5.1.2 Bio-P removal system configurations

Various system configurations have been developed for biological phosphorus removal, all of which have been extensively applied in practice. The main difference between these systems is the way in which an anaerobic zone is maintained and protected against the introduction of nitrate. In the following sections several system configurations are discussed.

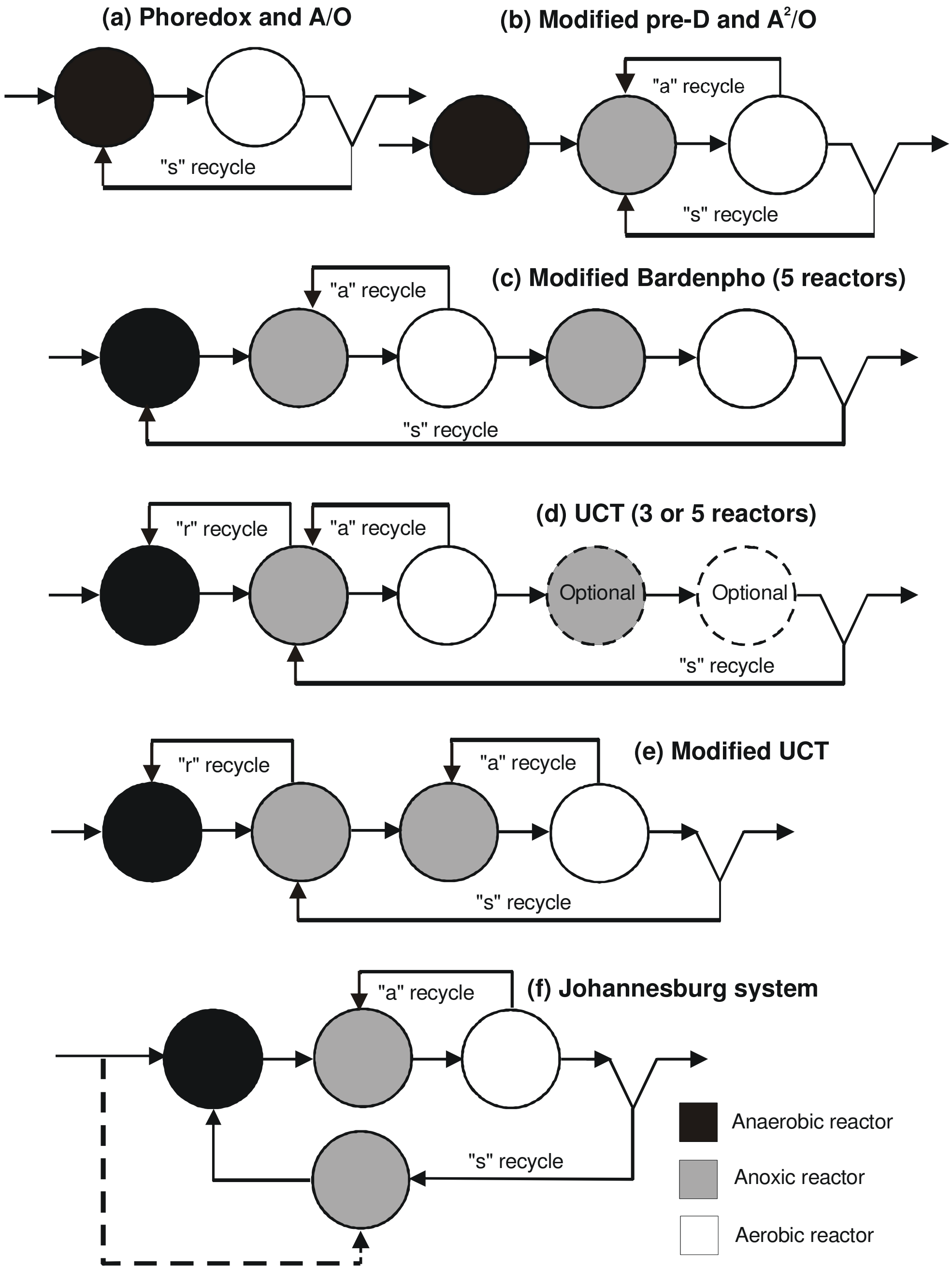

Figure 5.2 System configurations for biological phosphorus removal

(1) Phoredox and A/O configuration:

The Phoredox system proposed by Barnard (1976) is composed of two reactors in series, of which the first (receiving the influent) is anaerobic and the second aerobic. In Fig. 5.2a, a schematic representation of the Phoredox configuration is given. The return sludge flow is recirculated from the settler to the anaerobic reactor. There are no other recirculation streams between the reactors. The Phoredox system is only applicable when nitrogen removal is not required, as it is then not necessary to maintain a high sludge age for nitrification, nor is it required to include an anoxic zone for denitrification. For this reason the system volume is rather compact.

