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Use of inorganic coagulants and polyelectrolytes to sonicated sewage sludge for improvement of sludge dewatering

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ABSTRACT

The paper presents the research on the possible use of inorganic coagulants and polyelectrolytes for conditioning of sonicated and non-sonicated sewage sludges and the impact of conditioning process on the sludge rheological parameters and dewatering process. Dewatering of sludge with a high share of organic matter or sludge with a high percentage of fine fractions and colloidal suspensions causes clogging of the filter, and an increase in filtration resistance does not bring good technological and economic effects. To improve the degree of dewatering of such sonicated and non-sonicated sludges, coagulants and polyelectrolytes and their mixture in appropriate proportions and conditions could be used. The usage of both substances: PIX and polyelectrolyte helped to achieve a cleaner filtrate in comparison with when only polyelectrolyte is used. The rheological parameters of sludge, its structure as well as processes parameters, such as vacuum filtration and pressure filtration were determined during tests. The results show that during application in the conditioning of sonicated sludge, both chemical substances (inorganic coagulant and polyelectrolyte) resulted in a significant improvement of parameters used in order to determine the susceptibility to sludge dewatering.

Keywords: Sewage sludge; Sonication; Conditioning; Dewatering; Coagulants; Polyelectrolyte

1. Introduction

One of the interesting methods of sewage sludge processing is sludge disintegration which is basically an important factor in enhancing the efficiency of sludge stabilization [1–5]. During disintegration, the solid particles of sludge are fragmented and the destruction of microorganism cells takes place with its release to liquid sludge. The resulting dead and dispersed organic matter is then easily mineralized by biochemical methods. However, there are some disadvantages arising from the use of disintegration method. The main problem is associated with the release of nutrients from digested sludge into the effluent during sludge dewatering [6,7]. The problem of increasing degree of sludge dewatering, which

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accounts for more than half of total load of pollutants flowing into the wastewater treatment plant, still poses a very important challenge.

Sludge is made up of both organic and inorganic substances containing finely dispersed (colloidal) fractions and macromolecules. Clay particles, macroparticles, hydroxides, and the emulsions are chemically active. Various shapes of these particles such as plaques, threads, and needles affect the intensification of surface phenomena and their very small sizes cause physicochemical forces at the phase interface. Dewatering of sludge with a high share of organic matter or sludge with a high percentage of fine fractions and colloidal suspensions (sonicated sludge–sludge floc breaks under sonication process and fine suspension is created) causes clogging of the fabric filter. As a result, the increase in filtration resistance does not bring about any positive technological and economic effects. Thus, in the case of some kind of sludge, the use of only polyelectrolytes for conditioning provides no satisfactory results. Enhancing the degree of dewatering of such sludge as well as sonicated sludge can be achieved by using a combination of coagulants and polymers. The paper presents the research on the use of inorganic coagulants and polymers for conditioning of sonicated and non-sonicated sewage sludges and the effects of conditioning process on sludge dewatering and the quality of sludge supernatant.

2. Materials and methods

2.1. Sludge samples

Samples of sewage sludge were obtained from municipal wastewater treatment plant with an average daily flow of 40,000 m^3/d. The samples for research were taken after anaerobic digestion. The following symbols are assigned to sludge samples: OP—digested sludge; ON—digested and sonicated sludge.

2.2. Analytical methods

Sonication of sludge was carried out under static conditions. A volume of 300 ml of sludge was prepared each time. During sonification, powerful ultrasonic disintegrator with automatic tuning Sonics VC750 was used. The parameters of sonication were as follows: frequency 20 kHz and amplitude 30.5 μm. The time of sonification was a variable parameter and sludge was sonicated within t = 60, 120, 180, 240, and 300 s.

For sludge conditioning, a coagulant PIX 123 and polyelectrolyte 8160 Zetag of highly cationic nature were used. PIX is an inorganic coagulant based on the trivalent iron Fe^{3+}. It is an aqueous solution of ferric sulfate, its density at 20°C is in the range 1.5–1.6 g/cm^3 and viscosity at 20°C is 60 mPas. PIX 123 was diluted with water in a ratio of 1:9. Mixing of sludge with a coagulant was conducted in two stages. The first stage was carried out with rapid mixing within 60 s in order to mix the whole volume of sludge with a coagulant. In the second stage, a slow mixing within 30 min was applied just to ensure the formation of agglomerates. Polyelectrolyte is used in the form of 0.1% dilute solution.

