

### 5.2.3 Optimisation of operational conditions

A design for a waste water treatment plant with bio-P removal is aimed at the production of an effluent free of organic matter, suspended solids and macronutrients. As mentioned above, the simultaneous removal of nitrogen and phosphorus is difficult as the conditions for maximisation of removal of these nutrients are conflicting: for good phosphorus removal a large anaerobic zone is indispensable, but this will limit the size of the anoxic zone and consequently reduces the denitrification capacity.

On the other hand, if both anaerobic and anoxic zones are large, then the aerobic zone will be small and the nitrification process is less efficient (and possibly also the removal efficiency of organic material), apart from the risk of developing sludge bulking (refer to Chapter 6).

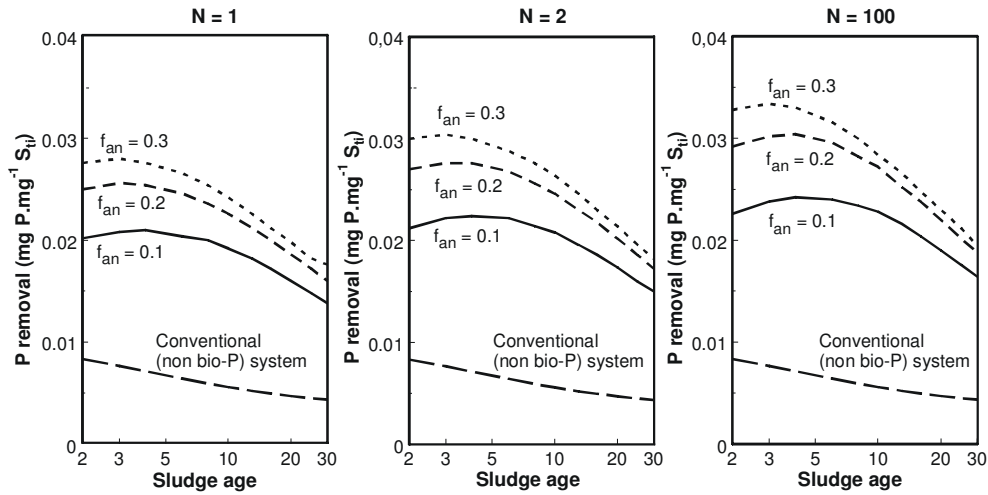
In general the design of an waste water treatment plant is subject to a set of requirements, which will all impose constraints to the design and might even be contradictory. Such priorities depend among other things on the effluent limits set by the authorities but could also be (in descending order of importance):

- Extensive removal of organic biodegradable material and suspended solids;
- Almost complete removal of ammonia and biodegradable organic nitrogen to levels between  $N_{ad} < 1$  to  $2 \text{ mg N.l}^{-1}$  (this demand in general will ensure that organic material and suspended solids removal will also be efficient);
- Low total effluent phosphorus concentration ( $P_e < 1 \text{ mgP.l}^{-1}$ );
- Low total effluent nitrogen concentration, for example  $N_{te} < 10 \text{ mg N.l}^{-1}$ .

The numerical values of the maximum concentrations depend on legislation, available options for reuse and the nature of the receiving water. In the design of a nutrient removal plant the values of the following three parameters have to be defined: (1) sludge age, (2) size of anaerobic-, anoxic- and aerobic sludge mass fractions and (3) the value of the different recirculation factors “a”, “s” and “r”.

#### (1) Sludge age

To minimise the construction- and operational costs, the activated sludge system should be designed and operated at the lowest possible sludge age permitting the production of effluent with the desired quality. Fig. 5.6 shows the biological phosphorus removal in UCT systems as a function of the sludge age and for different sizes of the anaerobic zone ( $f_{an} = 0.1$ ; 0.2 and 0.3). For each case three different configurations of the anaerobic zone were considered, i.e. a single completely mixed reactor ( $N = 1$ ), two completely mixed reactors in series ( $N = 2$ ) and a long series of completely mixed reactors approximating plug flow conditions ( $N = 100$ ). Furthermore it has been assumed in Fig. 5.6 that “r”, the recirculation factor to the anaerobic zone has a value of 1 and that no nitrate is recirculated to the anaerobic zone.



**Figure 5.6 Phosphorus removal (UCT configuration) as function of  $R_s$  for different values of  $f_{an}$  and  $N$  ( $f_{np} = f_{ns} = 0.1$ ;  $f_{sb} = 0.24$ ;  $S_{ti} = 500 \text{ mg.l}^{-1}$  and  $T = 20^\circ\text{C}$ )**

The simulation results show that for all considered design cases the phosphorus removal reaches a maximum at a rather short sludge age:  $R_s = 3$  to 5 days. For shorter sludge ages, due to the low active sludge concentration, the conversion of easily biodegradable material to VFA will be incomplete, resulting in a reduced availability of substrate for the PAO. On the other hand, for sludge ages longer than 3 to 5 days, almost all easily biodegradable material  $S_{bsi}$  will have been converted into VFA, but as the discharge of excess sludge will decrease at higher sludge ages, the removal of phosphorus will be lower as well. The subdivision of the anaerobic zone increases the phosphorus removal capacity, as more organic material will be converted into VFA. However, increasing the number of subdivisions to more than two does not result in a significant increase in phosphorus removal capacity, but will add to the investment costs.

## (2) Division of the sludge mass fractions

For each sludge age, a certain minimum aerobic sludge mass fraction is required to maintain the efficiency of the nitrification process (Eq. 4.40). Thus a maximum  $f_m$  is defined for the sum of the anaerobic- and anoxic mass fractions. In Fig. 5.6 the influence of the size of the anaerobic zone ( $f_{an} = 0.1, 0.2$  and  $0.3$ ) on the phosphorus removal efficiency is indicated.

