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Determining optimal volume fractions of a municipal wastewater treatment plant by dynamic simulation

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The aim of this paper is to present the results of an optimisation process of a municipal wastewater treatment plant. The plant was designed to be capable of biological excess phosphorous removal though effluent phosphorous concentrations were above the limit value for several occasions. In the summer period the total nitrogen concentration was also higher than required.
It was examined how the adjustment of volume fractions contribute to effluent quality and the optimal ratios were determined by use of dynamic simulation techniques. The aerobic volume fraction was not altered only the two un-aerated phases were modified. The results showed that the anaerobic volume fraction could be lowered up to 11.5 % concluding the anoxic ratio to be 34.5 %.

1. Introduction

There are two main motives of operating wastewater treatment plants, to meet the prevailing requirements on effluent quality and to keep the costs low. Nonetheless in the course of designing a new plant there may be factors that cannot be foreseen (e.g. the changes in water usage), which may cause deficiencies during operation.
The examined plant was built in 1976. Since then several reconstructions were carried out, the last stage will be finished by the end of 2010. This paper deals with the problem of total nitrogen and phosphorous effluent concentration exceeding limit values and examines the effect of volume fraction alteration on the effluent quality.

1.1. The theory of enhanced biological phosphorous removal

The gist of enhanced biological phosphorous removal is that some microorganism species store phosphorous in excess of the amount that is removed by others. Phosphorous uptake takes place in the aerobic phase where the orthophosphate is converted into polyphosphate. In anaerobic environment the stored polyphosphate is depolymerised and released as orthophosphate into the mixed liquor. These phosphorous accumulating bacteria (PAOs) are able to reproduce when no external electron acceptor is available (Henze et al., 2008). This provides competition free growth to these microorganisms; therefore the PAOs are able to store more phosphate in the aerobic phase than it was released in the anaerobic phase. The excess phosphorous is

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removed with the sludge. Phosphate uptake is possible under anoxic conditions, too but to less extent than in aerobic environment (Henze et al., 2000).

According to the corresponding literature the biological excess sludge removal is influenced by the following processes and factors (Henze et al., 2002, Henze et al., 2008 and Metcalf & Eddy, 1991):

1. Phosphorous is present in the wastewater mainly as orthophosphate (PO_4^{3-}) the rest is in organic form.
2. Significant efficiency improvement can be achieved if the majority of the phosphorous amount is in soluble form.
3. The theoretically optimal C:N:P ratio for aerobic growth of microorganisms is around 100:14:3. This ratio in municipal wastewater after primary sedimentation is around 60:12:3, i.e. the phosphorous amount exceeds the required ratio by 66%.
4. The anaerobic phosphate release is inhibited by the presence of both dissolved oxygen and nitrate. These components hinder the process of synthesising poly-ß-hydroxyalcanoates (PHAs) serving as nutrient and energy source. Since the stored amount of nutrient determines the uptake and storage of polyphosphate in the aerobic phase the less stored PHA results in decrease in the polyphosphate storage capacity, too.

The biomass of enhanced biological phosphorous removal systems may reach 5% phosphorous content contrary to the 2-2.5% phosphorous content of systems only capable of organic matter and nitrogen removal (Metcalf & Eddy, 1991). This way the effluent phosphorous concentration may decrease to less than 1 g/m^3.

When designing such a system determining the volume of the anaerobic phase is a key issue. This is highly influenced by the expected water temperature. In the 90's the definition of the anaerobic volume was done based on empirical knowledge (ATV, 1994). In areas where the winter water temperature may decrease to 10 °C, if the plant was designed to provide sufficient phosphorous removal in winter, 70-80% surplus capacity could develop in summer. This is due to the strong temperature dependency of metabolic processes in the aerobic phase, such as PHA consumption, oxygen uptake and growth (Brdjanovic et al., 1998). In order to avoid this, the reactor volume is determined to be sufficient for warmer water temperature (i.e. insufficient in winter time) and the excess phosphorous is removed in other cases by chemical precipitation. It is also proved that increasing anaerobic volume fraction has adverse affects on effluent phosphorous concentration especially in systems with larger sludge retention time (Orhon and Artan, 1994). Dynamic simulation with Activated Sludge Models (AMS2 and ASM2d) (Henze et al., 2000) may provide an optimum of the ratio of chemical and biological phosphorous removal.

2. Materials and methods

The examined municipal wastewater treatment plant has a capacity of 160,000 population equivalent (Figure 1). It receives the wastewater of 41 settlements; the longest distance is 23 km. This fact causes several operation problems such as odour formation hydrolysis and cooling down in the sewers.

The primarily clarified wastewater is fed to the biological stage where the biological phosphorous removal is completed with chemical treatment. A mixture of alum and ferric sulphate is added which also results in removing 10-30 % of the organic matter from the mainstream (Metcalf & Eddy, 1991).The primary and secondary sludge is pumped to the anaerobic digesters after dewatering. The dissolved oxygen (DO) concentration is controlled in the aerated tank. The composition of the effluent is shown in Figure 2. The wastewater temperature at the examined time period was 20°C.

