

Appendix C Summary

COMPARISON OF CHEMICAL AND BIOLOGICAL PHOSPHORUS REMOVAL IN WASTEWATER

- A MODELLING APPROACH

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Abstract

Phosphorus has been found to be the main culprit in eutrophication of lakes and water ways which is a major international environmental problem. Two methods are currently being used around the world to remove phosphorus in wastewater: biological and chemical phosphorus removal.

Presently, most plants in the world with phosphorus removal use chemical phosphorus removal but the tendency is that an increasing number of plants are built or reconstructed in order to use biological phosphorus removal.

The software EFOR which is a computer tool for predicting operating results from wastewater treatment is used to compare between chemical and biological phosphorus removal. Results obtained from the study demonstrate that chemical phosphorus removal yields better and more stable results as far as effluent quality of treated wastewater is concerned. Chemical phosphorus removal produces a lot more sludge than biological phosphorus removal and the difference is dependent on the type of chemical used. Biological phosphorus removal consumes more energy in terms of the aeration capacity of the process than chemical phosphorus removal. Moreover, biological phosphorus removal needs a lot more volume or space than the chemical process as the anaerobic unit of the latter process is not necessary and can be omitted. An economic evaluation in terms of sludge production and chemical cost only, revealed that about 602.000 SEK (if FeCl_3 is used) and 343.000 SEK (if $\text{Fe}_2(\text{SO}_4)_3$ is used) can be saved if biological phosphorus removal is used instead of chemical phosphorus removal. It was noted that it is not a good idea to conclude that any of the treatment methods is better than the other as each one has its advantages and disadvantages and the choice of which method should be used would depend on the priority that society places on the wastewater treatment and the costs they are ready to incur.

A final remark is that the winning concept these days should not be based on which process should be used in isolation to the other, but rather using the advantages of both processes together to obtain 'best' results, while at the same time minimizing their disadvantages.

KEYWORDS

Wastewater; chemical P removal; Bio-P; modelling

Introduction

A very important component of municipal wastewater is the nutrient salts. These consist mainly of phosphorus and nitrogen which are responsible for one major international problem known as eutrophication (over-fertilization) of lakes and waterways. It has been generally understood that phosphorus is the limiting nutrient in lakes and waterways (Gillberg et al, 2003). Despite the growing use of conventional biological treatment plants, many waterways have still suffered negative effects. In Sweden, for example, very stringent laws have been passed on the effluent quality of municipal wastewater with respect to phosphorus. To meet up with such laws, biological phosphorus removal methods and chemical treatment methods are being used.

The EU-directive (91/271/EEC) sets the limit for total phosphorus in effluent wastewater in sensitive areas to 1 or 2 mg P/l, depending on the size of the plant, or a minimum of 80% reduction of the influent concentration (Tykesson, 2005). Sweden is one of the countries in the EU that imposes lower limits for the discharge of phosphorus in recipient water bodies. The maximum limit of phosphorus in most wastewater treatment plants is between 0.3 and 0.5 mg/l total phosphorus as monthly or quarterly mean value in the water leaving the treatment plant, depending on the sensitivity of the recipient water body. This calls for better wastewater treatment technologies and more research is still being undertaken in this area. It is however clear that with conventional wastewater treatment; only about 20 to 30% of phosphorus is removed (Henze et al, 1995). Presently, there has been a trend towards combining biological and chemical phosphorus removal methods to achieve better results. In most plants, there has been a reduction for example in the use of precipitation chemicals, indicating that the Bio-P process is functioning properly and making use of the advantages of each of these methods seems to be a winning concept.

When considering what method is more effective for removing phosphorus in wastewater, apart from considering effluent concentrations, other factors are important to the wastewater engineer. Sludge handling and disposal, plant layout in terms of volume of individual units, costs of chemicals and consumption of energy. Based on these analyses an economic evaluation of the process can be made.

Background

Phosphorus removal from wastewater can take place by biological or chemical methods (Gillberg et al, 2003). For each treatment method, the plant-layout, and operation will be different and the consumption of energy and chemicals may be quite different. Further sludge handling and disposal can be different as well. Today most plants in the world with phosphorus removal use chemical precipitation but the tendency is that an increasing number of plants are built or reconstructed in order to use biological phosphorus removal. The reasons for this trend are many and a full comparison is needed in order to understand this development.

