Improvement of plant availability of phosphates in coagulated sludge

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Abstract

Nowadays wastewater sludge is regarded as a resource of phosphorus. Opposite to widespread approaches for the improvement of plant availability of phosphates, this study shows the results for the improvement of sludge quality at the step of its production. The possibility of partial substitution of inorganic coagulants by organic cationic polymers was studied. The experiments were carried out on synthetic wastewaters with high-medium-low concentrations of suspended solids and total phosphorus. Simultaneous and double types of dosing were applied. The results showed the substitution possibilities up to 46.5% at simultaneous type of dosing. The significant influence of cationic polymers was observed only in range of low coagulant dosages. The efficiency of double type of dosing was not detected.

Keywords: Cationic polymer**,** inorganic coagulant, phosphorus, substitution, wastewater treatment.

Introduction

Phosphorus is a key nutrient, which in sufficient amount provides normal vital activity and development of all living organisms. However, the excess amount of phosphorus in natural water resources, caused by discharges of wastewater or insufficiently treated wastewater, is a cause of eutrophication (Mainstone et al., 2002).

Nowadays at the majority of treatment plants a coagulation process is used for wastewater treatment. Such method provides high extent of phosphorus removal and guarantees efficient treatment of wastewater of different quality (Ebeling et al., 2003). High efficiency of treatment is achieved by the adjustment of coagulant dosage according to the inflow quality; however such approach usually requires addition of high coagulant dosages, which significantly deteriorates sludge value and reduces the possibility of its further use in agriculture.

On the other hand, the resources of mineral phosphorus are limited, and now wastewater sludge is increasingly regarded as a resource of valuable element (Cordell et al., 2011; Cassidy et al., 1998). Many research works are focused on finding ways to improve sludge quality in order to make contained in it elements available for plants. The most widespread approach is to treat sludge and transform bonded phosphorus into available form. So the sludge is regarded as a substrate which after several steps of transformation acquires new quality. The methods based on such approach are digestion, high temperature pyrolysis and chemical treatment of sludge (Hossain et al., 2011; Hargreaves et al., 2008). This requires significant energy consumption and the need for additional equipment.

The key difference of the approach used in this research work is that we tried to change the quality of sludge at the step of its formation. The amount of aluminium in sludge was reduced by partial substitution of coagulant by cationic polymer.

The results of reduction of required coagulant dosage by the use of organic polymers are represented in this paper.

Materials and Methods

We carried out experiments with model wastewaters and domestic wastewater from Lillestrøm WWTP. Compositions of synthetic wastewaters differed by phosphorus and suspended solids contents.

For the experiments with domestic wastewater we used outlet from biofilters before it entered secondary sedimentation tank.

The chemicals used were coagulants Kemira ALS (aluminium sulphate) and Kemira PAX XL-61 (prepolymerised aluminium coagulant) and in the experiments with domestic wastewater Kemira PIX-18 ($FeClSO_4$) was also used. The range of coagulant dosage variation included doses that were lower and higher than the optimum dose for each of the coagulants. In total, for each of coagulants we used five doses. The optimum doses were determined in the preliminary experiments.

As organic cationic polymers we have chosen FO 4350 and FO 4240. In the experiments we used 1g/l solutions of polymers. For each of the polymers the dosage range included values 1 mg/l, 3 mg/l and 5 mg/l.

The coagulation experiments were carried out at pH values (6,0 ±0,2) and (7,5±0,2). For the coagulation process to result in the desired pH value, we adjusted the initial pH of raw water depending on the coagulant dosages we added.

For the coagulation experiments we used jar-test apparatus (Kemira Flocculator 2000) with six beakers. The mode of mixing was: rapid mixing for 30 seconds, then slow mixing during 10 min followed by sedimentation for 15 min.

In the experiments we used simultaneous and double types of dosing of coagulant and polymer. While using simultaneous type of dosing, coagulant and organic polymer were added simultaneously to the jars at the beginning of rapid mixing. At the double type of dosing, for each polymer dose we used two beakers. At the first step the same dose of cationic polymer was added to the jars at the beginning of rapid mixing, and after sedimentation 500 ml of supernatant was taken from each of the beakers. Then, these collected samples were mixed together, making up 1l of supernatant. As the second step, a coagulant was added to the jar with supernatant. After sedimentation, we collected about 200 ml of supernatant and used it as a sample for further analysis.