The susceptibility of sludge to dewatering was measured by capillary suction time (CST). Mechanical dewatering of sludge and the pressure and vacuum filtration were carried out with laboratory equipments. The following parameters were applied: vacuum 0.05 MPa and pressure 0.5 MPa.

Rheological studies were performed using a rheometer RC20, which was controlled by a computer equipped with software Rheo 2000. The rheological tests were carried out at the controlled shear rates from 0 to 350 s^{-1} during 300 s. The experiment was performed at the temperature of 20°C. To observe the

Table 1
Physical and chemical characteristics of the sewage sludge

Parameter	Value
pH	7.45
Initial hydration, %	98
Dry matter, g/dm^3	20.3
Mineral matter, %	36.1
Organic matter, %	63.9
CST, s	1,878.5

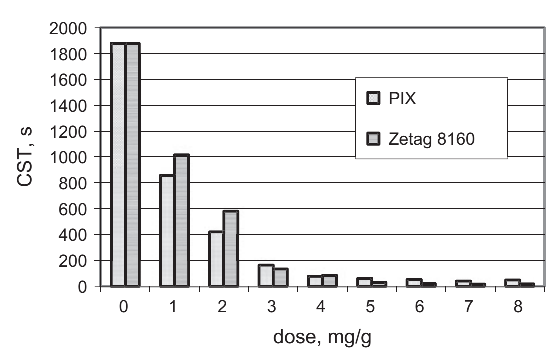

Fig. 1. The effect of PIX-123 and Zetag 8160 dosage on CST for OP sludge.

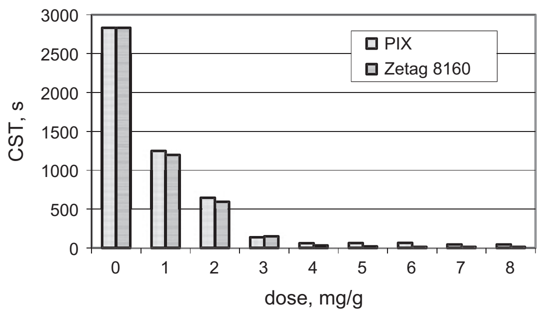

Fig. 2. The effect of PIX-123 and Zetag 8160 dosage on CST for ON sludge sonicated within 60s.

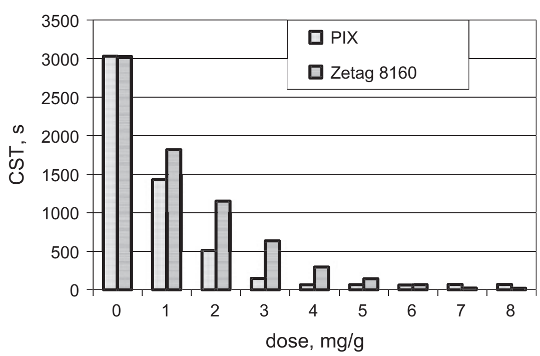

Fig. 3. The effect of PIX-123 and Zetag 8160 dosage on CST for ON sludge sonicated within 120s.

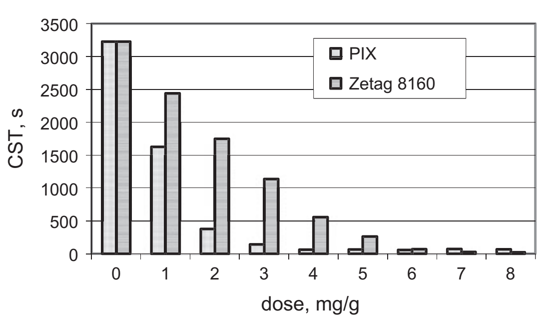

Fig. 4. The effect of PIX-123 and Zetag 8160 dosage on CST for ON sludge sonicated within 180s.

structure of the sludge, the image analysis system (Quick Photo Camera) with digital camera Olympus 7070 WZ integrated with an optical microscope Olympus BX41 was used.

The degree of contaminants removal from supernatant was estimated by parameters such suspension and COD.

