EFFECT OF REDUCED CARBON SUPPLY ON ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL AND DENITRIFICATION

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Abstract

Changes in phosphorus and nitrogen elimination due to variation of carbon source in a wastewater treatment plant (WWTP) with enhanced biological phosphorus removal (Bio-P) are observed. After periods of low organic sewage load during the weekends and rain an approximately 2 days lasting increase of outlet phosphate concentration and load are found. The same can be observed for nitrate. The need of biologically useable carbon in the processes of Bio-P (anaerobic P-release) and denitrification are responsible for the effects. Primary they are directly caused by the dynamics of intermediates in the metabolism of phosphorus accumulating microorganisms (PAOs) in the activated sludge. Secondary an intervention between Bio-P and denitrification was expected due to their contribution within the same anaerobic compartments.

Keywords: biological phosphorus removal, nitrogen removal, phosphorus accumulating microorganisms (PAOs), full-scale plant, carbon source and phosphorus uptake

Introduction

Enhanced biological phosphorus removal (EBPR) is an attractive possibility to remove phosphorus from municipal wastewater. The process uses the ability of certain organisms to store carbon compounds under anaerobic conditions in exchange with intracellular phosphate. Providing there is an electron acceptor such as nitrate or oxygen afterwards available, the organisms are able to utilize the stored organic substances for growth. A part of the produced energy is employed to take up phosphate again and store it as polyphosphate. This phosphorus fraction can be removed together with excess sludge.

The microbiological mechanisms of polyphosphate storage have only been partially elucidated. The activated sludge model assumed by process engineers (Wentzel et al., 1992; Tsumo et al., 1987; Ubukata et al. 1994) in pure cultures; however, only for a bacteria growing on amino acids. For this reason, there should be a closer collaboration between microbiologists and engineers to investigate the microbiological mechanisms occurring in mixed cultures and to develop a better working model.

The proposed PAOs depends on respiration and anaerobically stored substrate for its cell growth. For this reason, the activated sludge should be able to run through several anaerobic/anoxic/aerobic cycles. The growth rate is low than for other heterotrophic bacteria. The advantage of phosphorous-accumulating organisms is the capacity to store substrate in an environment which does not allow other bacteria to grow. Other bacteria can only utilize the easily degradable substrate efficiently when a corresponding electron acceptor is available (oxygen or nitrate), as the possibility of storage does not exist for them.

For mixed cultures in an anaerobic environment, a definitive relationship between the disappearance of dissolved BOD (Biochemical Oxygen Demand) and an increase in the orthophosphate content of the water exists. The bacteria do not assimilate all substances equally well. Volatile fatty acids such as acetic acid, propionic acid or butyric acid are assimilated most efficiently. These substances, which are very easily degradable under either aerobic or anoxic conditions, are seldom found in high concentrations in the influent. There are exceptions; for example, for long residence times in the sewer or in the preclarification tank where through fermentation a substantial fraction of the BOD is made available in the form of volatile fatty acids for the redissolution of phosphate. The fraction of easily degradable substances could also be increased by adding volatile fatty acids from primary sludge acidification. Otherwise the substrate has to be "produced" *in situ* by fermenting the particulate substances during a sufficiently long anaerobic residence time.

In order to carry out the biological removal of phosphorus, the activated sludge has to be alternatively exposed to aerobic and anaerobic conditions. At high concentrations of easily degradable substrate matter in the anaerobic tank, the nitrate from the returned sludge is denitrified and the phosphate is redissolved by the phosphorus-accumulating bacteria. To what extent the redissolution and assimilation of phosphate occur simultaneously under anoxic conditions cannot yet be quantified.

The purpose of this study was to explain the influences of variation of carbon source in wastewater inlet of a treatment plant (WWTP) with enhanced biological phosphorus removal (Bio-P) to the PAOs activities in activated sludge. Therefore, these may suggest some solution for improving and maintaining the phosphorus removal in the low carbon source in the influent.