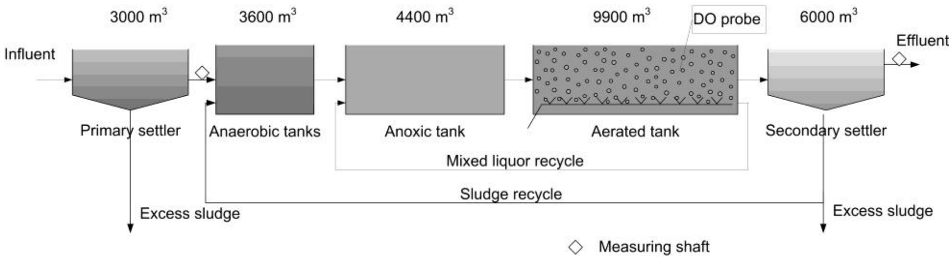

Figure 1: Schematic representation of the plant

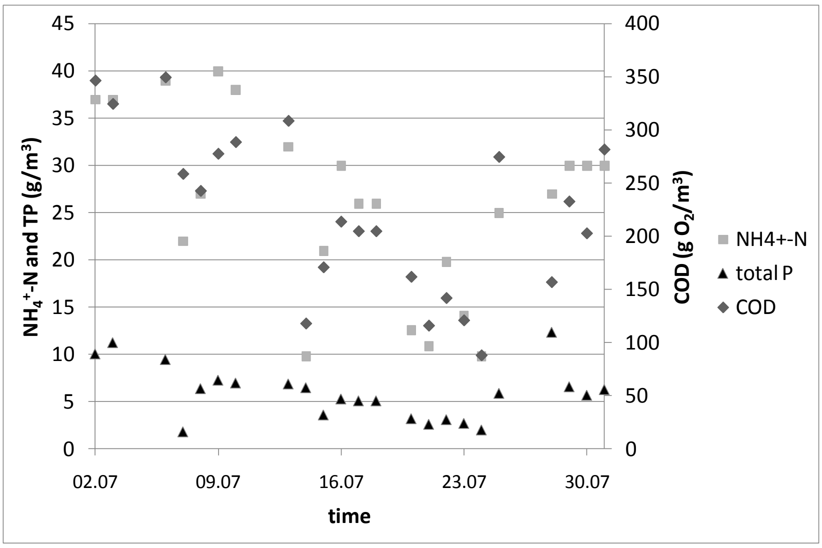

Figure 2. Wastewater concentration after primary settling

In order to describe the biological and chemical phosphorous removal at the plant the activated sludge model ASM2d (Henze et al., 2000) was chosen. ASM2d is an extension of the ASM1 describing biological phosphorous removal by introducing new state variables for characterizing PAOs. Contrary to ASM1 the heterotrophic organisms in this model are able to store organic materials in the form of PHA temporarily. The PAOs are able to use the internal cell storage products for denitrification. Additionally ASM No.2d is able to model chemical precipitation.

The input variables are derived from measurement data. Default parameters of the ASM2d were modified in order to fit measured values of the effluent.

Control of aeration was achieved with the applied DO controller shown in Eq. (2). This way the DO concentration is kept within 2.3-2.5 g/m^3. Thus only an estimation of the real control could be achieved since at the plant values were held between 2.0-2.5 g/m^3 but the exact concentration were highly dependent on the noise of the real control. Recirculation and excess sludge removal rates were defined as a percentage of the influent flow rate, 80 % (nitrate recycle), 100 % (sludge recycle) and between 1% (excess sludge) respectively, in accordance with the practice of the WWTP operation. This caused inaccuracies in cases when heavy rainfall was experienced but calculating the appropriate ratio for these occasions would have increased the simulation time significantly. In the examined time period there were nine such days (8th, 14th-15th, 18th, 21st-22nd and 24th-26th July 2008).

$$F = \max(1-\frac{S_{O,2}}{sp},0) \tag{1}$$

where:

F: the factor applied to control the dissolved oxygen concentration,

$S_{O,2}$: the DO concentration in the second (aerated) reactor (g/m^3),

sp: DO set-point, defined to be 2.5 g/m^3.

The simulations were carried out with the prototype of a program developed by the Environmental Expert System Research Group at the University of Pannonia in the frame of the ÖKORET project (RET_06 PEKHIT). The software creates the customized program code according to the technological description, input data and control strategy provided.

3. Results and discussion

Dynamic simulation was carried out in the period of 2nd-31st. July 2008. The results of the simulation are shown in Figure 3 and 4. The differences between measured and calculated values are due to the uncertainties of the data gathered from the plant operation, noise of the real DO control and the effect of rainfall which could not be modelled exactly. Despite of these inaccuracies it is clear that even in summer time the plant has operational problems concerning total nitrogen and total phosphorous effluent concentrations. The limit values to be achieved are highlighted with dashed lines.