The A/O system (Timmerman, 1976) has the same configuration as the Phoredox system, but due to a compartmentalisation of the anaerobic zone a plug-flow regime is induced, which promotes the conversion of easily biodegradable material to acetate and increases the phosphorus removal capacity. Currently the Phoredox process has only found application in regions with a cold climate, principally in Europe and the US. In regions with temperate and hot climates the applicability is limited, as nitrification cannot completely be prevented, even at low sludge ages. The introduction of nitrate in the anaerobic zone is unavoidable and results in a reduction of the phosphorus removal capacity of the system. Burke et al (1990) demonstrated that it is impossible to prevent the establishment of (partial) nitrification in a pilot scale Phoredox system operated at 20 ^oC and at a sludge age of only three days.

(2) The modified pre-D, A^2/O and Bardenpho configurations:

In the modified pre-D and Bardenpho system (Fig 5.2b and c), an anaerobic zone is added upstream of the pre-D anoxic reactor. The anaerobic reactor receives the influent and the return sludge flow. However, if the removal of nitrate in the pre-D anoxic reactor is not complete then nitrate will be introduced in the anaerobic zone. It will then reduce the availability of the easily biodegradable material to the PAO and thus reduces the phosphorus removal capacity of the system. The modified pre-D system is equivalent to the plug-flow A^2/O system. The modified Bardenpho configuration has been widely applied, although it has been replaced in popularity by the UCT and modified UCT configurations.

(3) UCT system and modified UCT configurations:

In the UCT system proposed by Rabinowitz and Marais (1980) and represented in Fig 5.2d, the introduction of nitrate in the anaerobic zone is avoided, because the recycle stream is taken from the anoxic instead of the aerobic zone. In the anoxic zone the concentration of nitrate is controlled at a low level due to manipulation of the recirculation factor “a”, in such a way that the nitrate available for denitrification is always smaller than the available denitrification capacity in the pre-D zone.

The modified UCT system (Fig. 5.2e) was designed to ensure that the introduction of nitrate in the anaerobic zone is impossible, even with a variable nitrate concentration in excess of the denitrification capacity. The anoxic zone is split into two parts, introducing the return sludge in the first (upstream) part and using the second (downstream) part for denitrification of the nitrate recycled with recirculation “a”. Under these conditions, denitrification will be complete in the first part of the anoxic zone and no nitrate will be returned to the anaerobic zone. The disadvantage of this configuration is that the anoxic zone as a whole is under-loaded with nitrate. Therefore a larger total anoxic volume is required compared to the modified Bardenpho configuration. If the anoxic volume is not enlarged, the nitrate concentration in the effluent will increase, which might cause problems in the settler (floating sludge).

(4) The Johannesburg configuration:

In the Johannesburg system (Osborn and Nicholls, 1978, Fig. 5.2f), the mixed liquor from the aerobic zone passes through the settler, while the return sludge is directed to an anoxic zone. As the sludge concentration in the settler is a factor (s+1)/s larger than the mixed liquor entering the settler, the denitrification rate in the post-D zone will also be proportionally increased. This means that it is possible to produce a mixed liquor without nitrate in the discharge of the post-D reactor to the anaerobic zone, even while there will be nitrate present in the effluent. This configuration can be advantageous if effluent nitrate limits are not very strict.

Table 5.1 Comparison of different configurations for biological phosphorus removal

Configuration	Advantage	Disadvantage
Phoredox / A/O	- Small and simple system - Short residence time	- No nitrogen removal - In hot or moderate climate the system will not be reliable
Modified Pre-D / A^2/O	- High denitrification rate - Short sludge age	- Might not function properly (due to recirculation of nitrate) - Denitrification incomplete - Tendency to induce sludge bulking
Modified Bardenpho (3 or 5 reactors)	- Excellent configuration for nitrogen removal	- If denitrification is incomplete then nitrate will be recycled to the anaerobic zone, adversely affecting P-removal
UCT	- Prevents recirculation of nitrate	- The utilisation of the denitrification capacity is inefficient.
Modified UCT	- Ensures absence of nitrate in the anaerobic reactor	- The utilisation of the denitrification capacity is inefficient (even more so than in the UCT system).
Johannesburg	- Efficient use of denitrification reactor	- Denitrification incomplete

In Table 5.1 the various configurations discussed above are compared. It can be observed that the main difference is the way in which the anoxic zone is used. In the systems with the highest degree of protection against the recycling of nitrate to the anaerobic zone, the pre-D anoxic zone is relatively under-loaded and the removal of nitrate will be less than the denitrification capacity. On the other hand, the higher one exploits the denitrification capacity in the pre-D anoxic zone, the lower the protection of the anaerobic zone against contamination with nitrate will be. Consequently the process of biological phosphorus removal will then be more vulnerable to disturbances.

