Chemical wastewater treatment – a cost effective method to upgrade overloaded WWTPs

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Abstract
Lab scale experiments were conducted to examine pollutant removal efficiencies of chemical pre-treatment. 60-85% of the COD and TOC, and 50-65% of the BOD_5 content of raw sewage could be removed by coagulation-flocculation and sedimentation. The minimum effective Al^{3+} and Fe^{3+} doses required for organic removal were in the range of 10-30 and 20-60 mg/L, respectively. The dose of chemicals necessary for optimal organic removal was sufficient to reduce TP below 1.0 mg/L and PO_4-P to less then 0.3 mg/L. Iron containing coagulants could play a major role in odour reduction, as H_2S content of the wastewater decreased significantly due to the addition of Fe(III)-salts. Introduction of chemical pre-treatment provides appropriate treated sewage quality and hydraulic load improvement of WWTPs at low cost. 250 000 USD/yr may be saved as operational cost when introducing chemical pre-treatment at a 13 000 m^3/d capacity AS plant.
Keywords
Coagulation; cost saving; phosphorus; pre-precipitation; upgrading; wastewater

INTRODUCTION

Introducing the tax for the load of the environment (Hungarian Act LXXXIX of 2003) and adopting EU legislations (91/271/EEC) are expected to accelerate the development of the wastewater treatment sector in Hungary. Several new wastewater treatment plants are to be built and pollutant removal efficiencies are required to be improved at most of the ones (typically high loaded AS plants) constructed before 1990. Cost-efficient upgrading methods are needed to minimise the discharge of organic matter (COD) and total phosphorus (together with inorganic nitrogen) to surface waters. Since new regulations have been introduced, the removal of phosphorus is financially encouraged also on those areas where recipients are not sensitive to eutrophication. Because of several changes in the water sector (Buzás et al., 2003) wastewater flows have decreased and pollutant concentrations have increased in the past 15 years in Hungary. Due to the former improper design habits many of our treatment plants receive organic load higher then designed (Licskó et al., 1999; BME, 2004). At the same time, odour nuisance became more serious, as the residence time of sewage in collection system increased and anaerobic conditions have occurred more frequently (Szabó and László, 2002).

One of the possible upgrading methods is the combination of chemical wastewater treatment with biological treatment. Therefore, pollutant removal efficiencies of chemical pre-treatment in different wastewaters were investigated in lab scale experiments. The main objectives were: (1) examining and comparing the pollutant (mainly organic matter and phosphorus) removal efficiencies of different coagulants; (2) selecting the optimal coagulant and the required dose of the chemicals at each WWTP; (3) investigating the correlation between suspended solid (TSS) and total phosphorus (TP) removal; (4) examining the capability of chemicals to remove dissolved organics and different fractions of particulate organic matter; (5) examining the efficiency of iron(III)-containing chemicals in transforming volatile sulphur compounds into poorly water-soluble matters, and thus investigating the role of ferric salts in odour control; (6) estimating the cost of plant upgrading by chemical pre-treatment.

MATERIALS AND METHODS

Coagulation-flocculation Jar tests were carried out in 1-litre glass cylinders with a KEMIRA flocculator device (KEMIRA, 1990). Coagulation, flocculation and sedimentation were performed with the following parameters: 1 min rapid mix (350 rpm); 10 min slow mixing (20 rpm); 20 min settling. Different iron(III) and aluminium salts [Prefloc (iron(III)-sulphate), Bopac (poly-aluminium-chloride), $FeCl_3 \cdot 6H_2O$ and $Al_2(SO_4)_3 \cdot 18H_2O$] were used as coagulants/precipitants. The parameters analysed before and after the coagulation-flocculation and phase separation were as follows: pH; chemical oxygen demand (COD); biochemical oxygen demand (BOD_5), total organic carbon (TOC), total phosphorus (TP), ortho-phosphate (PO_4-P) and total suspended solids (TSS). PO_4-P, dissolved organic carbon (DOC) and dissolved COD/BOD_5 values were measured in the filtrate of 0.45 um pore size membrane filter. Raw wastewater was taken from nine different municipal WWTPs in Hungary where possible plant upgrading by chemical pre-treatment was assessed. Experiments were carried out at original pH and alkalinity.