We controlled suspended solids (SS), total phosphorus (T-P), ortho phosphates (O-P) and turbidity in the collected samples. Determination of residual SS content was done by gravimetric method. Residual T-P and O-P contents were measured according to standard ISO 6867/2004. Turbidity was measured by Hach 2100Q portable turbidimeter. The extents of SS removal and T-P removal were the main parameters by which the evaluation of treatment efficiency was done.

In order to reduce the number of required experiments while retaining the most important features, we made fractional factorial design of the experiment using UNSCRAMBLER program.

Results and Discussion

We have carried out experiments according to the experimental design. There was an obvious difference between results obtained with simultaneous and double types of dosing.

The results for simultaneous dosing of ALS and cationic polymers clearly show the difference in efficiencies of treatment achieved with addition of cationic polymers and without it. Although this difference changed with the synthetic wastewater type, in each case the lines depicting dependences of T-P and SS removal efficiencies on coagulant dosage had the same trend.

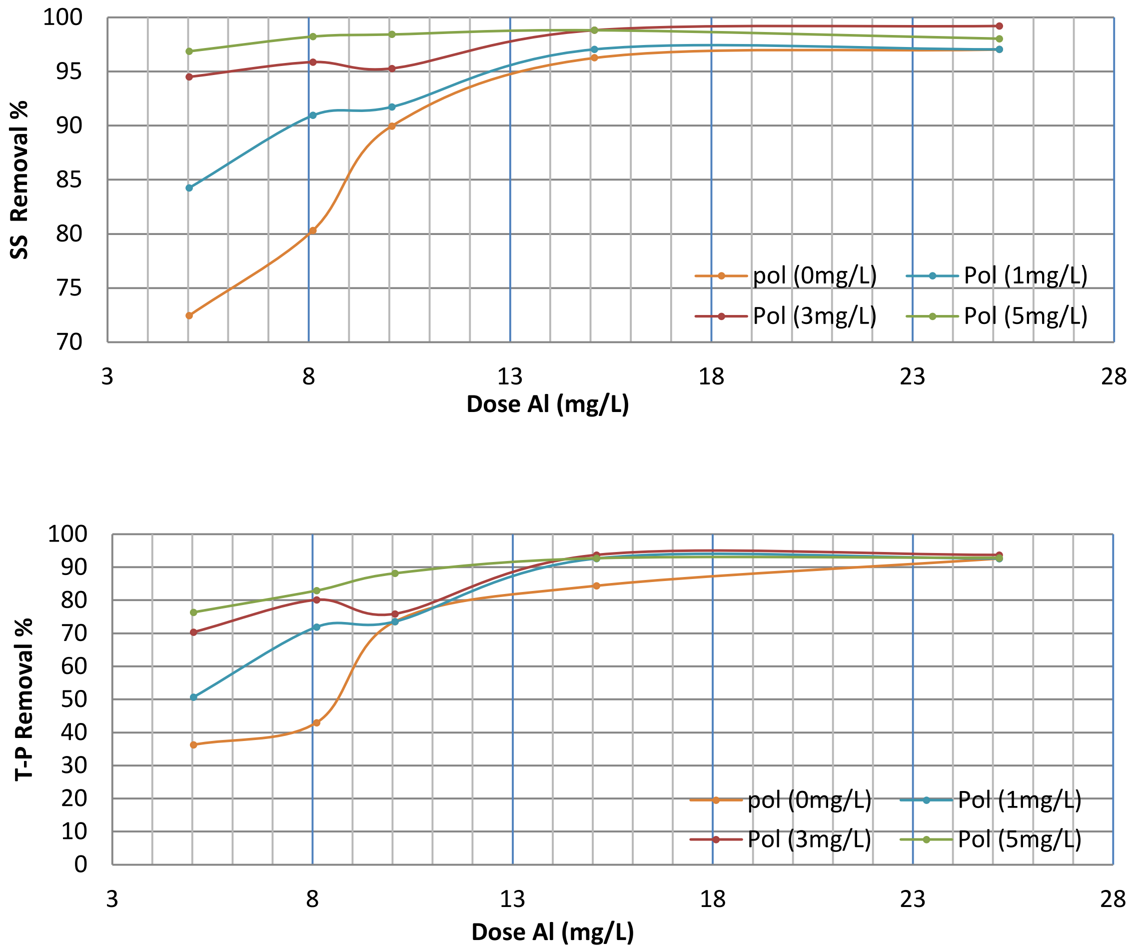

Figure 1 Influence of cationic polymer and ALS on SS (above) and T-P (below) removal in synthetic wastewater with high SS and high T-P content at pH 7.5.