In the biological phosphorus removal, the main actors are the polyphosphate accumulating organisms (PAOs) whose ability to take up large amounts of phosphorus from phosphates by exposing them to alternating anaerobic and anoxic/aerobic conditions is exploited. In chemical phosphorus removal, a metal salt (usually aluminium and iron salts) is used to convert the dissolved inorganic

phosphorus compounds in the wastewater into a low solubility metal phosphate which can be removed in the subsequent sedimentation stage of an activated sludge process.

Comparison of chemical and Bio-P removal

It was not easy working with the EFOR model. The major challenge was calibrating the model in such a way that the results are similar to those observed at the plant. The model does not have a single set of parameters that can be changed. Instead, it has multiple sets of parameters associated with the different units.

Comparison based on effluent quality

The discharge limits of the Öresundsverket wastewater treatment plant are set based on total phosphorus, BOD₇ and total nitrogen annual mean values (Table 1.1). These values as well as the effluent quality observed in 1996 have been used as guidelines for the model effluent quality. From the results obtained, it was observed that the simulated effluent quality in terms of chemical and biological phosphorus and nitrogen removal are within the discharge limits (Tables 1.2). Chemical phosphorus removal was observed to reach whatever effluent quality requirement as more and more chemicals are dosed. Biological phosphorus removal was observed to reach a minimum of 0.4 mg P/l in the effluent.

Table 1.1 Characteristics of the effluent and discharge limits at Öresundsverket (Modified from Tykesson, 2005).

<i>Parameter</i>	<i>Influent</i>	<i>Discharge limits (annual mean values)</i>	<i>Effluent 1996</i>
<i>Flow (m³/d)</i>	54.000		
<i>COD (mg/l)</i>	468		38
<i>Tot-N (mg/l)</i>	36	10	7.6
<i>Tot-P (mg/l)</i>	6	*0.4	0.27
<i>Temp (°C)</i>	20		

* 0.4 if biological phosphorus removal is applied, otherwise 0.3mg/l. (Tykesson, 2003)

Table 1.2 Overall treatment efficiency for biological and chemical methods.

<i>Parameter</i>	<i>SS mg/l</i>	<i>COD mg/l</i>	<i>COD_f mg/l</i>	<i>COD_p mg/l</i>	<i>P_{tot} mg/l</i>	<i>NH₄ mg/l</i>	<i>N_{tot} mg/l</i>	<i>Sludge Tons SS/d</i>
<i>FeCl₃ (50%)</i>	4.69	16.95	13.50	3.45	0.28	0.35	6.85	2.57
<i>FeSO₄ (90%)</i>	4.67	17.17	13.66	3.51	0.29	0.41	6.89	2.50
<i>Bio-P 1.5 (/d μ)</i>	4.45	19.01	14.27	4.74	0.40	0.25	7.16	1.93

Comparison based on sludge production

The type of chemical, dose, effluent quality and sludge production for chemical phosphorus removal are given in Table 1.3. The results obtained for effluent quality

and sludge production for different growth rates of the poly-P biomass have been tabulated (see Table 1.4). From the tables it is observed that chemical phosphorus removal produces more sludge than biological phosphorus removal. From a quantitative analysis of the results, chemical phosphorus removal with FeCl_3 produces about 0.64 tons SS (about 25%) more sludge per day than biological phosphorus removal.

The production of sludge is considered a very important factor in the choice of a wastewater treatment method nowadays. This is further complicated by the fact that in countries like Sweden, the farmers association has placed a ban on the use of sludge from wastewater treatment plants as a fertilizer for agriculture.

Table 1.3 Chemical phosphorus removal and sludge production.

