EXPECTED EFFICIENCY OF CHEMICAL WASTEWATER TREATMENT– CASE STUDIES IN HUNGARY

Anita Szabó and István Licskó
(Budapest University of Technology and Economics, Budapest, HUNGARY)

ABSTRACT: Lab scale experiments were conducted to examine pollutant removal efficiencies of chemical pre-treatment. Depending on the quality of raw sewage, type and dosage of coagulants, 60-85% of the COD and 50-65% of the BOD_5 content of raw sewage could be removed by coagulation-flocculation and subsequent 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; however, further decreasing often requires extra suspended solids removal (e.g. sand filtration). At optimum coagulant dose the dissolved phosphorus (PO_4-P) has not exceeded 0.3 mg/L. Iron(III)-containing coagulants also have a significant role in odour reduction at WWTPs, as H_2S content of the wastewater decreased significantly due to addition of Fe(III)-salts. The introduction of chemical pre-treatment provides appropriate quality and quantity (volume) improvement of WWTP at low cost. 250 000 USD can be saved annually as operational cost when introducing chemical pre-treatment at a 13 000 m^3/d capacity plant.

INTRODUCTION

In Hungary several new wastewater treatment plants (WWTPs) are to be built and a significant number of the old ones have to be upgraded at low cost. Since the beginning of the 1990s (parallel to the social-economic changes in Hungary) at the existing WWTPs we face the problem of lower wastewater flows and higher pollutant concentrations due to the drinking water consumption decreasing. Very often our WWTPs are hydraulically under-loaded while receiving near the same suspended solid and organic load as designed. 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.

Typical pollutant concentrations in raw wastewater in Hungary and concentration values during the experiments described in this paper are shown in TABLE 1. Due to the relatively low per capita drinking water consumption wastewaters in Hungary have medium to high strength. Lower concentration values occur at areas with combined sewerage systems, usually at the time of rain events and snow melting.

One of the possible solutions is the application of chemical wastewater treatment in itself, or in combination with biological treatment. Therefore, pollutant removal efficiencies of chemical pre-treatment in different wastewaters were investigated at lab scale experiments. The objective were different at the WWTPs investigated: (1) examining and comparing the pollutant (mainly organic matter and phosphorus) removal efficiencies of different coagulants; (2) selecting

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the optimal coagulant and the required dose of the chemical 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; (5) investigating the role of ferric salts in odour control; (6) estimating the operational costs of activated sludge treatment plant upgrading by chemical pre-treatment.

TABLE 1. Pollutant concentrations in raw municipal WW in Hungary

Component	Typical concentration in Hungary [mg/L]	Range in lab experiments [mg/L]	Average in lab experiments [mg/L]	Medium-high strength WW (Metcalf & Eddy, 2003)
COD	400-800	250-4000	570	430-800
BOD_5	200-400	70-460	305	190-350
TP	5-12	2-17	9	7-12
PO_4-P	3-6	0.9-7.4	3.7	
TSS	150-400	40-2050	320	210-400
NH_4-N	30-80	-	-	25-45

MATERIALS AND METHODS

Coagulation-flocculation Jar tests were performed in 1-litre glass cylinders with a KEMIRA flocculator device (KEMIRA, 1990). Coagulation, flocculation and sedimentation were carried out 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), TP, ortho-phosphate (PO_4-P) and TSS. PO_4-P and dissolved COD/BOD_5 values were measured in the filtrate of 0.45 um pore size membrane filter. Raw wastewater was taken from eight 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

Results of lab experiments showed that chemical pre-treatment can significantly reduce organic matter and phosphorus contents of raw wastewater.

Depending on the quality of raw sewage, type and dosage of coagulants, the removal rates of organic content are in the range of 60-85% as COD and 50-65% as BOD_5. Higher removal rates are reached when high portion of the organic matter is in particulate (>0.45 um) form. FIGURE 1. shows the removal rate of

organics and the residual organic matter concentration after chemical treatment and settling.

The residual COD and BOD_5 can be reduced to 130-250 and 80-120 mg/L, respectively. COD and BOD_5 removal is typically determined by the particulate portion of organic matter, as primarily that is the fraction that can be removed by coagulation-flocculation and phase-separation with a high efficiency (FIGURE 2-3.). However, significant part (25-40%) of the dissolved (<0.45 um) organic matter can also be removed in certain cases.