It can be observed that an increase of the anaerobic fraction results in an increased phosphorus removal capacity. However, the increase of  $f_{an}$  from 0.2 to 0.3 has only a relatively minor effect. On the other hand, a large anaerobic zone will reduce the available size of the anoxic zone and consequently also the denitrification capacity. Apart from a high nitrate concentration in the effluent, this might result in serious operational problems such as denitrification in the clarifier and sludge bulking. For this reason the size of the anaerobic mass fraction  $f_{an}$  is in practice limited to a value between 0.1 and 0.2.

The anoxic zone is often subdivided into two or more parts. This subdivision has two objectives: (1) protection of the anaerobic zone against introduction of nitrate (this is in effect a subdivision of the pre-D reactor as applied in the modified UCT system), and (2) optimisation of the nitrogen removal using pre-D and post-D reactors. It should be remembered that the denitrification capacity is always larger in the pre-D reactor than in a post-D reactor of comparable size.

In Fig. 5.7 the effect of size of the anaerobic mass fraction on the denitrification capacity in a bio-P sludge system is given, both for a pre-D and a Bardenpho configuration. As can be expected, the denitrification capacity decreases rapidly when the anaerobic mass fraction increases (and the anoxic mass fraction decreases as  $f_m$  is limited to a maximum value of  $f_{max} = 0.6$ ).

In the example considered the denitrification capacity in the pre-D configuration is higher than that in the Bardenpho configuration, due to the higher rate of denitrification in the pre-D versus the post-D reactor. However, once again it should be stressed that when complete denitrification is required, operation in a Bardenpho configuration will be necessary. Otherwise part of the nitrate load generated in the aerobic reactor, i.e. the part that is not recycled to the pre-D reactor, will leave with the effluent. Therefore, for complete nitrogen removal the following two requirements should be met: (1) operation in Bardenpho configuration and (2) a combined denitrification capacity  $D_{c1} + D_{c3}$  exceeding the available nitrate  $N_c = N_{av1} + N_{av3}$ .

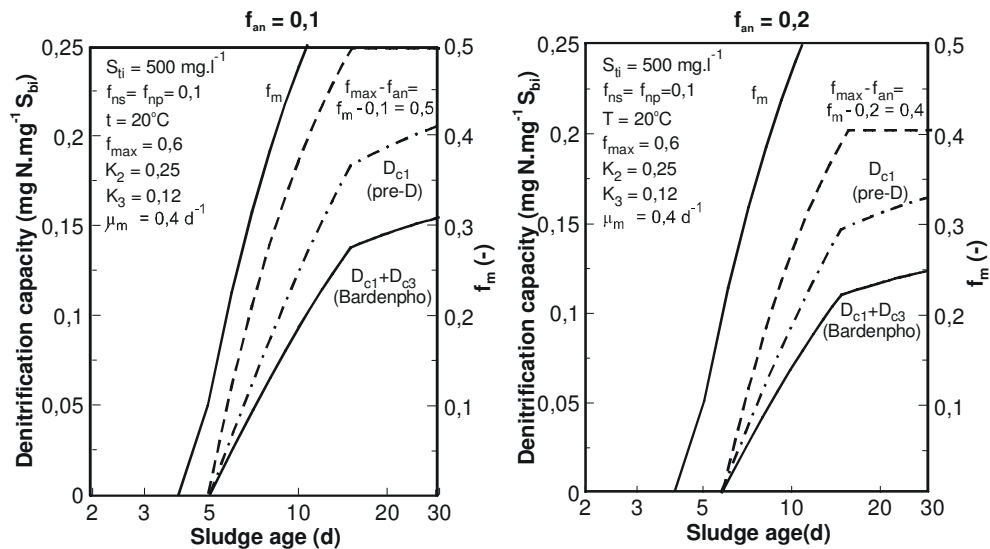


Figure 5.7 Denitrification capacity in bio-P removal systems for different anaerobic mass fractions, in both pre-D configurations (pre-D and A<sup>2</sup>/O) and UCT/modified Bardenpho configurations

### (3) Recirculation factors

The UCT configuration has three internal recirculation flows:

- (1) The return sludge flow “s”;
- (2) The recirculation flow of nitrified mixed liquor from the aerated zone to the pre-D reactor “a”;
- (3) The recirculation flow of denitrified mixed liquor from the pre-D anoxic reactor to the anaerobic zone “r”.

The value of “s”, the return sludge- or sludge recycle factor, is set by the requirements for the proper operation and design of the final settler. The value of the “a” factor is determined by the condition that the nitrate concentration in the pre-D reactor will have to be small, not only to avoid recirculation of nitrate to the anaerobic zone, but also to reduce the risk of sludge bulking.

The value of the “r” factor is in practice about 1. A smaller value permits a high concentration of easily biodegradable organic material in the anaerobic zone, as there is little dilution of the influent with the recirculated mixed liquor. However, at the same time the sludge concentration in the anaerobic reactor will be very low, because the return sludge is also being recycled to the anoxic zone instead of to the anaerobic zone. This means that a large anaerobic volume is required in order to obtain a proper performance.

On the other hand, when the value of the “r” factor is large, the concentration of easily biodegradable organic material  $S_{bs}$  in the anaerobic zone will be low and this will result in a decrease in the amount of phosphate released. Furthermore, if the anaerobic zone is small, part of the easily biodegradable organic material may be carried over to the anoxic zone and will not be available for bio-P removal. The value of “r” = 1 is a compromise between the two unfavourable extremes.