

5.2.2 Improving substrate availability for nutrient removal

As has been discussed earlier, both biological phosphorus removal and biological nitrogen removal are enhanced by the availability of easily biodegradable material and as such may be competing processes. However, if the activated sludge system has been configured to promote the establishment of a large denitrifying PAO fraction, the extent of competition will be limited, and mainly due to the fact that the inclusion of an anaerobic zone will reduce the anoxic mass fraction. Depending on the composition of the raw waste water, the limited availability of biodegradable COD will be further aggravated when techniques such as primary sedimentation or anaerobic (methanogenic) pre-treatment are applied: the removal of COD from the waste water is higher than that of nitrogen and phosphorus, making extensive nitrogen- and phosphorus removal more difficult.

However, providing that they are properly designed and operated, it is quite feasible for most activated sludge systems treating municipal waste water to be compliant with the effluent limits that are applied nowadays (such as total nitrogen $\leq 10 \text{ mg N.l}^{-1}$ and total phosphorus $\leq 1 \text{ mg P.l}^{-1}$). Sometimes additional phosphorus removal using chemical (supplementary) precipitation of phosphorus might be required. This will be demonstrated in Example 5.4. The following general design approach can be used for municipal waste water:

- The activated sludge system is designed for both biological nitrogen and phosphorus removal;
- Priority is given to biological nitrogen removal, i.e. sufficient easily degradable organics should be available for denitrification in order to comply with the nitrogen effluent discharge limits;
- The system is further optimised for maximum biological excess phosphorus removal;
- When required, the biological phosphorus removal process is supplemented by additional chemical methods (mainly through simultaneous precipitation with metal salts (Section 5.3)).

In some cases the availability of S_{bsi} , the easily biodegradable COD concentration in the influent, is a limiting factor. In some cases it might be attractive to increase S_{bsi} using biological processes, as an alternative to the addition of an external carbon source or to chemical phosphorus removal. Two main alternatives can be considered: (1) anaerobic pre-treatment of the influent and (2) hydrolysis of primary sludge. In both cases the anaerobic treatment is only partial, i.e. the anaerobic process is limited to the production of VFA and is not allowed to proceed to the production of methane.

(1) Anaerobic pre-treatment of the influent

The two main concepts that have been developed for partial anaerobic pre-treatment of the influent flow are:

- The hydrolysis upflow sludge blanket reactor or HUSB (Wang, 1994);
- The activated primary tank or APT (Rössle et al, 2001).

The main drawback of both of these concepts is that at low temperatures anaerobic hydrolysis proceeds at a very low rate. Heating of the complete influent flow is clearly not a cost-effective solution and prohibits application of these concepts in regions with a cold to moderate climate. The HUSB is basically a UASB system, operating at such a reduced sludge age that only hydrolysis and acid fermentation develop. The result is that volatile fatty acids are produced instead of methane.

As an additional benefit, the removal percentage of suspended solids in the influent is very high, as suspended solids are entrapped in the sludge blanket. In the Netherlands the HUSB was extensively researched between 1992 and 1996. The results indicated that this process was not attractive in the Netherlands (and in other countries with a moderate climate) as:

- During winter times the municipal waste water temperature ranges from 6 to 10°C. At these temperatures the hydrolysis process is very slow, requiring either a very large sludge age (and reactor volume) or the installation of heat exchangers to increase the reactor temperature;
- At a typical HRT of 2 hours, the amount of additional VFA produced from the raw influent was on average about 40 mg COD.l⁻¹, approximately sufficient for the removal of only 2 mg P.l⁻¹;

In the activated primary tank, the sludge blanket in the primary settler is allowed to increase, thus increasing solids retention time and allowing for the development of sludge hydrolysis. An advantage is that application of an APT is easy if a primary settler is already constructed. Primary settler effluent is recycled through the sludge bed to transfer the produced VFA to the influent. The main disadvantages of this concept are:

- At high rainwater flows the high level of the sludge bed may lead to primary settler failure and subsequent increased solids washout to the activated sludge system;
- VFA production is low, especially at low temperatures.

(2) Hydrolysis of primary sludge

Two main configurations have been developed to achieve hydrolysis of primary sludge:

- Use of the primary sludge thickener. In moderate climates, a solids retention time of 2.5 - 4 days is typically applied to primary sludge thickeners and this is sufficient for some hydrolysis to occur. However, VFA production will only be low to moderate. Sludge recirculation is required to transfer the produced VFA to the supernatant, which will interfere with the primary function of the thickener, i.e. to increase the solids content in the primary sludge;
- Use of a dedicated (completely mixed) sludge hydrolysis reactor. This reactor can be heated to the optimum temperature of 25 to 30°C, as the volumetric flow to be treated is much smaller compared to the influent flow. The hydraulic residence time is 5 - 10 hours. The hydrolysed sludge is separated from the liquid using gravity- or mechanical thickening. The supernatant is directed to the anaerobic zone of a bio-P system.

The latter configuration is considered to be the most attractive. In Denmark, pre-precipitation of phosphorus in the primary settler using Me(III)-salts, in combination with sludge hydrolysis, has been extensively researched in the so-called HYPRO process (Harremoes et al, 1991). As COD removal in the primary settler increases when pre-precipitation is applied, so does the VFA yield in the hydrolysis reactor. Some full-scale installations have been built on this principle in Scandinavia and they seem to be performing well. Some operational and process characteristics regarding sludge hydrolysis reactors are summarised in a study by De Jong et al (1996):

- It is recommended to mix the fresh primary sludge with the hydrolysed sludge;
- The solids concentration in the reactor should not exceed 20 kg TSS.m⁻³;
- The pH should not be allowed to decrease below a value of 5.5 - 6.0;

- Nitrogen released from digestion is returned to the activated sludge system, together with the produced VFA. However, if conventional anaerobic sludge digestion is applied, this nitrogen load is also returned to the activated sludge system;
- The VFA yield that can be obtained from the primary sludge is significantly influenced by the nature of the sewer system. A long anaerobic residence time (as in pressure lines) might result in a partly hydrolysed influent, where primary sludge hydrolysis will not increase VFA production any further. On the other hand, the presence of oxygen in a gravity collection sewer system might reduce the amount of available easily biodegradable COD;
- The yield of soluble COD products from primary sludge VSS usually is in the range of 9 - 12% (at 25 - 30°C), but values as far apart as 40 to 400 mg COD.g⁻¹ VSS have been reported as well;
- The recovery of produced VFA can be increased by thickening the hydrolysed sludge.

In the same study by De Jong et al (1996), the break-even point for the cost of primary sludge hydrolysis as compared to that of acetate addition, was found for a VFA production of 160 mg COD.g⁻¹ VSS (for an acetate cost of 0.5 US\$ dollar per litre), but this concentration cannot be achieved reliably in regions with a cold to moderate climate. Influent- and/or primary sludge hydrolysis has not found wide application in these regions for the following reasons:

- The investment costs of an external carbon source dosing system are limited compared to those required for the hydrolysis of sludge or influent (although operational costs are much higher);
- The operational uncertainties (and potential VFA yield) involved with hydrolysis are such that often a back-up external carbon source dosing system will be installed anyway;

However, for regions with a hot climate, where heating of the hydrolysis reactor is not required, it might be a viable alternative, as will be discussed in Chapter 9. It is then important to experimentally establish the potential VFA yield before making an investment decision.