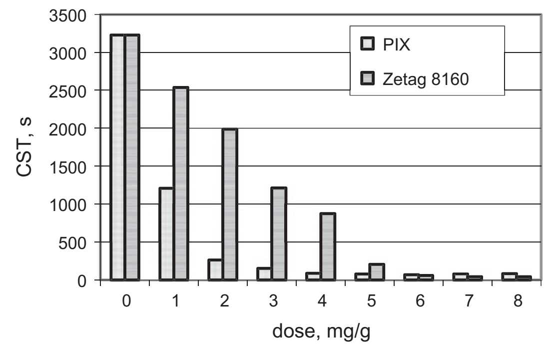

Fig. 5. The effect of PIX-123 and Zetag 8160 dosage on CST for ON sludge sonicated within 240s.

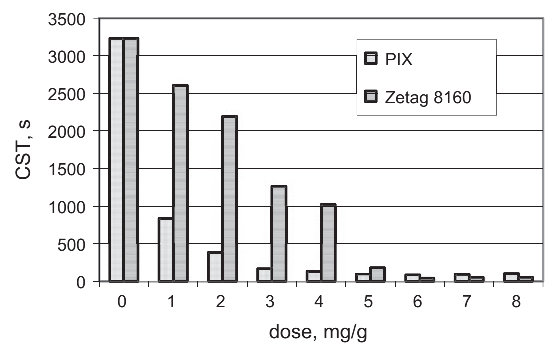

Fig. 6. The effect of PIX-123 and Zetag 8160 dosage on CST for ON sludge sonicated within 300s.

3. Results and discussion

Physical and chemical characteristics of the sewage sludge is given in Table 1.

The results of CST measurements show that the process of conditioning with PIX-123 and Zetag 8160 enhanced the sludge susceptibility to dewatering. The value of CST for non-prepared sludge OP was 1,878.5 s. In Fig. 1, the relation between the CST and dose of PIX 123 and Zetag 8160 is presented. The CST decreases together with the increase of coagulant and polyelectrolyte dose. Significant changes of CST are within the dose in the range 1.0–4.0 mg/g, the higher doses had no significant impact. The lowest value of CST—15.8s—was obtained for sludge prepared by Zetag 8160 at a dose of 7 mg/g. For sludge samples prepared by PIX-123, the lowest value of CST was 35.3 s and it was also observed in the case of a dose of 7 mg/g.

The CST of sonicated sludge samples was much higher than CST for non-sonicated sludge, and it was in the range 2832.1–3232.8 s. The highest value of CST was achieved for a sample which was sonicated within 300 s (Fig. 6), while the lowest value of CST

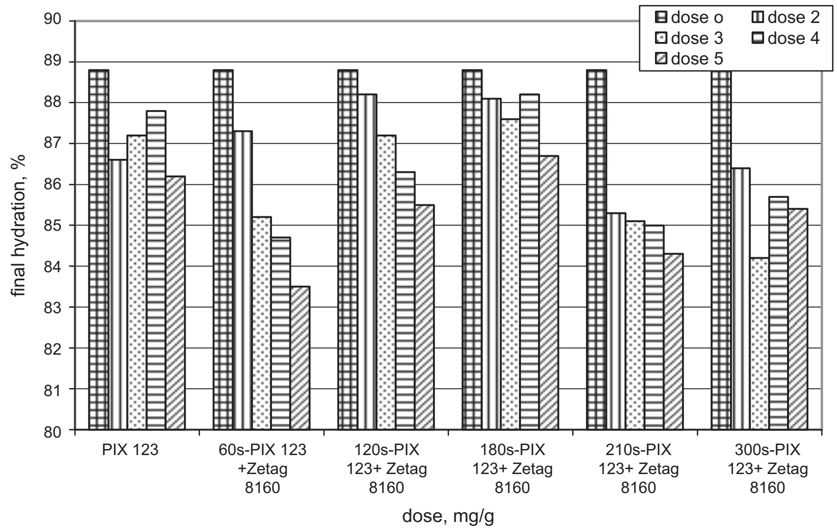

Fig. 7. Changes of sludge final hydration in the process of vacuum filtration.