RESULTS AND DISCUSSION

Chemical pre-treatment can significantly reduce organic matter and phosphorus content of raw wastewater. Maximum removal rates of organics typically vary between 60-85% as COD and TOC and 50-65% as BOD_5 depending on the composition of raw sewage, type and dosage of coagulants (Figure 1.). Residual COD, TOC and BOD_5 concentrations are 130-250 mg/L; 40-70 mg/L and 80-130 mg/L, respectively.

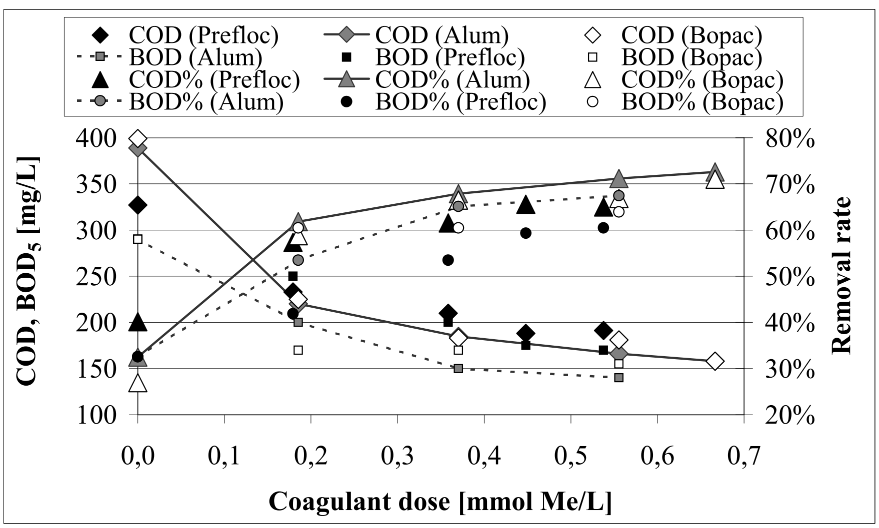

Figure 1. Removal of organic matter by feeding different coagulants

Organic removal is determined mostly by the particulate matters, as primarily that is the fraction that can be removed by coagulation-flocculation and phase-separation with a high efficiency (Figure 2.). Practically all the organic matter >8 um can be coagulated and settled when applying high enough metal dose. In certain cases, significant part (15-40%) of the dissolved (<0.45 um) organic matter can also be removed; however in other wastewaters the removal of DOC (or dissolved COD) is negligible. At the nine investigated WWTPs due to the different raw wastewater composition significantly different coagulant dosages were required for appropriate organic removal. Comparing coagulants on molar base, aluminium and ferric salts removed COD, TOC and BOD_5 with similar efficiency. It is explained by the fact that approximately the same amount of active metal-hydroxide is formed from the same amount of added coagulant (metal-ion, expressed in mmol/L). The minimum effective Al^{3+} and Fe^{3+} doses required for organic removal were in the range of 10-30 and 20-60 mg/L, respectively. Pre-polymerised Al salts provided similar organic matter removal efficiency than the simple trivalent metal salts.

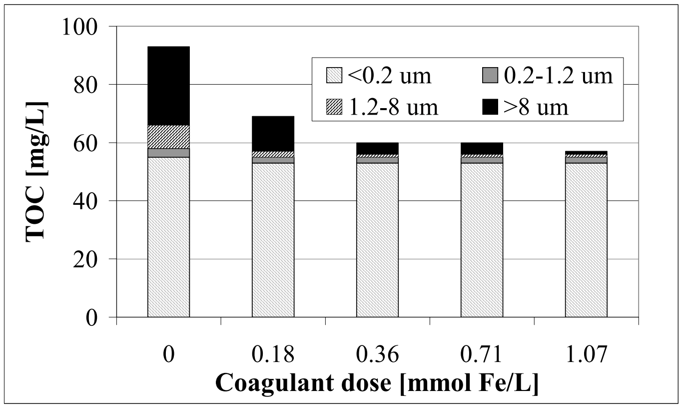

Figure 2. Residual TOC fractions (ferric-chloride)