Experimental

At a full scale wastewater treatment plant for enhanced biological phosphorus removal the variation of phosphate release and uptake as well as denitrification capacity was observed with an FIA on-line phosphate and nitrate system in the anaerobic, anoxic and aerobic compartments. The experimental lane treated the wastewater for about 15,000 population equivalents a consists of 6 reactors compartments (Figure 1). Plant was setup with AAO scheme and consisted of 2 compartments of anaerobic, 1 compartment of anoxic, 1 bivalent compartment for adjusting of anoxic volume seasonally and two oxic conditions. Total plant volume was 3,030m^3, aerated volume: 1,420m^3, inlet: 4,100 m^3/d, internal recycle: 1st oxic to 1st anoxic compartment: 8,600 m^3/d, TSS: 1.95kg/m^3 and sludge age: 17 days.

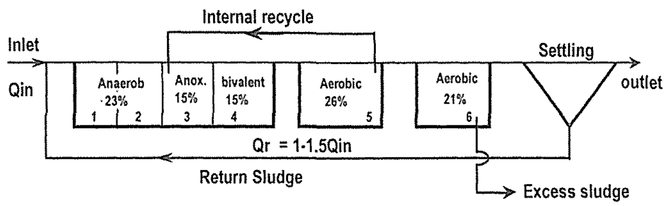


Figure 1. Full scale WWTP flow scheme of the experimental lane for enhanced biological phosphate removal. The bivalent compartment was partial aerated.

Analytical method: An on-line flow injection analysis system (Flow Injection Analyse, ASIA, Ismatec AG, Glattbrugg) for analyzing of NO_3^- and PO_4^{3-} concentrations was installed and calibrated in each compartment of a large WWTP. Samples were almost continuously taken with the interval period of 30 minutes.

Nitrite/Nitrate: nitrate is reduced almost quantitatively to nitrite in the presence of cadmium (Cd). This method uses Cd granules treated with copper sulfate, to form a Cu coating. The nitrite produced thus is determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine to form a highly colored azo dye that is measured colorimetrically. The measured range is 0.1-10 $g_N m^{-3}$ and the average value is received from 2-4 measurements.

Dissolved Phosphorus/Orthophosphate: The ascorbic method is used for determination of dissolved phosphorus/orthophosphate. Ammonium molybdate and potassium antimonyl-tartrate react in acid medium with orthophosphate to form a heteropoly acid-phosphomolybdic acid-that is reduced to intensely colored molybdenum blue by ascorbic acid. The measured range is 0.1-5gPm^{-3} and the average value is received from 2-4 measurements.

Results and discussion

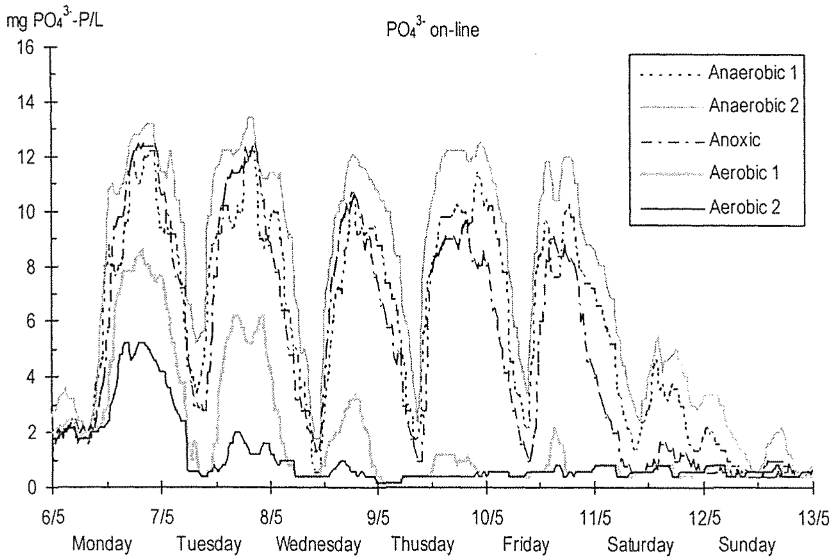
After periods of low organic carbon loads, at weekends and public holidays, the phosphate load in the effluent is significantly increased on the following 1-2 days. This is of quantitative and qualitative relevance because the average phosphate load in the effluent was about 60% increased due to this effect.