was obtained for a sample sonicated within 60 s (Fig. 2). There was no big difference when coagulant or polyelectrolyte was used for sludge sonicated within 60 s. However, when sludge disintegration time lengthened to 300 s, it was observed that CST decreased faster when PIX-123 was used for sludge conditioning (Figs. 3–6). In addition, in the case when sonicated sludge was conditioned with Zetag 8160, it was noted that for each dose of polyelectrolyte the time of sonication caused an increase of CST, respectively, 60—1197.2 s, 120—1817.5 s, 180—2438.1 s, 240—2538.9 s; 300—2605.6 s. There was no similar relationship for sludge sonicated and prepared by PIX-123. For further research, the following doses of PIX were chosen: 2.0, 3.0, 4.0, and 5.0 mg/g and they were combined with Zetag 8160 of 2.0 mg/g dose.

Indicators used for determining the susceptibility of sludge for dewatering process in the vacuum and pressure filtration were: final hydration, filtration velocity, resistivity, and filtration performance. From a technological point of view, the most important parameter is a final hydration of a filter cake. The changes of this parameter for sonicated and prepared sludge in the vacuum filtration are shown in Fig. 7. The final hydra-

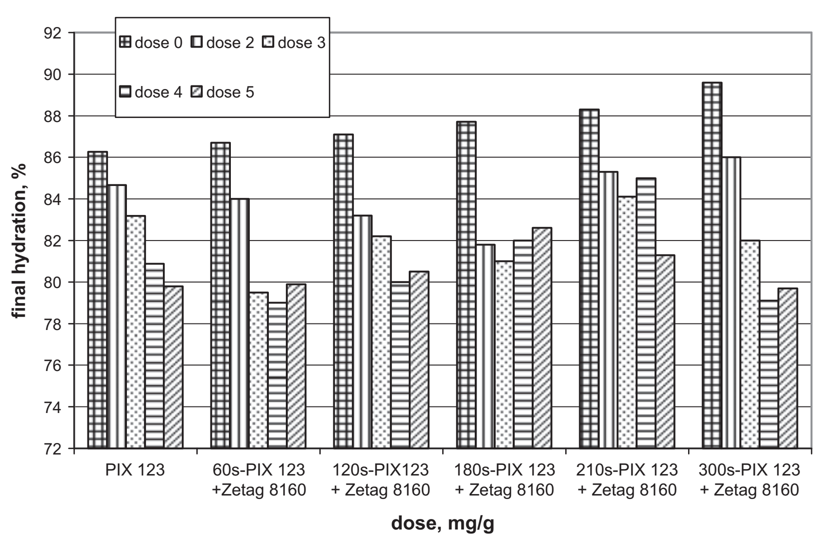

Fig. 8. Changes of sludge final hydration in the process of pressure filtration.

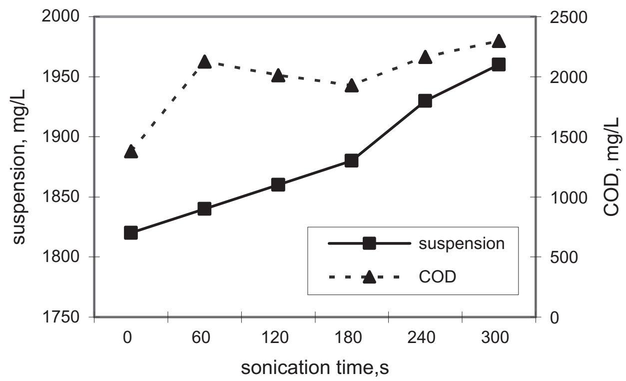

Fig. 9. The influence of sonication time on the quality of supernatant sludge liquor.

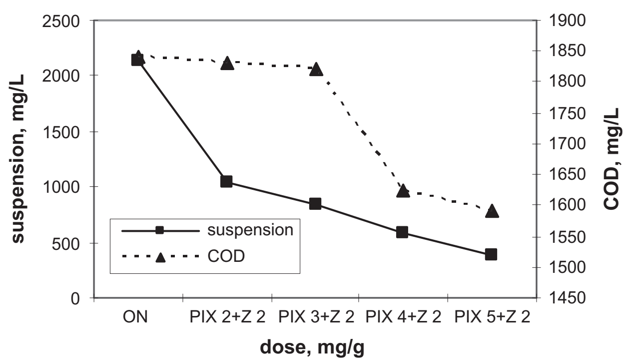

Fig. 10. The influence of sonication and chemical conditioning on the quality of supernatant sludge liquor ($t = 60$ s, PIX-123 of 2.0, 3.0, 4.0, 5.0 mg/g dose, Zetag 8160 of 2 mg/g dose).

