.l^{-1}$, the denitrification rate will be independent of the nitrate concentration.

3) Suitable conditions for bacterial growth

Temperature and mixed liquor pH are among the most important environmental conditions for bacterial growth. The denitrification rate increases with temperature until an optimum is reached at 40˚C. At higher temperatures the denitrification rate is quickly reduced. The influence of temperature on denitrification kinetics is discussed in more detail in Section 4.3.3.

Concerning the influence of pH, it has been established that there is a maximum denitrification rate for the pH range of 7 to 8.5, whereas for pH values smaller than 6 and larger than 8.5 there is a sharp decrease in the denitrification activity. It is very unlikely that a $pH > 8.5$ is established in an activated sludge process. On the other hand, a low pH value like $pH < 6$ is not only inhibitory for denitrification, but also for nitrification, rendering nitrogen removal practically impossible. For municipal waste water, in order to maintain the pH in the optimal range of $7 < pH < 8$, a minimum influent alkalinity of 35 ppm $CaCO_3$ is required

Another environmental requirement for efficient denitrification is that toxic compounds must be either absent or present at a low concentration. There is little information about the influence of specific compounds on the denitrification rate, except from the influence of the hydrogen ion mentioned above (pH). In general, it is observed that nitrifiers are much more sensitive to the presence of toxic materials than the heterotrophic bacteria. Hence, in general, if nitrification is possible in an activated sludge process, so is denitrification.

4) Presence of an electron donor

The presence of an electron donor is essential for the reduction of nitrate. The electron donor in the denitrification process is biodegradable organic matter. In accordance with the nature of organic matter two different types of denitrifying systems can be defined:

- Systems with an external carbon source. In these systems the organic matter is added to the mixed liquor after nitrification is complete. Methanol is among the most frequently used organic compounds for denitrification but other materials (ethanol, acetone and acetic acid) have been used as well;
- Systems with an internal carbon source. In this case the influent organic matter is used for the reduction of nitrate. Alternatively, the bacterial mass generated in the activated sludge process may also be used (endogenous respiration).

The choice of the type of organic matter to be used is of fundamental importance for the configuration of the denitrification system. The relationship between the source of organic matter and the system configuration will be discussed in the next section.