It is possible to design activated sludge systems for nutrient removal in such a way that the system configuration can be modified as the conditions change (for instance the ratio TKN/COD, temperature, sludge age, f_{sb}, μ_m or toxic materials). Fig. 5.3 shows a configuration that permits one to operate in any of the alternative configurations discussed above, through manipulation of the recirculation flows and the relocation of aerators.

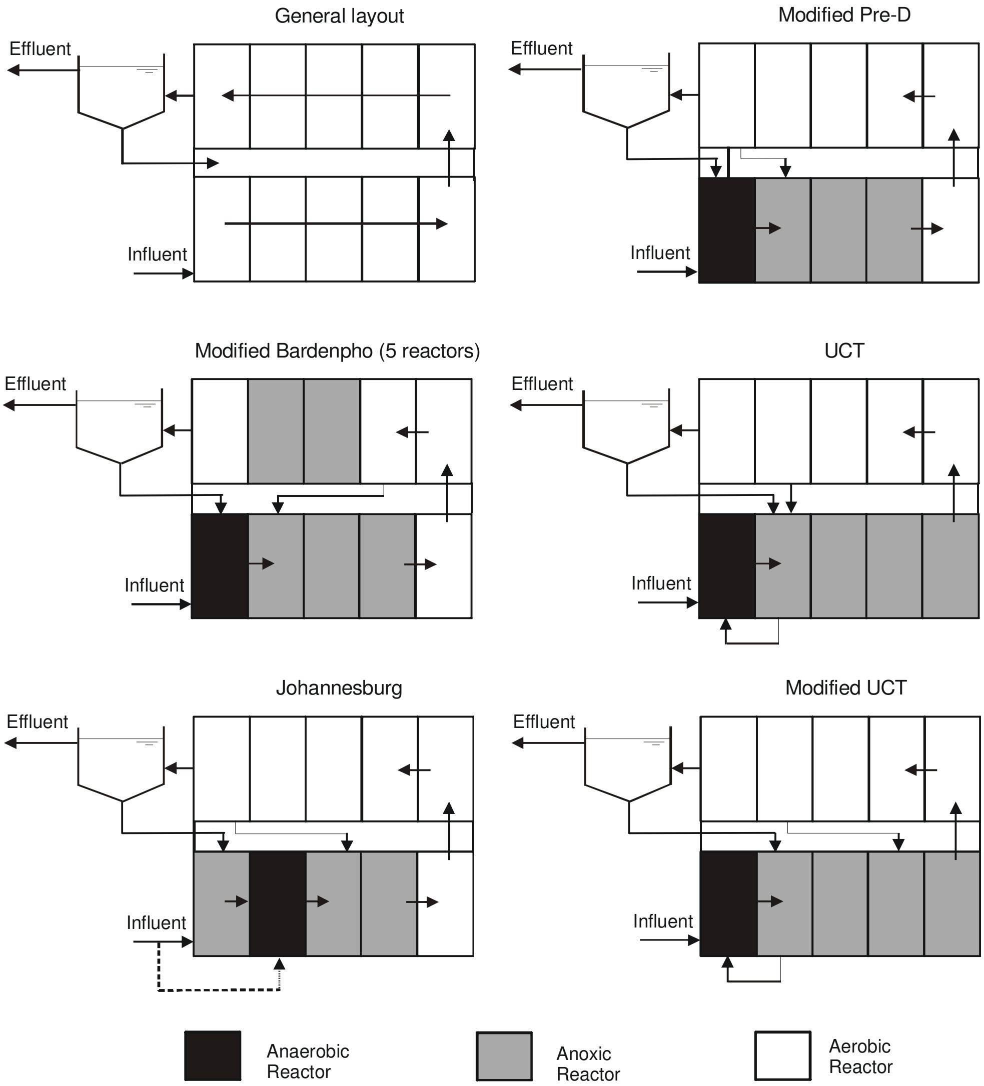

Figure 5.3 Schematic drawing that demonstrates how with small modifications it is possible to operate a single waste water treatment plant in different bio-P removal configurations