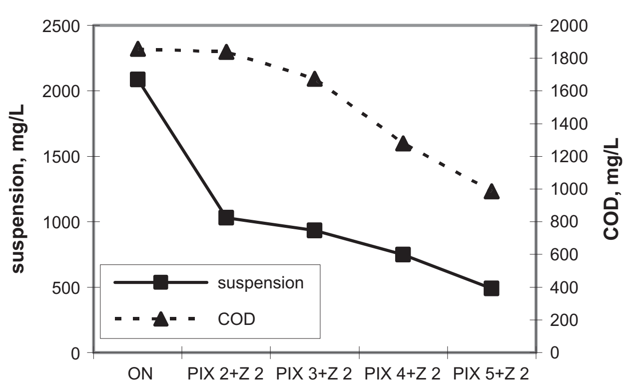

Fig. 11. The influence of sonication and chemical conditioning on the quality of supernatant sludge liquor ($t = 120$ s, PIX-123 of 2.0, 3.0, 4.0, 5.0 mg/g dose, Zetag 8160 of 2 mg/g dose).

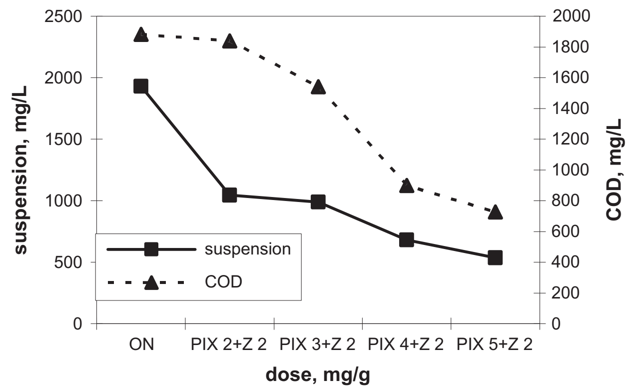

Fig. 12. The influence of sonication and chemical conditioning on the quality of supernatant sludge liquor ($t = 180$ s, PIX-123 of 2.0, 3.0, 4.0, 5.0 mg/g dose, Zetag 8160 of 2 mg/g dose).

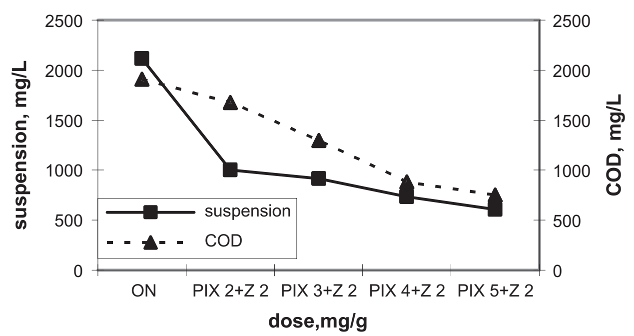

Fig. 13. The influence of sonication and chemical conditioning on the quality of supernatant sludge liquor ($t = 240$ s, PIX-123 of 2.0, 3.0, 4.0, 5.0 mg/g dose, Zetag 8160 of 2 mg/g dose).

tion of non-prepared sludge was 88.8%. For sonicated and prepared with both PIX-123 and Zetag 8610 sludge, the final filtration was in the range 88.2–84.2%. The higher the dose of PIX was used, the lower was the value of final filtration. However, in the case of sludge prepared only with PIX-123, the final filtration increases together with the coagulant dose. The highest drop in final hydration was achieved for sludge which was sonicated within 300 s and prepared by both PIX-123 of 3 mg/g dose and Zetag 8160 of 2 mg/g dose. Its final hydration was 84.2%. The changes of final hydration for sonicated and prepared by coagulant and polyelectrolyte sludge in the pressure filtration are shown in Fig. 8. The final hydration of non-prepared sludge in this case was 86.3%. For sonicated sludge and sludge prepared with both PIX-123 and Zetag 8610, the final filtration was found in the range 89.6–79.0%. The best results of dewatering were achieved for sludge which was sonicated within 60 s and prepared by PIX-123 of