The dosage of simple (trivalent) metal salts necessary for optimal organic removal was sufficient to reduce TP below 1.0 mg/L and dissolved phosphorus (PO_4-P) to less than 0.3 mg/L (Figure 3.). At high doses there is practically no residual PO_4-P present; however chemically treated wastewater contains small amount colloidal matters including a portion of the P containing precipitate. Consequently the residual phosphorus content depends on the removal efficiency of suspended solids (Figure 4.). Decreasing TP concentration below 0.5-1.0 mg/L often requires extra suspended solids removal (e.g. sand filtration).

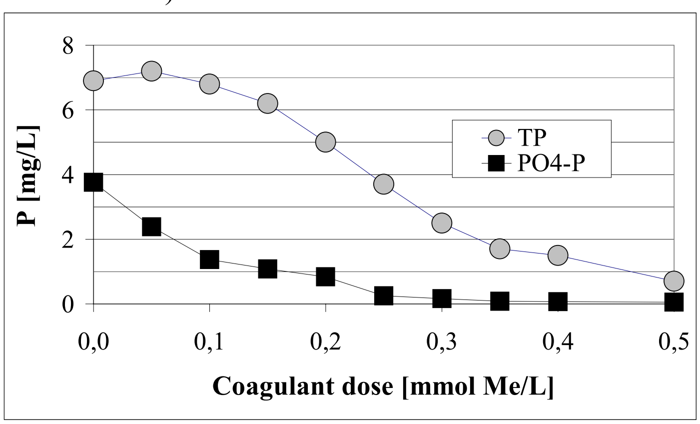

Figure 3. Residual TP and PO_4-P concentration (aluminium-chloride)

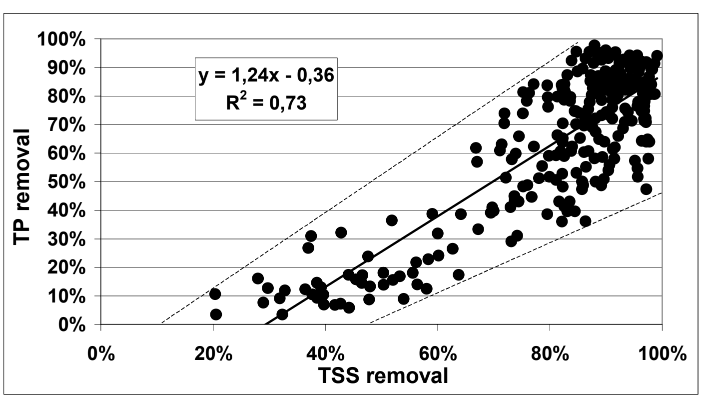

Figure 4. TP removal versus TSS removal

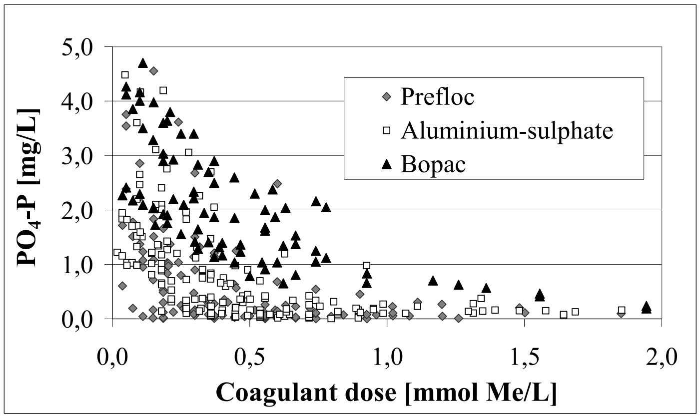

Figure 5. Residual PO_4-P concentration in different WWs

While the different trivalent Al and Fe salts show similar efficiencies (on molar base) in phosphate precipitation, pre-polymerised salts are less efficient in removing PO_4-P (Figure 5.). Phosphate is primarily removed by chemical precipitate formation. As the extent of precipitate formation decreases with increasing OH/Me ratio; higher the basicity (polymerisation degree), lower the phosphate removal efficiency will be (Ratnaweera et al., 1992; Gilberg et al., 1996).

