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Coagulant and polyelectrolyte application performance testing in sonicated sewage sludge dewatering

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ABSTRACT

The article presents the results of research on the impact of inorganic coagulants and polyelectrolytes and their common action on non-prepared and sonicated digested sludge. Sonication of sludge samples was carried out under static conditions for 60, 120, and 180 s. An ultrasonic wave of $f = 20$ kHz and two different amplitudes of $A = 15.25$ and 30.5 μm were used in tests. The coagulant PIX123 and the polyelectrolyte Zetag 8160 were used for conditioning. On the basis of CST test, doses of chemical reagents were chosen for conditioning. The results indicated the effect of the PIX123 and Zetag 8160 application on non-sonicated and sonicated sludge. The lowest CST values were achieved, while the combination of coagulant in a fixed dose of 1.0 mg/g and polyelectrolyte was used. This effect was observed for non-sonicated sludge as well as for sonicated sludge. The higher dose of chemical reagent used for non-sonicated sludge, the lower the final hydration was achieved. For non-sonicated sludge, better results were obtained when the Zetag 8160 was used. For sonicated sludge, better results were achieved when PIX123 was used. The effect of the final hydration reduction for sonicated sludge and prepared with Zetag 8160 was not satisfactory. The application of the coagulant and the polyelectrolyte combination does not allow achieving lower final hydration of sludge in comparison with only PIX 123. However, it was possible to achieve higher suspension and COD reduction.

Keywords: Coagulant; Conditioning; Polyelectrolyte; Pressure filtration; Sewage sludge; Sonication

1. Introduction

Successful implementation of ultrasonic disintegration in some Polish wastewater treatment plants (e.g. Bydgoszcz, Rzeszów, or Dabrowa Gornicza) inspires the interest among wastewater treatment technologists/engineers in Poland [1]. Polish company, Center for Applied Electronics CES from Cracow, after many years of testing and improvement projects, has installed and launched more than 100 ultrasonic reactors in 12 countries all over the world, since 2004. Ultrasonic disintegration is widely used as one of the modern methods of sewage sludge treatment applied prior to anaerobic digestion [2–5]. The application of

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ultrasonic energy field is common due to the fact that the process of sludge structure destruction is possible at the low energy expenditure. As a result, the time of sludge anaerobic digestion is shortened and its efficiency increases [6]. The application of ultrasonic field for sewage sludge disintegration can cause a change in a degree of suspension dispersion, an increase in particles fragmentation or a decrease in fragmentation as a result of ultrasonic coagulation. The effect of a coagulating action of an ultrasonic wave depends on the frequency of ultrasonic wave and the suspension particles size. For different particles size the optimum frequency range is defined [7]. As a result of ultrasonic disintegration, sludge has a completely different structure and properties. These changes affect the process of sludge mechanical dewatering. The water removal from flocculated suspension is difficult. The floc shape, the size, or the particle concentration influences the rate of the dehydration process and its effectiveness. Currently, the dominant method of sludge treatment prior its thickening and dewatering is chemical conditioning [8–12]. The aim of chemical conditioning is to loosen the bonds between water and sludge molecules and consequently, to speed up the process of sludge dewatering or even its enabling. Chemical conditioning relies on mixing sewage sludge with inorganic or organic chemicals (e.g. polyelectrolytes). Under conventional conditioning chemical reagents such as aluminum sulfate, ferrous sulfate, and ferric chloride are used. The time and the method of mixing are chosen to achieve a well dehydrated sludge structure with strong dehydration of solids and colloids. The sludge structure could not be damaged by too strong and prolonged mixing. The reaction time depends on the coagulation agent used for conditioning. While, using iron salt solutions the time should be around 5–10 min [13]. The chemical conditioning using different chemical agents is intended to change physicochemical properties of sludge to achieve a high dry matter concentration and high effluent quality after mechanical dewatering. The achievable dry matter content and the consumption of energy and chemical agents during mechanical dewatering vary depending on the type of sludge [14]. The maximum yield of the dry matter content can help in reducing the cost of transport and sludge disposal. Then, more efficient ways of sludge conditioning are still the issue regarding water removal. The combined use of coagulants and polyelectrolytes can contribute to the improvement of the degree of dehydration of sludge treated by ultrasounds. The aim of research was to determine the influence of inorganic coagulant PIX 123 and polyelectrolyte Zetag 8160 as well as the combination of these reagents on sewage sludge capillary suction time (CST), sludge final hydration, and sludge structure after ultrasonic disintegration. The research was done using different doses of chemical reagents.

2. Materials and methods

2.1. Sludge samples

Samples of sewage sludge were obtained from mechanical and biological wastewater treatment plants. Sludge is stabilized in the process of anaerobic digestion, then mechanically dewatered, and thermally dried. Sludge after anaerobic digestion was used for laboratory experiments. The following symbols were assigned to sludge samples: OP—digested sludge, ON—digested, and sonicated sludge.