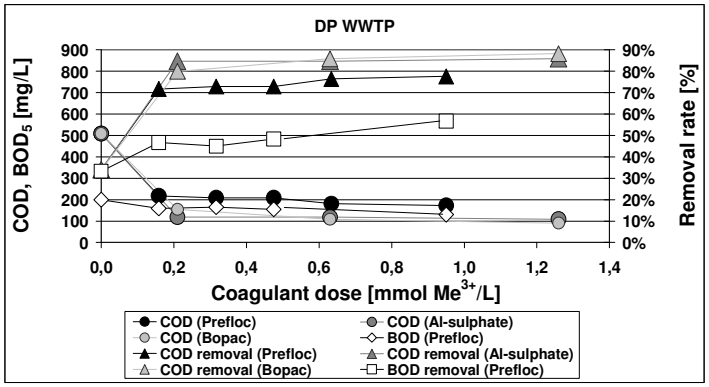

FIGURE 1. Removal of organic matter by feeding different coagulants

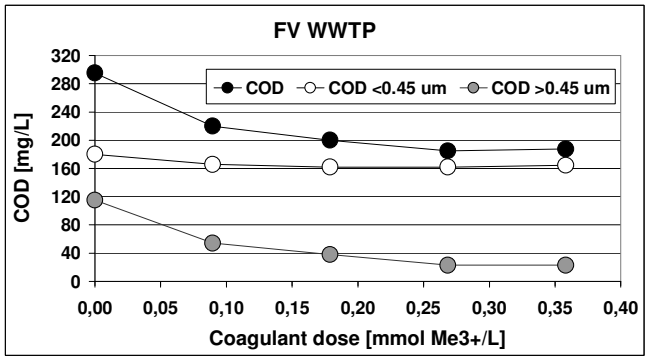

FIGURE 2. Residual COD fractions

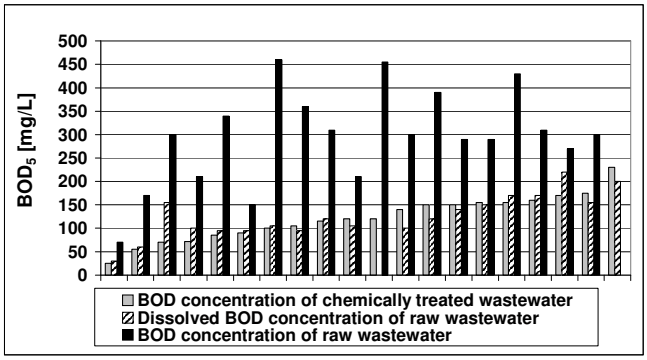

FIGURE 3. BOD_5 concentration in raw and coagulated wastewater

Coagulation-flocculation and the subsequent phase-separation changes the composition of biodegradable organic matter, and the dynamics of biochemical degradation. By chemical treatment or by filtering raw wastewater through 0.45 um pore size membrane filter most of the slowly biodegradable organic matter is removed, and the remaining organic matter is rapidly biodegradable (FIGURE 4.). Due to this, less oxygen and shorter residence time are required for the bacterial degradation.

At the eight 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 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 slightly higher organic matter removal efficiency than the simple trivalent metal salts.

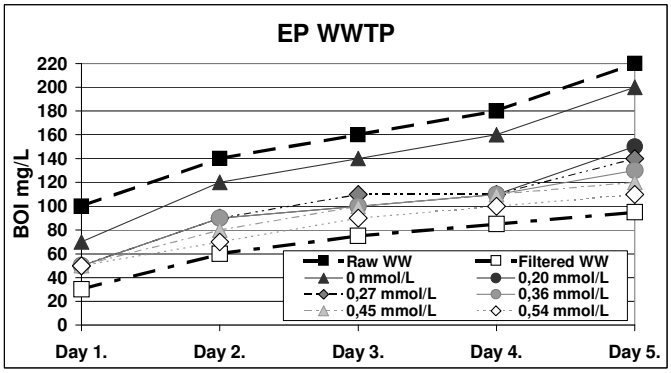

FIGURE 4. Daily BOD values in raw, filtered and chemically treated wastewater

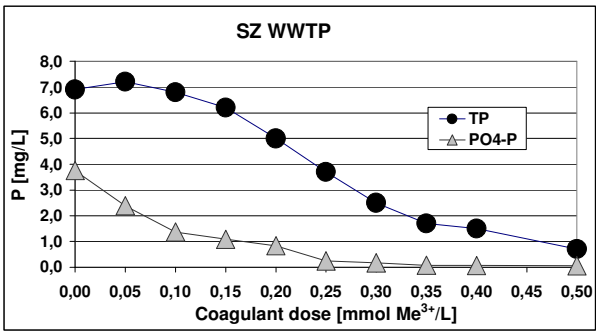

FIGURE 5. Residual TP and PO_4-P concentration

The dose of chemicals necessary for optimal organic removal was sufficient to reduce TP below 1.0 mg/L and dissolved phosphorus (PO_4-P) to