The described effects were of quantitative relevance. Technical-scale experiments in the Bio-P activated sludge system in the plant scale were carried out. As shown in the Table 1 increased outlet octhophosphate concentrations of around 0.5 mgP/L (daily mean) on 2/3 of all Mondays and Tuesdays compared with about 0.2 mgP/L the remaining days could be seen. On-line measured maximum outlet concentrations on Mondays and Tuesdays were 5 mgPO_4^{3-}P/L. The weekly mean (arithmetic mean) for outlet PO_4^{3-}P load was increased from 0.7 kgP/d to 1.1 kgP/d (60% increase) due to the values on Mondays and Tuesdays.

Table 1. Variation and mean values of outlet of phosphate concentrations and loads of the full scale WWTP (in the first half-year)

	Orthophosphate concentration (mgP/L)	Orthophosphate load (kgP/d)	Total phosphorus concentration (mgP/L)	Total phosphorus load (kgP/d)
Wednesday to Sundays	0.02 – 1.2	0.07 – 5.3	0.15 – 2.3	0.5 – 10.8
Mean value	0.2	0.7	0.5	1.9
Mondays and Tuesday	0.01 – 1.8	0.22 – 6.5	0.37 – 2.7	0.9 – 13.1
Mean value	0.5	2.0	1.0	4.7
Monday to Sunday mean value	0.3	1.1	0.7	2.7
Mean value in inlet	1.7	6.9	4.6	29

The charts of the on-line PO_4^{3-} concentration of the last aerobic compartment and of the PO_4^{3-} outlet load of the large WWTP (Figure 2) displayed a strong daily and weekly variation with increases on Mondays and Tuesdays in the second day half and hardly rising over zero the other time. PO_4^{3-} concentration of the last aerobic compartment equals approximately outlet PO_4^{3-} concentration. The on-line concentration of the anaerobic compartment (Figure 2) showed how the PO_4^{3-} release almost broken down during the weekends, immediately being on the typical working day values on Monday noon. Other data showed that only during weekends nitrate was presented in relevant amounts in the aerobic compartments.



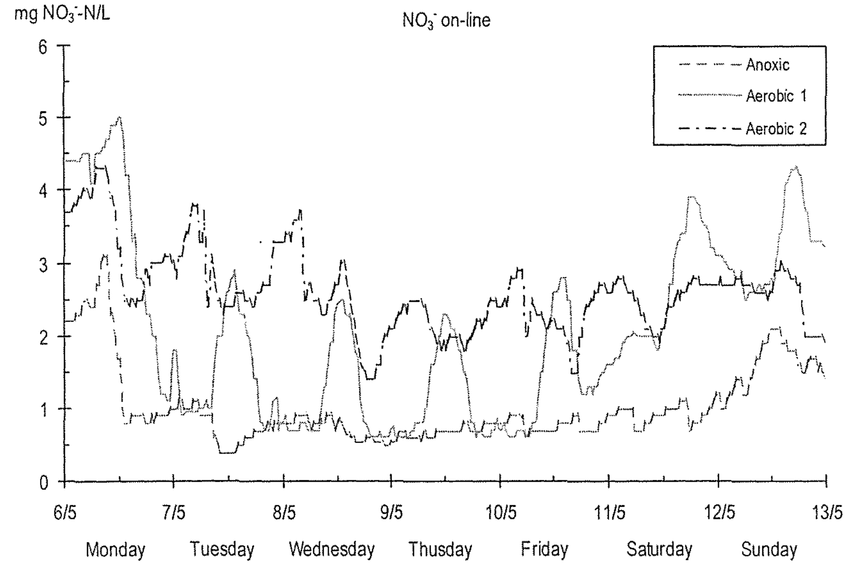


Figure 2. On-line measured orthophosphate (above) and nitrate (below) concentrations in the different compartments of the large scale WWTP.