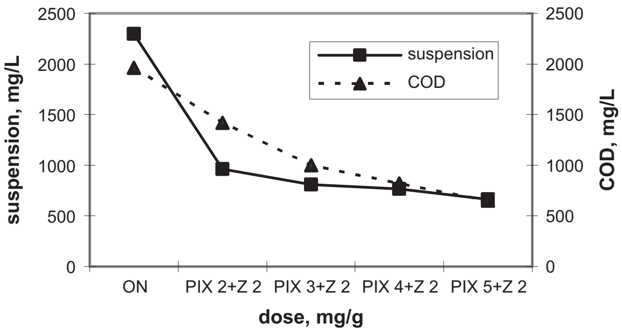

Fig. 14. The influence of sonication and chemical conditioning on the quality of supernatant sludge liquor ($t = 300$ s, PIX-123 of 2.0, 3.0, 4.0, 5.0 mg/g dose, Zetag 8160 of 2 mg/g dose).

4 mg/g dose and Zetag 8160 of 2 mg/g dose. For such sludge samples, the final hydration was 79%. The highest values of the final hydration were obtained in the case of sludge that was only sonicated. Increase in sonication time resulted in an increase of the final hydration up to 89.6%.

It could be stated that the combination of chemical conditioning with physical method could be a satisfactory solution resulting in a better process of municipal sludge dewatering.

Application of ultrasounds leads to the destruction of sludge flocs and microbiological cells. Propagation of an ultrasound wave in the sludge produces gas bubbles which disintegrate rapidly during cavitation. This leads to the generation of high shears and microspheres with extreme conditions of high temperature up to 5000 K and pressure of $1 \cdot 10^8$ Pa. The formation of high shears has a decisive influence on the sludge disintegration. During sonication, the degree of fragmentation increases with time exposure and ultrasonic power. As a result, sludge flocs break into a fine suspension and the clarity of water is worse, and at the same time an increase of COD is observed (Fig. 9). The longer sonication time leads to the stronger disintegration. However, the combined effect of inorganic coagulants and polyelectrolytes makes it possible to reduce the amount of suspended solids and COD (Figs. 10–14).

The microscopic images of the sludge structure show some differences after sludge conditioning using PIX-123, Zetag 8160, and after sludge sonification. Sonicated sludge has an uniform structure, which is slightly broken down into smaller particles. However, for both sonicated and prepared sludge, it was observed that the higher the dose of coagulant used, the bigger the size of particles (Fig. 15).

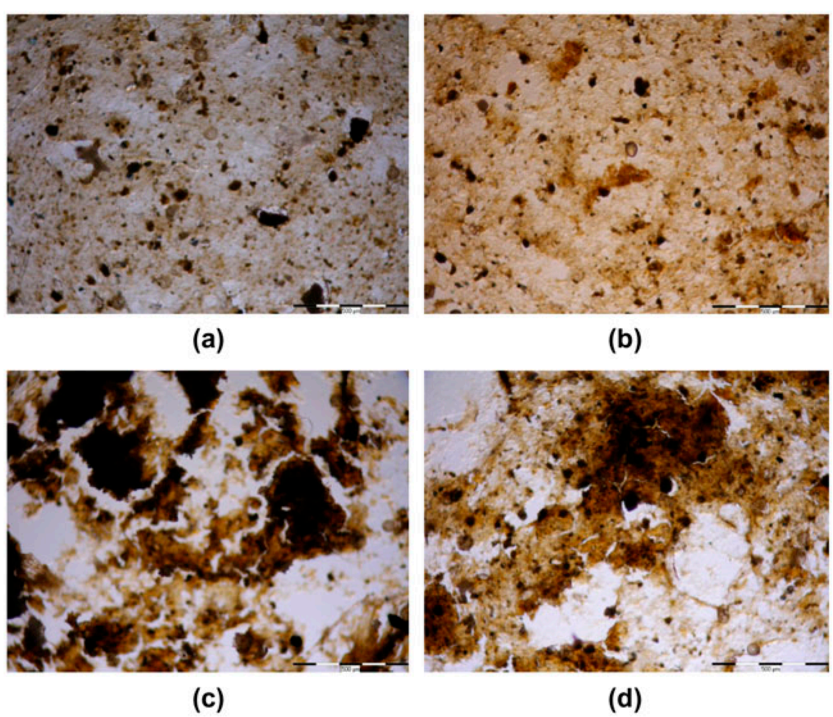

Fig.15. The structure of sludge sonicated within 300s and prepared by PIX-123 of: (a) 0 mg/g; (b) 2.0 mg/g; (c) 3.0 mg/g; and (d) 4.0 mg/g dose rate and Zetag 8160 of 2 mg/g dose rate.