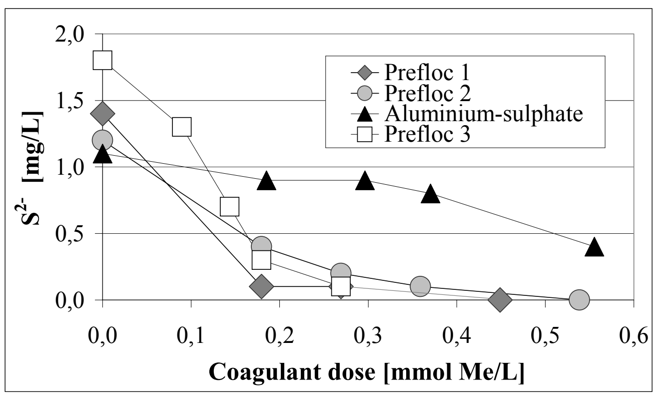

Figure 6. Residual dissolved sulphide concentration

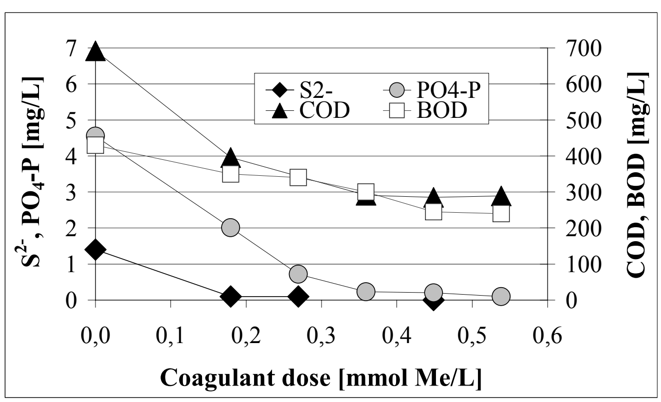

Figure 7. Residual dissolved sulphide, ortho-phosphate and organic concentration

Results of lab experiments show that iron(III)-containing coagulants might be effective in odour reduction at WWTPs (Figure 6.). However, the very low coagulant dose, which can be sufficient to decrease H_2S and different mercaptans, is not enough to precipitate PO_4-P completely (Figure 7.). Very often the efficient coagulation-flocculation of suspended matters and thus the removal of organic matters require even higher doses. With increasing coagulant doses we can reach that iron-sulphide and particulate organics, which appear in the form of colloid dispersion, can be converted into easily settleable flocs.

According to cost estimations, introduction of chemical pre-treatment provides appropriate quality and quantity (volume) improvement of WWTPs at low cost. The cost saving appears in the reduced oxygen utilization - initiated by organic load reduction - in the downstream treatment processes. Another important cost factor in Hungary is the tax for the load of environment that WWTPs are obliged to pay since 2004 when discharging - among others - COD and TP (Hungarian Act LXXXIX of 2003). Costs were evaluated based on a case study carried out at an activated sludge treatment plant having a wastewater flow of 13 000 m^3/d. Not considering the costs of sludge treatment it is estimated that 250 000 USD may be saved annually as operational cost when introducing chemical pre-treatment (Table 1.).

Table 1. Estimated annual operational costs of biological and combined chemical-biological treatment

Activated sludge treatment with nitrification (13 000 m^3/d)	**Only biological treatment**	**Chemical pre-treatment**	
Total oxygen consumption	1 370	1 000	kg O_2/h
Energy requirement for aeration	685	500	kWh
COD concentration in treated wastewater	65	45	mg/L
TP concentration in treated wastewater	11	1,5	mg/L
Energy cost	600 000	440 000	USD/year
Water pollution tax (after COD and TP)	370 000	110 000	USD/year
Coagulant cost		170 000	USD/year
Annual operational cost	970 000	720 000	USD/year
Annual savings		**250 000**	**USD/year**