As shown in the figure 1, at low coagulant dosages the highest efficiencies of treatment were achieved with the use of 3 mg/l and 5 mg/l of polymer. For example, to remove 80% of T-P was possible with 12 mg – Al/l, with 7 mg – Al/l combined with 5 mg/l of cationic polymer or with 8 mg – Al/l and 3 mg/l of polymer. It means that combination of inorganic coagulant with cationic polymer can significantly reduce required dosage of coagulant without any deterioration of treatment efficiency. In this particular case, the required dosage of coagulant can be 1.7 times lower if instead of coagulant use its combination with organic polymer. However, with the increase in coagulant dose, the positive effect of cationic polymers becomes insignificant.

Opposite to this, the results for PAX XL-61 show that influence of cationic polymers was insignificant during the whole range of coagulant dosages. In most of cases the difference in treatment efficiencies was not more than 5 – 7%, and the addition of different dosages of polymer gave almost the same results.

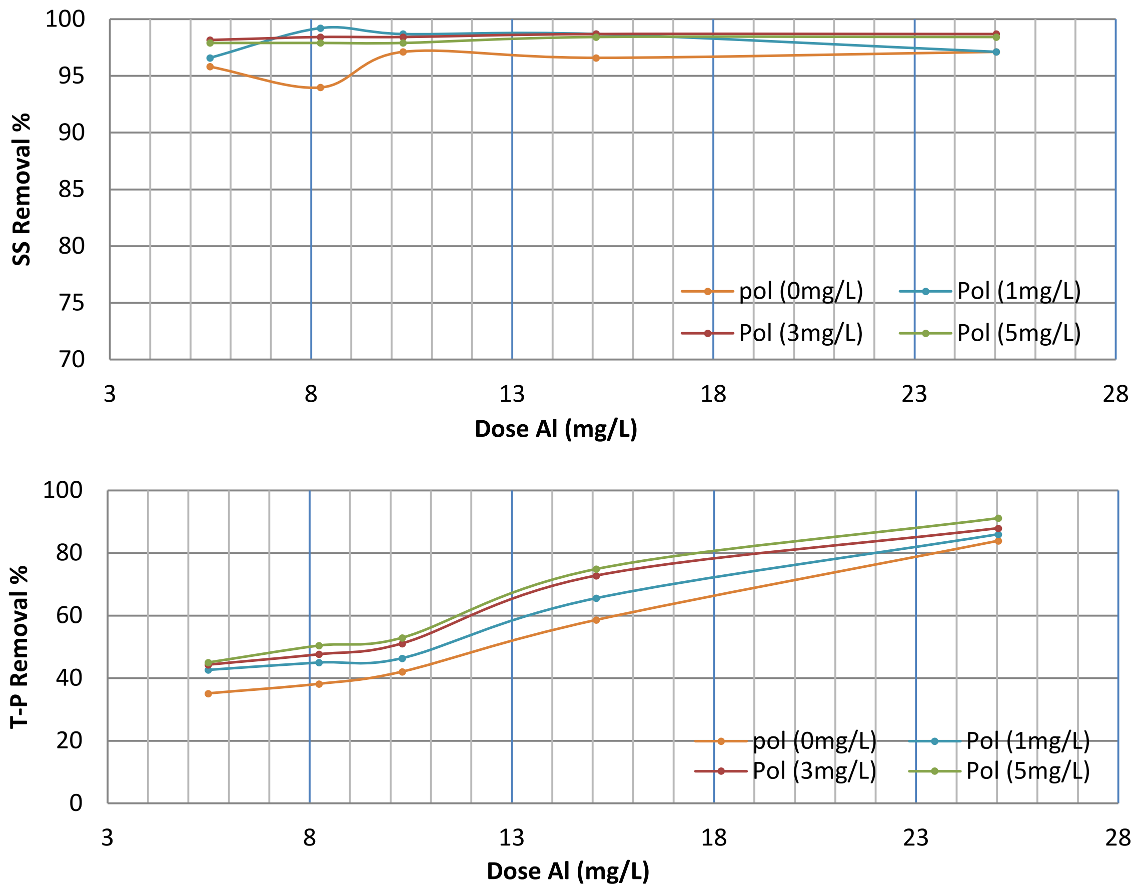

Figure 2 Influence of cationic polymer and PAX XL-61 on SS (above) and T-P (below) removal in synthetic wastewater with medium SS and medium T-P content at pH 6.0.

