4.2.4 Nitrification in systems with non aerated zones

In activated sludge processes designed for biological nitrogen removal, part of the reactor volume is not aerated in order to allow for denitrification. The presence of these anoxic zones influences the nitrification efficiency, because the nitrifiers can only grow in an aerobic environment. If it is assumed that the decay of the nitrifiers is not affected by the presence or absence of dissolved oxygen, the effect of anoxic zones on nitrification can be evaluated as follows: in a steady state system the total nitrifier mass MX_n has a constant value and can be expressed as:

$$dMX_n/dt = 0 = (dMX_n/dt)_g + (dMX_n/dt)_d + (dMX_n/dt)_e \quad (4.35)$$

Indices g, d and e refer to growth, decay and excess sludge discharge respectively. Since the nitrifiers only grow in an aerobic environment one has:

$$dMX_n = (1\text{-}f_x)\cdot V_r\cdot(dX_n/dt)_c = (1\text{-}f_x)\cdot V_r\cdot\mu_m\cdot X_n \quad (4.36)$$

f_x = anoxic sludge mass fraction
V_r = biological reactor volume (aerobic plus anoxic zones)

By substituting Eq.(4.36) in Eq.(4.35) and using Eqs.(4.28 and 4.29) one has:

$$N_a = K_n\cdot(b_n + 1/R_s)/[(1\text{-}f_x)\cdot\mu_m - b_n - 1/R_s] \quad (4.37)$$

The expression for the residual ammonium concentration in a process containing anoxic and aerobic zones (Eq. 4.37) is very similar to the one derived by Downing for the completely aerobic process (Eq. 4.30). When the two equations are compared, it can be noted that the presence of the anoxic sludge mass fraction f_x has the effect of a reduction of the μ_m value by a factor $(1\text{-}f_x)$ i.e.:

$$\mu'_m = (1\text{-}f_x)\cdot\mu_m \quad (4.38)$$

Where μ'_m = apparent maximum nitrifier growth rate in systems with non aerated zones (d^{-1})

Fig. 4.9 shows the residual ammonium concentration as a function of the anoxic sludge mass fraction for three different μ_m values: 0.2 d^{-1} (low), 0.4 d^{-1} (normal) and 0.8 d^{-1} (high). It can be noted that for each of these cases there is a maximum anoxic sludge mass fraction above which nitrification does not occur. Equation 4.37 can also be written explicitly in terms of the anoxic sludge mass fraction:

$$f_x = 1 - (1 + K_n/N_a)\cdot(b_n + 1/R_s)/\mu_m \quad (4.39)$$

When a certain nitrification efficiency is to be maintained and therefore a maximum residual ammonium concentration is specified, there is a consequential maximum to the sludge mass fraction that can be placed in an anoxic environment. This maximum anoxic mass fraction f_m can be calculated from Eq. 4.39 by substituting N_a with the specified effluent residual ammonium concentration N_{ad}:

$$f_m = 1 - (1 + K_n/N_{ad})\cdot(b_n + 1/R_s)/\mu_m \quad (4.40)$$

The maximum anoxic sludge mass fraction does not only depend on the specified value of the residual ammonium concentration, but also on the sludge age and the kinetic constants for nitrification.

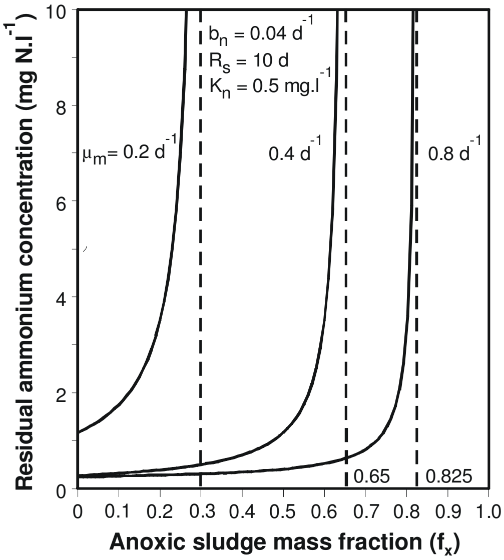

Figure 4.9
Residual ammonium concentration as a function of the anoxic sludge mass fraction for different values of μ_m