The described daily and weekly variations of P outlet concentrations load and anaerobic PO_4^{3-} release correspond to the variation of COD inlet load in Figure 3. Periods of increased PO_4^{3-} outlet-load are coupled with periods with decrease in COD inlet load which means a reduction in the supply of microbial useable carbon. The decrease in COD inlet load on Saturdays and Sundays as well as increased value on Mondays and Tuesdays are pointed out clearly in Figure 2. A delay time about 2 days takes place between the decrease in carbon-supply and the corresponding increase of PO_4^{3-} outlet load. On the other hand a direct and undetailed relationship between carbon-supply and anaerobic PO_4^{3-} release takes place (see Figure 2 and 3). Other data show how the daily variation in PO_4^{3-} release in Figure 2 fits the daily variation in COD-input. Finally the total P-inlet load normally is increased at the beginning of the week (week 2).

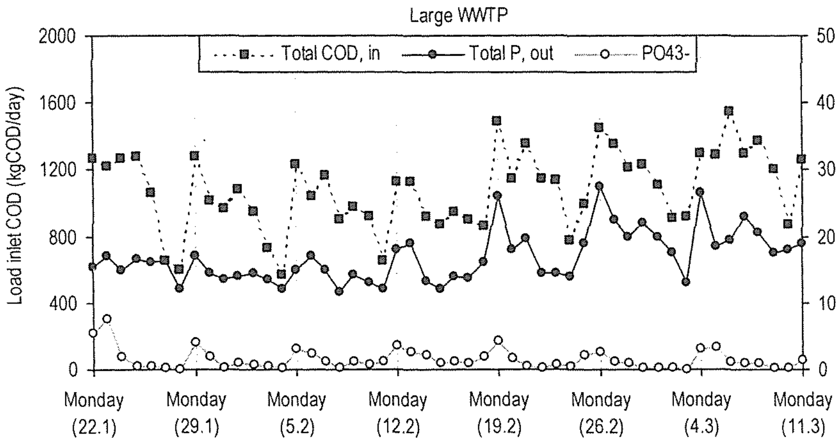


Figure 3. Daily mean values for total COD and total P-inlet load as well as for PO_4^{3-} outlet-load on full scale WWTP. Described parameters: Mondays; plant characteristics: see Figure 1, except aerated volume: 1,880 m^3 and no internal recycle.

Temmink et al. (1996) described a similar behavior at a small pilot plant. After the inlet was replaced by recirculated effluent for 20 hours, the polyhydroxyalkanoate (PHA) pools decreased and phosphate uptake capacity deteriorated significantly. After inlet flow started again the plant needed about 20 hours to reach full P-uptake capacity.

The following mechanisms are assumed to be mainly responsible for the observed phenomena:

- Due to the lower COD to N ratio during weekends, readily biodegradable COD is mainly used up for denitrification which leads to a temporarily smaller anaerobic phase.
- Lack of biodegradable organic carbon and due to temporarily anoxic conditions in the anaerobic compartments polyphosphate accumulating organisms (PAOs) reduced their P-release as well as the synthesis of the internal substrates PHA and glycogen during weekends. Since the internal substrates are also used for growth and polyphosphate storage during weekends, PHA and glycogen pools are significantly reduced on Monday mornings.
- On Monday, the anaerobic carbon supply being back, the polyphosphate accumulating organisms first have to regenerate all the pools in the metabolism as well as the internal substrates PHA and glycogen before P-uptake reaches normal conditions again. This lasts about 1-2 days.
- On the other hand increased P-loads and reduced anoxic P-uptake due to high COD loads on Mondays can additionally increase PO_4^{3-} effluent concentration.