If to compare efficiencies of T-P and SS removals provided by ALS and PAX XL-61, it becomes clear that ALS is more effective for the removal of phosphates, while PAX XL-61 acts more like polymer and gives higher extents of SS removal.

For double type of dosing the situation was completely different because results were unstable and significantly differed one from another, so it was impossible to find a common function, suitable for explanation of all the obtained data. In order to have more accurate results, we decided to carry out each test in several replicates. However, this did not give any improvement because the results for the tests carried out under the same conditions differed up to 15 – 17%.

After analysis of the obtained data, we have proposed several factors that could contribute to such fluctuations in treatment efficiency. These factors could be the temperature of model water and the sampling method we used for taking supernatant from jars after coagulation. To evaluate the contribution of each of these factors additional tests were carried out.

In these tests we found out that the sampling method did not influence the results, however the temperature of model water had an important role. For example, the treatment efficiency was higher when the experiments were carried out on model water with average temperature 16 – 18ºC, and it was about 10% lower when the temperature of water was about 12 – 14ºC. Interestingly, that such difference was observed only at low coagulant doses. After that it was decided to consider the impact of temperature, therefore in further experiments model water with temperature about 12 – 14ºC was used.

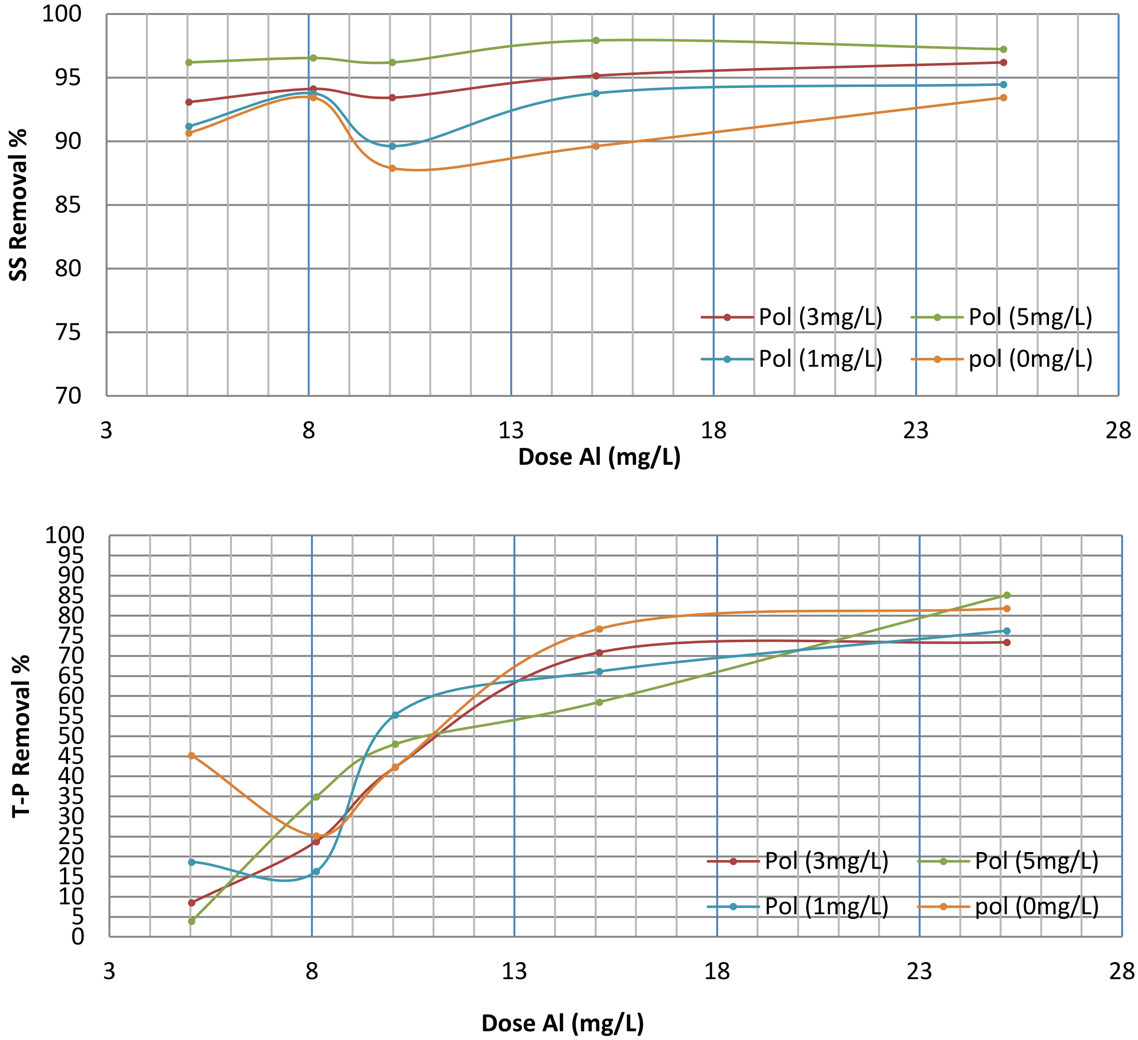

Figure 3 Influence of cationic polymer and ALS on SS (above) and T-P (below) removal in synthetic wastewater with high SS and medium T-P content at pH 7.5.

It is clear from these figures that temperature was not the only factor that influenced the results because even at almost constant temperature of model water the treatment efficiencies differed greatly.

Table 1 Influence of cationic polymers on SS and T-P removal at simultaneous and double types of dosing.

Raw water		Difference	Simultaneous dosing			Double dosing		
Particle content	Phosphate content	removal efficiency	with 5 mg-Al/l	with 8 mg-Al/l	with 10 mg-Al/l	with 5 mg-Al/l	with 8 mg-Al/l	with 10 mg-Al/l
H	H	SS %	25	24	9.3	5.3	3.5	8.3
		TP %	41	35.5	11.2	1.8	4.4	4.7
H	M	SS %	24.4	18	9.4	19.2	3	
		TP %	40	40	14.6			2
H	L	SS %	33	22.6	7.1	6.8	5.7	4.6
		TP %	46.5	39.5	12		19.4	4.2
M	M	SS %	3.8	4.7	3.4		2	