0.3 mg/L (FIGURE 5.). Consequently the residual phosphorus content depends on the removal efficiency of suspended solids (FIGURE 6.), however decreasing TP concentration below 0.5-1.0 mg/L often requires extra suspended solids removal (e.g. sand filtration).

The applied coagulants are very efficient in precipitating ortho-phosphate. PO_4-P <0.5 mg/L are safely reached by feeding trivalent metal salts in a dosage of 0.5 mmol/L. In certain cases much smaller coagulant doses (0.1-0.2 mmol/L) are enough to reach such a low concentration. However, depending on raw wastewater characteristics residual PO_4-P can vary in a wide range, especially when the applied coagulant dose is smaller than 0.4 mmol/L. The efficiency of phosphate precipitation depends on the applied coagulant dose, the basicity (Me/OH ratio) of the coagulant, the initial PO_4-P concentration, pH, TSS, COD and dissolved COD concentrations of raw wastewater.

While the different trivalent Al and Fe salts show similar efficiencies (on molar base) in phosphate precipitation, pre-polymerised salts are less efficient in precipitating PO_4-P.

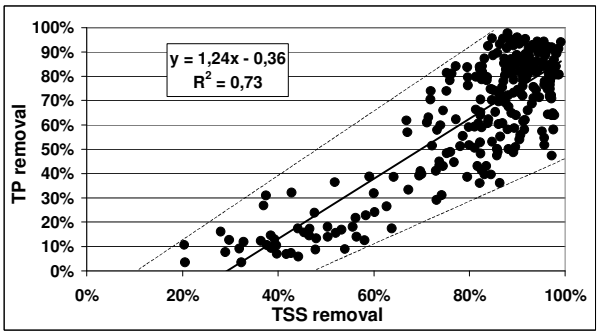

FIGURE 6. TP removal versus TSS removal

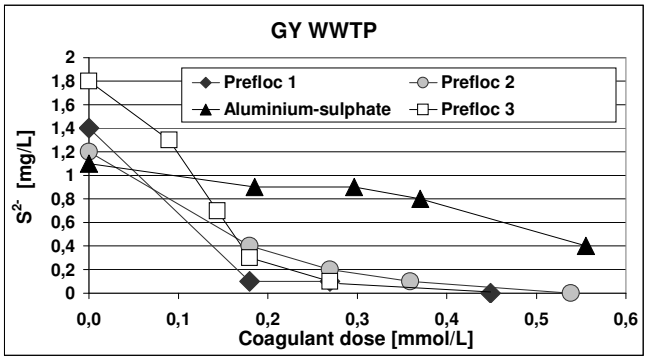

FIGURE 7. Residual dissolved sulphide concentration

Results of lab experiments show that iron(III)-containing coagulants might be effective in odour reduction at WWTPs (FIGURE 7.). However, the very low coagulant dose, which can be sufficient to decrease H_2S and different mercaptans, is not efficient in coagulation-flocculation and sedimentation of suspended organic matters. 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.

TABLE 2. 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	1 370	1 000	kg O_2/h
Energy requirement for aeration	685	500	kWh
COD concentration in	65	45	mg/L
TP concentration in treated	11	1,5	mg/L
Energy cost	600 000	440 000	USD/yea
Water pollution tax (after COD	370 000	110 000	USD/yea
Coagulant cost		170 000	USD/yea
Annual operational cost	970 000	720 000	USD/yea
Annual savings		**250 000**	

It was proved that introduction of chemical pre-treatment provides appropriate quality and quantity (volume) improvement of WWTP 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 law, 2003. LXXXIX.). 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 can be saved annually as operational cost when introducing chemical pre-treatment (TABLE 2.).

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. Organic removal efficiency of chemical wastewater treatment - which is well-known in phosphorus removal - was assessed. Lab experiments conducted at 8 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. Due to this, price of the coagulant and the method of sludge treatment and utilization will be decisive when selecting the optimal coagulant.

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

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