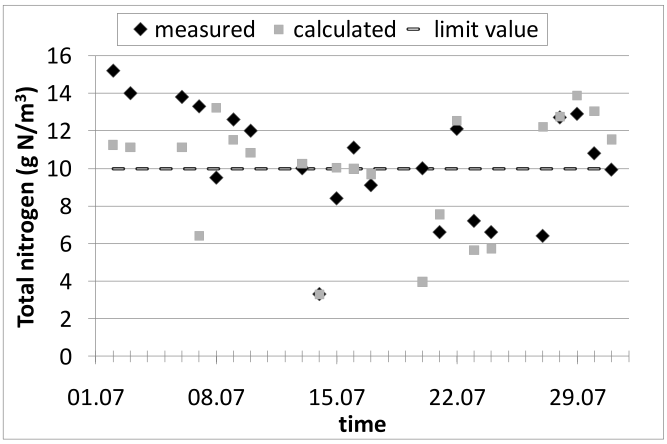

Figure 3: Result of simulation compared to measured values (total nitrogen concentration)

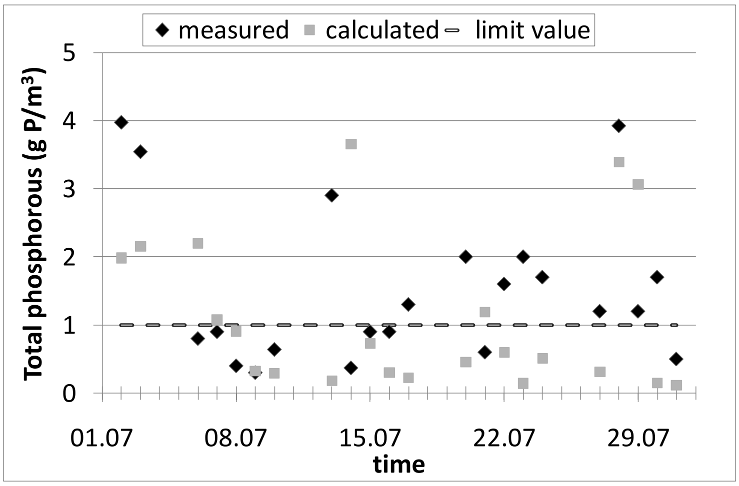

Figure 4: Result of simulation compared to measured values (total phosphorous concentration)

In order to determine how changing the volume fractions can affect the effluent quality 23 additional simulations were carried out. The aerated volume remained as in the original case but anaerobic and anoxic volumes were changed with as step size of 100 m^3. If the anaerobic volume was decreased the anoxic volume was increased with the same extent. This way from the original volume fractions (anaerobic : anoxic : aerobic) the model volume fractions were changed gradually from *22.99:22.99:54.02* to *9.77:36.21:54.02*. The results of the simulation series are shown in Fig. 5. The concentration values were totalled and displayed in the function of the anaerobic volume fraction.

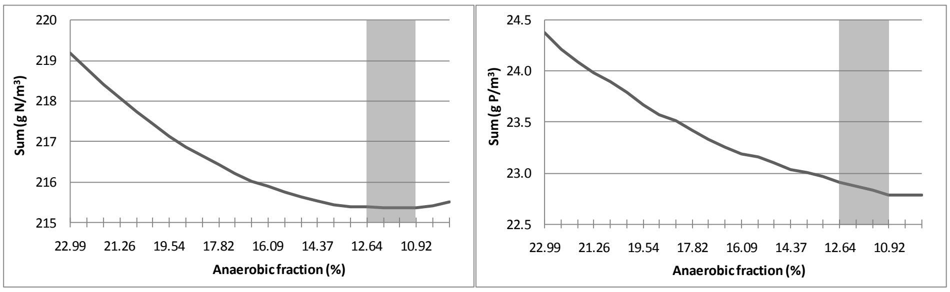

Figure 5: The sums of the components different anaerobic and anoxic volume fractions (left: total nitrogen, right: total phosphorous concentrations)

4. Conclusions

The changes are small at the different volume fractions but it is clear that the best results were received when the anaerobic volume was between 2200-2000 m^3. At smaller volumes the total nitrogen concentration started to rise slightly and total phosphorous concentration could not be lowered anymore. These results are in accordance with the relevant literature.
The limit violations could not be eliminated with this solution by itself therefore further research on optimal nitrate and sludge recycle flows is planned to be carried out.
It is advised to dose the chemical taking the influent flow and phosphorous concentration both into consideration in order to avoid peaks in the effluent TP concentration. A control based on the phosphorous mass of the influent is a possible solution.

Acknowledgement

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