		TP %	7.1	16.2	6.3			
M	L	SS %	4.9	4.3	6.4	3.8	5	4.1
		TP %	12.3	20.6	4.5	1.3	8	3.6
L	L	SS %	5	4.7	7.5	4.4	4.9	6.4
		TP %	8.9	5.6	8.2	19.6	13	12.4

Each of the given in the table values shows how cationic polymers in combination with coagulant increase the efficiency of treatment compared to coagulant used alone. At simultaneous type of dosing and coagulant dosages 5 mg – Al/l and 8 mg – Al/l, addition of cationic polymer can improve the extent of treatment up to 46.5%. This means that it is possible to reduce the molar ratio Al:P approximately in 1.86 times. However, such significant influence of cationic polymers is observed only in model waters with high particles content, and in model waters with medium and low particles content the treatment efficiencies were lower and were close to that achieved at double type of dosing.

In the set of experiments on real wastewater only simultaneous type of dosing was used because it gave telling results. Only one type of cationic polymer (FO 4350) was used because experiments with model waters showed that polymers FO 4350 and FO 4240 had the same efficiency. In addition to ALS and PAX XL-61 we used coagulant PAX 18.

In all cases addition of polymer improved the efficiency of treatment, and the highest extents of SS and T-P removal were achieved when coagulants were combined with 5 mg/l of cationic polymer. This confirms the results of the experiments with model water and shows that combination cationic polymer and coagulant treats water more effectively than coagulant used alone.

Conclusions

Cationic polymers can significantly influence the extent of SS and T-P removal. This phenomenon is observed at coagulant dosages up to 10 mg – Al/l.

In several cases the improvement of treatment efficiency reaches the value of 46.5% which confirms that combination of polymer and coagulant can provide the efficient treatment at relatively low coagulant dosages

Partial substitution of coagulant by the addition of cationic polymer reduces the required dosage of coagulant and results in lower coagulant content in sludge. This improves the quality of sludge and makes it applicable in agriculture as fertilizer.

Simultaneous type of dosing is preferable as the efficiency of double dosing has not been proved yet.

As further steps, research of factors that influence the results at double type of dosing is recommended. A mathematical model for the prediction of changes in efficiency of SS and T -P removal at simultaneous usage of coagulant and cationic polymer can be made.

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