CONCLUSION

Increased attention has been driven to more efficient pollutant removal at WWTPs by a new Hungarian law that stimulates WWTPs to minimise their COD and TP discharge to recipients by introducing a tax for the load of environment. Lab experiments conducted at 9 different WWTPs proved that coagulation-flocculation processes (that have been being applied in surface water treatment since decades) are able to transform suspended solids of wastewaters to settleable form. Non-settleable suspended solids of raw wastewater contribute to 30-45 % of the COD load of the biological treatment stage. This organic matter fraction can effectively be removed by chemical pre-treatment (coagulation-flocculation and settling) already in the primary sedimentation tank and thus only 25-35 % of the organic load present in raw wastewater reaches the aeration tank.

Based on the case studies it can be concluded that different coagulants show similar pollutant (COD, BOD_5, TSS, TP, PO_4-P) removal efficiencies; however pre-polymerised metal salts have smaller capability in phosphate precipitation. Removal of TP depends on the suspended solids removal rate, therefore very low residual TP can only be reached by applying phase-separation methods more efficient than settling. Iron(III)-containing coagulants can play a role in odour control at WWTPs as they are able to precipitate dissolved sulphides, thus prevent the formation of malodorous hydrogen-sulphide.

Normally, the price of the coagulant and the method of sludge treatment and utilization will be decisive when selecting the optimal coagulant. However, optimum doses might vary a lot depending on the objectives. Significantly different doses are needed for the sufficient removal of the different pollutant substances requires, reflecting a conflict that requires optimisation.

Chemical pre-treatment can provide a cost-effective method to upgrade high-loaded WWTPs. It was estimated that 250 000 USD may be saved annually as operational cost when introducing chemical pre-treatment at a 13 000 m^3/d capacity activated sludge plant.

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REFERENCES

Buzás K., Licskó, I. and Melicz, Z. (2003). Lessons of a Decade: Changes in Sewerage and Wastewater Treatment in Hungary, *Wastewater 2003 - 5th International Biennial Conference and Exhibition, 13-15 May, 2003, Olomouc*, pp. 9-14.
Gillberg, L., Nilsson., D and Åkesson, M. (1996). The Influence of pH when Precipitating Orthophosphate with Aluminum and Iron Salts, In: *Chemical Water and Wastewater Treatment IV. - Proceedings of the 7th Gothenburg Symposium Edinburgh 1996, H. H. Hahn, E. Hoffmann and H. Ødegaard (Eds.), Springer-Verlag Berlin Heidelberg New York*, pp. 95-105.
KEMIRA KEMI AB Water Treatment, 1990. *The Handbook on Water Treatment*, KEMIRA KEMI, Helsingborg.
Licskó, I., Melicz, Z., Ádám, R., Fürst, Á., Vadnay, Á., Tóth, Gy. and Mészáros, J. (1999). Impacts of Drastic Sewage Decrease on the Operation of Municipal WWTPs in Hungary: case studies, *8th IAWQ Conference on Design, Operation and Economics of Large Wastewater Treatment Plants, 6-9 September, 1999, Budapest, Hungary*, pp. 504-510.
BME (2004). *Korszerű szennyvíztisztító rendszerek kialakítása az EU csatlakozás tükrében* (*Development of Advanced Wastewater Treatment Systems to Meet EU Requirements*), NKFP-3A/0042/2002 Research Report 2004, Budapest University of Technology and Economics (BME), Budapest (In Hungarian)
Ratnaweera, H., Fettig, J. and Ødegaard, H. (1992). Particle and phosphate removal mechanisms with prepolymerized coagulants, In: *Chemical Water and Wastewater Treatment II. - Proceedings of the 5th Gothenburg Symposium 1992, R. Klute and H. H. Hahn (Eds.), Springer-Verlag Berlin Heidelberg New York*, pp. 3-17.
Szabó, A. and László, B. (2002). Odour formation in sewer systems in Hungary, *1st IWA Young Researchers Conference, September 9-10, 2002, Cranfield University, UK*, pp. 121-127.
Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment
Hungarian Act LXXXIX of 2003 *on the tax for the load of environment* (In Hungarian)