<i>FeCl₃ Dosage (Kg/hr)</i>	<i>P effluent (mg/m³)</i>	<i>Sludge (Tons/d)</i>	<i>FeSO₄ (Kg/hr)</i>	<i>P effluent (mg/m³)</i>	<i>Sludge (Tons/d)</i>
0	1.61	1.77	0	1.61	1.77
3.15 (10% dilution)	1.10	1.95	1.58	1.35	1.86
12.6 (30% dilution)	0.31	2.43	6.30	0.64	2.12
15.75 (40% dilution)	0.28	2.57	7.88	0.48	2.21
(90% Dilution)	Not necessary	Not necessary	14.18	0.29	2.50

Table 1.4 Biological phosphorus removal and sludge production.

<i>Growth rate of Poly P biomass</i>	<i>P effluent concentration (mg/l)</i>	<i>Sludge production (tons SS/d)</i>
0.1/d M _μ p	1.61	1.77
1.0/d M _μ p	0.43	1.90
1.5/d M _μ p	0.40	1.93
2.0/d M _μ p	0.40	1.94

Comparison based on needed plant volume

The volume of the anaerobic zone was reduced and the effects on the chemical and biological phosphorus removal were observed.

From the results, it was noted that the reduction of the volume of the anaerobic zone has no effects on the chemical phosphorus removal in terms of phosphorus removal

On the contrary, as the volume of the anaerobic zone of the Bio-P process is reduced, there are changes in the effluent quality. It is known that a reduction of the volume of the anaerobic zone reduced the efficiency of phosphorus removal. This is probably due to the fact that the anaerobic zone is a very important unit in the Bio-P process. It is in this unit that the PAOs take up readily degradable organic matter (VFA) from the wastewater using energy obtained from the breakdown of polyphosphates in the cell. Therefore any reduction in the anaerobic zone in the Bio-P process is not good for the process.

Comparison based on consumption of energy and chemicals

An oxygen setpoint of 2mg/l was specified in the model and the aeration capacity was reduced steadily for each process to see which one can better maintain the required setpoint. It was possible to reduce the capacity of the aeration device down to 1000 kg O₂/hr and still have good treatment results in terms of COD and nitrogen removal in the Bio-P process. Beyond this limit (less than 1000 kg O₂/hr), COD and Nitrogen at the effluent are too high. On the other hand, as far as chemical method was concerned, about the same amount of COD and nitrogen in the effluent observed in the Bio-P process at 1000 Kg O₂/hr were observed in the chemical method at 500 Kg O₂/hr. This indicates that the chemical method is more resistant to reduction in aeration capacity than the Bio-P process by at least 500 kg O₂/hr aeration capacity. This means that in the design of an activated sludge process by chemical method, the design capacity can be reduced equivalent to 500 kg O₂/hr compared to the Bio-P process. Figure 1.1 is an illustration of how much chemicals is saved if Bio-P is preferred over chemical P removal. From the same figure it can be observed that sludge production is higher for chemical than for Bio-P removal. The consumption of chemicals was observed to be about 138 tons FeCl₃ per year to maintain a 0.28 mg P / m³ effluent standard and 124 tons FeSO₄ per year to maintain an effluent concentration below the discharge limit (Figure 1.1).