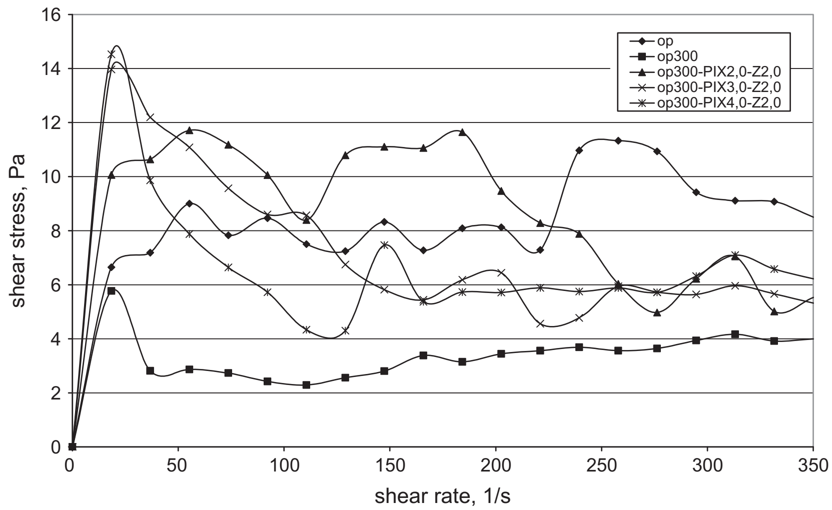

Fig. 16. Effect of PIX-123 dose rate on the shear stress of sonicated sludge ($t = 300$ s).

Coagulant neutralizes the electrical charges on the surface of solid particles more effectively than polyelectrolyte. In that way, it creates better conditions for particle connection. In the case of sewage sludge, the coagulant alone is not in a position to create large and stable flocs, which could then be effectively separated in the process of sludge thickening and dewatering. Instead, it gives an excellent prerequisites to create large and strong flocs and to enhance the sludge dewaterability. To obtain the total effect, the polyelectrolyte has to be used after coagulant. Polyelectrolyte acts as a bridging and cross-linking agent allowing the large and stable flocs to form.

The rheological tests show that the shear stress is lower when sludge is only sonicated (Fig. 16). The value of shear stress increases for non-prepared sludge and sludge prepared by both methods (sonicated and conditioned with coagulant and polyelectrolyte sludge). The results are consistent with the results given in [8].

4. Summary and conclusions

Sewage sludge is a complex multiphase system. The sludge has to be conditioned in order to achieve the best results in the process of sludge dewatering. To achieve this purpose, the combination of inorganic coagulant PIX-123 and polyelectrolyte Zetag 8160 was used in the research. Different dosages of these reagents were applied for non-prepared digested sludge and sludge that was preliminary sonicated in order to find the optimal range of doses. Also, the time of sonication was analyzed because using ultrasounds for sludge disintegration causes some changes in sludge structure and as a result the process of sludge dewatering is changeable. On the basis of research results, the following conclusions are formed:

(1) Application of an ultrasonic wave causes an increase of CST value, the longer the time of sonication, the higher the CST value obtained.
(2) Application of inorganic coagulant PIX-123 and polyelectrolyte Zetag 8160 causes a decrease of CST value.
(3) Applied doses of chemical reagents (PIX-123, Zetag 8160) make it possible to achieve lower final hydration in the process of vacuum and pressure filtration.
(4) Conditioning of sonicated sludge with both inorganic coagulant and polyelectrolyte helps to obtain better quality of supernatant sludge liquor after dewatering.
(5) The knowledge of sludge structure helps to apply the optimal methods of conditioning in order to enhance the dewatering process.

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