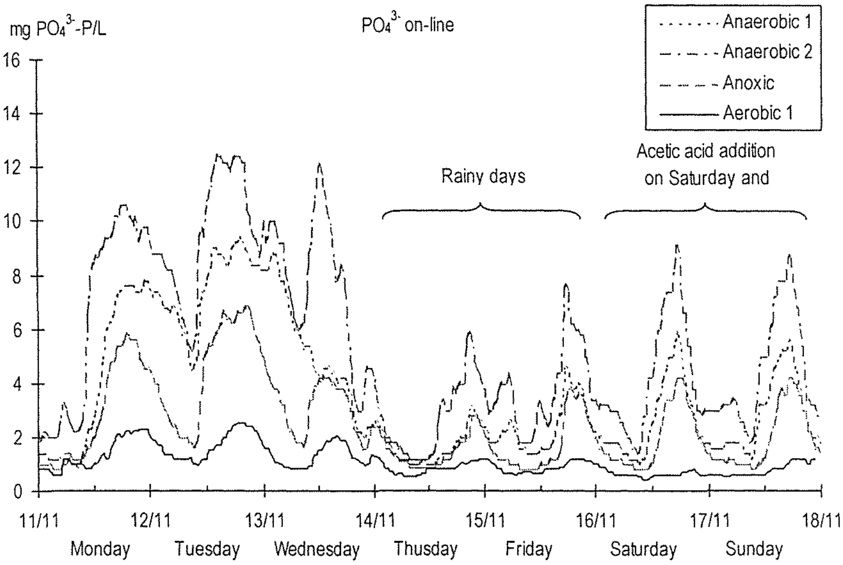


Figure 4. On line measured phosphate concentrations in the different compartments during a week with addition of volatile fatty acids on Saturday and Sunday (addition about 200% of biodegradable organic carbon of inlet, measured COD).

Due to addition of volatile fatty acids from raw sludge acidification (addition about 200% of biodegradable organic carbon of inlet, measured as COD) denitrification and P-release were significantly improved (Figure 4). The consequence was an increased P-elimination on Mondays of about 1 gP/m^3 influent (figure 5). Possible ways to improve phosphorus removal after weekends could be additional organic carbon supply to compensate low-input or additional chemical precipitation controlled by P-effluent concentration.

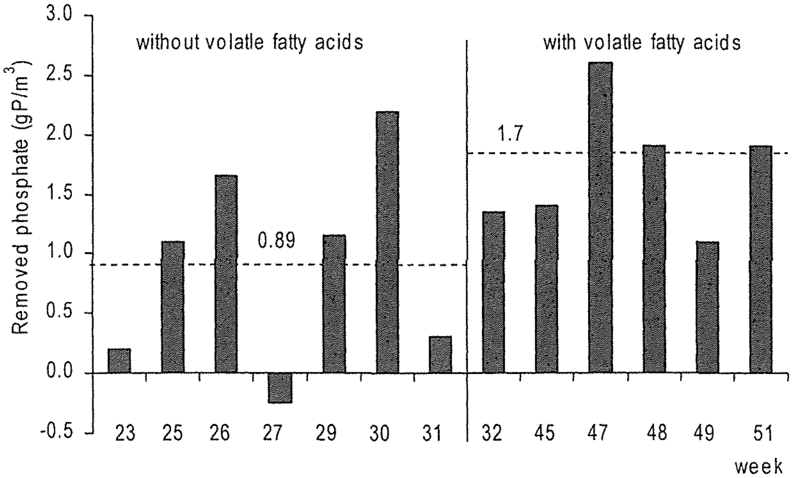


Figure 5. P-elimination on Mondays after weekends with addition of volatile fatty acids (addition about 200% of degradable organic carbon of inlet, measured as COD) compared with weekends without carbon source addition.

Conclusion

Reduced carbon sources in influent in weekends or rainy days were significantly influenced to the high nitrate and phosphate concentration in effluent of a full scale WWTP. After low organic carbon source periods the P-uptake of PAOs were recovered in 1 or 2 days. These phenomena were explained by the suggestion by biological mechanisms related to the energy pools of PAO's activities. Addition of organic carbon in the influent during low organic carbon supply periods to compensate low-input or additional chemical precipitation are solutions for improving and controlling nitrogen and phosphorus concentration in effluent.

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