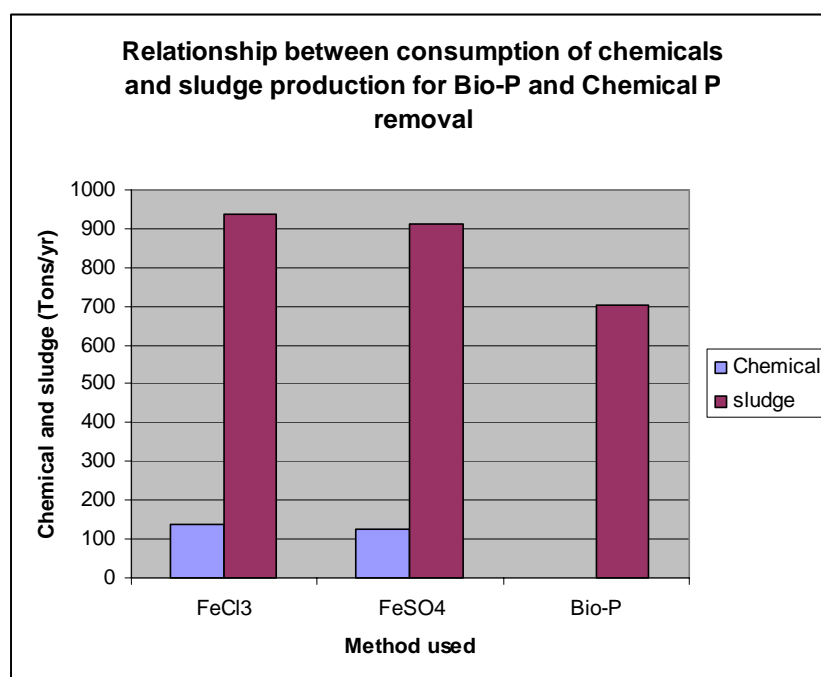


Figure 1.1 Relationship between consumption of chemicals and sludge production for the Bio-P and Chemical-P removal.

Comparison based on economic cost of treatment

The economic cost of treatment has been evaluated based on a summation of the individual costs associated with sludge production, cost of chemicals, energy cost and costs associated to volume savings. The aim of an economic cost is not to reflect the exact financial cost but an estimate that could be used as a guideline for the construction of a new plant or for comparison of the two processes. According to the

results obtained from this study, there is a 0.64 tons/day more sludge produced by chemical wastewater treatment compared to the biological method.

This gives an annual cost saving of 82.000 SEK/year attributed to sludge disposal if biological treatment is used instead of chemical method (Table 1.3). There is an annual cost of 520.000 SEK/yr spent on the purchase of chemicals for chemical phosphorus removal which would have been avoided using biological phosphorus removal. An economic evaluation in terms of sludge production and chemical cost only, reveal that about 520.000 SEK (if FeCl_3 is used) and 270000 SEK (if $\text{Fe}_2(\text{SO}_4)_3$ is used) can be saved. The cost of volume and energy savings for the two processes was difficult to assign a cost as this would depend on many different factors not of interest in this study.

Table 1.3 Cost savings with chemical and biological phosphorus removal.

<i>Parameter</i>	<i>Chemical process</i>	<i>Biological process</i>	<i>Saving</i>	<i>Annual cost saving (SEK/yr)</i>
<i>Sludge Prod. (Tons SS/yr)</i>	938.05 FeCl_3	704.45	233.6	82.000
	912.5 FeSO_4		208.05	73.000
<i>Chemicals (Tons of FeCl_3/yr)</i>	137.97	0	137.97	520.000
<i>Chemicals (Tons of $\text{Fe}_2(\text{SO}_4)_3$/yr)</i>	124.22	0	124.22	270000
<i>Energy requirement (Kg O_2/hr)</i>	500	1000	500	
<i>Volume Reduction of anaerobic zone (m^3)</i>	0	4080	4080	
<i>Total in terms of FeCl_3</i>				602.000
<i>Total in terms of $\text{Fe}_2(\text{SO}_4)_3$</i>				343.000

Conclusion

The EFOR model is a useful tool in determining the differences between the biological and chemical wastewater treatment.

Chemical phosphorus removal performs better in terms of effluent quality than biological phosphorus removal.

Chemical phosphorus removal produces about 0.64 tons/d more sludge than biological phosphorus removal. This is equivalent to about 25% more sludge by chemical than by biological means.

A good deal of volume equivalent to 4.079 m^3 can be saved in the use of chemical phosphorus removal than in the use of biological phosphorus removal.

Biological phosphorus removal requires more energy in terms of capacity of aeration device than chemical phosphorus removal. The study demonstrates that a possible saving of energy amounting to about 500 Kg O_2 /hr equivalence of energy associated to aeration capacity can be saved by using chemical phosphorus removal rather than the Bio-P process.

The annual amount of 137.37 tons of ferric chloride equivalent to 520.000 SEK is required to treat wastewater to discharge limits which can be saved if biological phosphorus removal is used.

It is not a good idea to state that any treatment method is better than the other. Each one has its own advantages and disadvantages. The choice of which method is to be used will depend on the society, the discharge requirements and the costs they are ready to incur.

As a final conclusion, the winning concept these days should not be based on which process should be used in isolation to the other, but rather using the advantages of both processes together to obtain 'best' results, while at the same time minimizing their disadvantages.

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