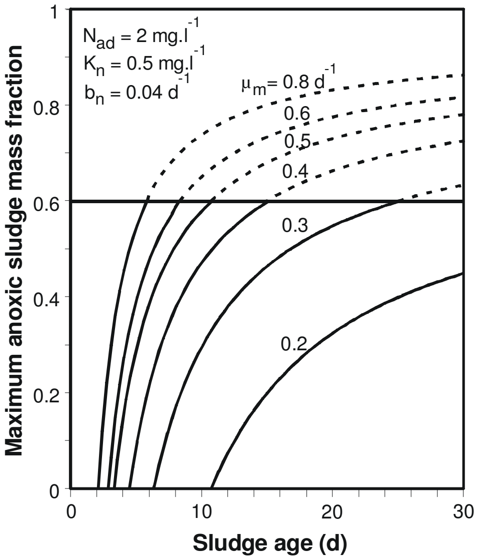

Figure 4.10
Maximum anoxic sludge mass fraction f_m as a function of the sludge age for different values of μ_m

The values of K_n and b_n have relatively little influence on the value of f_m and when no information is available default values may adopted, such as $b_n = 0.04 \cdot (1.03)^{T-20}$ and $K_n = 0.5 \cdot (1.123)^{T-20}$. In contrast, the influence of μ_m on the maximum anoxic sludge mass fraction is considerable. In Fig. 4.10, f_m values are shown plotted as a function of the sludge age for μ_m values between 0.2 and 0.8 d^{-1}.

The numeric value of f_m is of great practical importance: the extent of denitrification tends to increase as the anoxic sludge mass fraction is enlarged. Hence in principle, to maximise the nitrogen removal capacity of a system, the anoxic sludge mass fraction should be maximised. However, apart from the maximum set by the need for efficient nitrification, there are two other factors that may influence the value of f_m: (l) the removal efficiency of organic matter and (2) the sludge settleability.

When the anoxic sludge mass fraction is very large, there is the possibility that the metabolism of organic matter in the process becomes incomplete because the rate of metabolism in an anoxic environment is lower than in an aerobic environment (refer to Section 4.3). In such a case, the organic matter may still be removed efficiently from the liquid phase, but the sludge production will increase, because part of the stored organic matter will not be metabolised but will instead be discharged as excess sludge.

Furthermore in processes with a high anoxic sludge mass fraction, sludge settleability may be poor and development of filamentous or bulking sludge (refer to Chapter 6) may be frequent, possibly because of the presence of non-metabolised organic matter in the sludge. Thus there is an upper limit to the anoxic sludge mass fraction, independent of the maximum value set by the requirements for efficient nitrification.

Presently, there are full-scale plants with an anoxic sludge mass fraction of fifty percent that operate satisfactorily, but there is little information about the possibility to increase the anoxic sludge mass fraction beyond this point. In the Netherlands for example, the anoxic mass fraction in activated sludge system designed for nitrogen removal seldom exceeds forty percent. Based on the results of a pilot plant study (Arkley et al, 1982), the water research commission of South Africa (1984) suggests a maximum value of f_m =0.6. This value is indicated in Fig. 4.10 as well.

There may yet be another limitation to the value of the anoxic sludge mass fraction: as f_m increases, the volume of the aerobic reactors decreases and consequently the OUR increases. Hence, to maintain the flocs in an aerobic environment (i.e. to prevent anoxic conditions **within** the sludge floc), operation at higher bulk dissolved oxygen concentration is required. The higher dissolved oxygen concentration in turn leads to an increased energy requirement for aeration. Due to the increase of aeration costs, an increase of f_m may become unattractive from the point of view of economics.