2.2. Experimental

For sludge conditioning, a coagulant PIX-123 and polyelectrolyte Zetag 8160 were used. These reagents were used for sludge conditioning at wastewater treatment plants where the sludge was taken from. PIX 123 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 1.5–1.6 g/cm^3 and a viscosity at 20˚C is 60 mPas. ZETAG 8160 is a synthetic high molecular weight polyacrylamide of medium–high cationic charge. Its density is 0.7 g/cm^3. PIX 123 was prepared as a 10% solution and the polyelectrolyte of 0.1%. Sonication of sludge samples of 400 ml volume was carried out under static conditions. Powerful ultrasonic disintegrator with automatic tuning Sonics VC750 was used for sonication. The sonication wave of $f = 20$ kHz and two different amplitudes of $A = 15.25$ and 30.50 μm were used in tests. The sludge was sonicated for 60, 120, and 180 s. The ability of sludge to dewater was measured by CST. Mechanical dewatering of sludge using pressure filtration of 0.5 MPa was carried out with some laboratory equipment. Experiments were done four times for each sample.

Tests were done according to the scheme given in Table 1. For the first test, Zetag 8160 was used for sludge preparation. For the second test, only PIX 123 was used but for the last test both Zetag 8160 and PIX 123 were applied. PIX 123 was used in a fixed dose of 1.0 mg/g, but polyelectrolyte Zetag 8160 was used in different doses.

3. Results and discussion

Physicochemical characteristics of an investigated sewage sludge are given in Table 2.

Table 1
The scheme of tests

Series	Test I Zetag 8160 (mg/g s.m.o.)	Test II PIX 123 (mg/g s.m.o.)	Test III PIX 123 (mg/g s.m.o.)	Test III Zetag 8160 (mg/g s.m.o.)
I	0.5	0.5	1.0	0.5
II	1.0	1.0	1.0	1.0
III	1.5	1.5	1.0	1.5
IV	2.0	2.0	1.0	2.0
V	2.5	2.5	1.0	2.5
VI	3.0	3.0	1.0	3.0
VII	3.5	3.5	1.0	3.5

Table 2
Physical and chemical characteristics of digested sewage sludge

Parameter	Value
pH	6.82
Initial hydration, %	98.1
Final hydration, %	91
Dry matter, g/dm^3	18.8
Mineral matter, %	35.6
Organic matter, %	64.4
CST, s	1,563

The value of CST for non-prepared sludge OP was 1,563 s. The results of CST when Zetag 8160 or PIX 123 was used for sludge conditioning showed that the process of conditioning improved the ability of sludge for dewatering. Figs. 1–7 show that CST of sludge samples decreases with a higher value of the chemical reagent dose. For non-prepared sludge, the best results in CST times were achieved when both coagulant PIX-123 and polyelectrolyte Zetag 8160 were applied. The lowest value of CST—30.6 s was obtained for sludge prepared by PIX-123 at a dose of 1.0 mg/g and Zetag 8160 at a dose of 3.5 mg/g (Fig. 1). This value was nearly 48 times lower than CST for non-prepared digested sludge. Sludge prepared by ultrasonic wave of amplitude $A = 15.25$ µm results in shorter time of CST in comparison with non-prepared sludge. For sonication time of 120 s and 180 s CST was 1,320 and 1,194 s, respectively. While, for 60 s of sonication time a longer CST was achieved—1,623 s (Figs. 2–4). In contrast, when an amplitude of 30.5 µm was used for sonication higher CST was observed. It was between 2214.3 and 2382.2 s (Figs. 5–7). The highest value of CST was achieved for a sample which was sonicated within 180 s (Fig. 7), while the lowest value of CST was obtained for a sample sonicated within 60 s (Fig. 5). The lower amplitude of ultrasonic wave was used in tests, the lower was the CST of sludge samples. Higher amplitude of ultrasonic wave caused stronger fragmentation of sludge structure and as a result this caused a higher value of CST. While an amplitude of $A = 15.25$ µm was used during

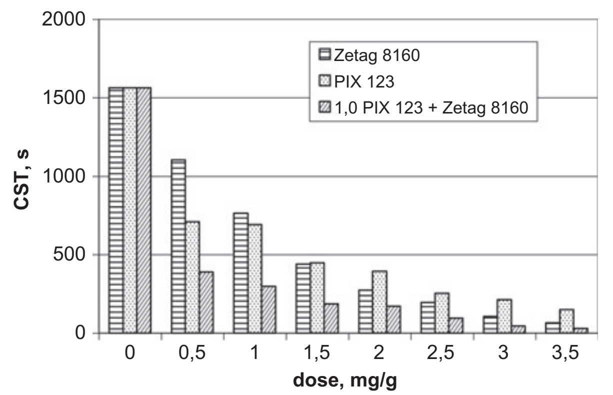

Fig. 1. The effect of chemical reagents dose on CST for OP sludge.

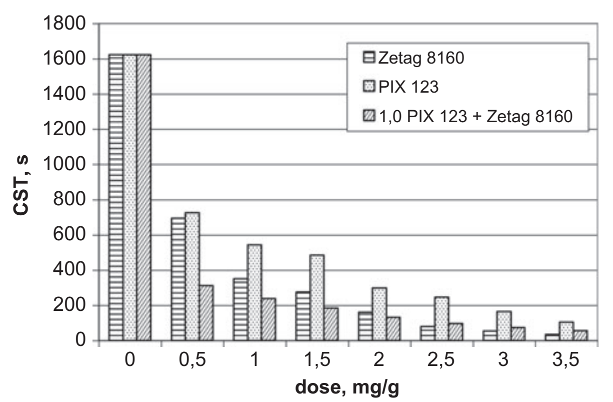

Fig. 2. The effect of chemical reagents dose on CST for ON sludge sonicated for 60 s with $A = 15.25$ µm.

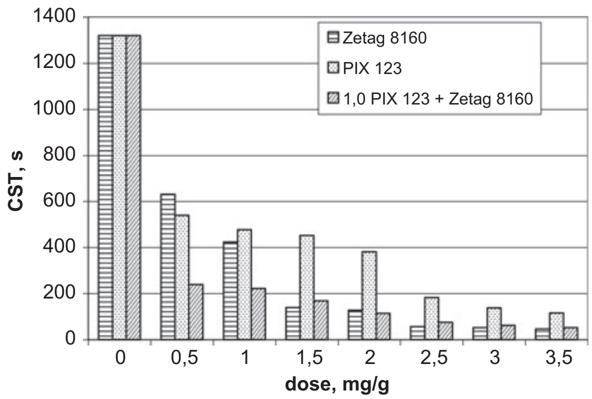

Fig. 3. The effect of chemical reagents dose on CST for ON sludge sonicated for 120 s with $A = 15.25$ μm.

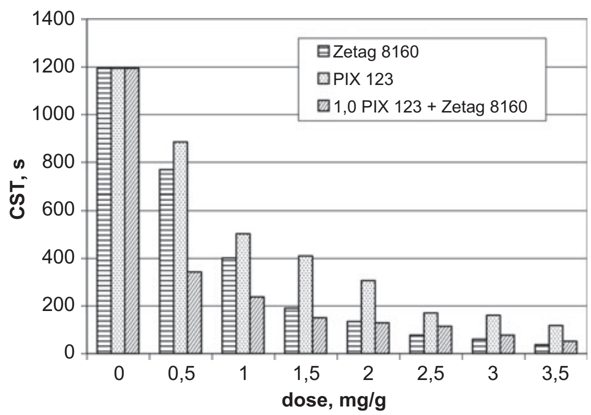

Fig. 4. The effect of chemical reagents dose on CST for ON sludge sonicated for 180 s with $A = 15.25$ μm.

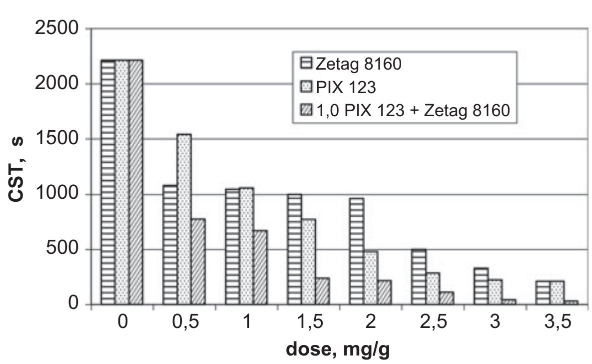

Fig. 5. The effect of chemical reagents dose on CST for ON sludge sonicated for 60 s with $A = 30.5$ μm.

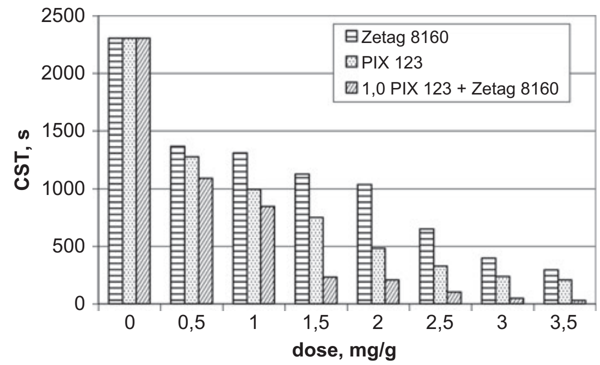

Fig. 6. The effect of chemical reagents dose on CST for ON sludge sonicated for 120 s with $A = 30.5$ μm.

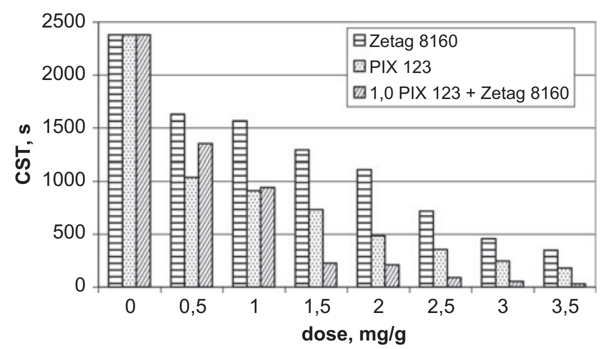

Fig. 7. The effect of chemical reagents dose on CST for ON sludge sonicated for 180 s with $A = 30.5$ μm.

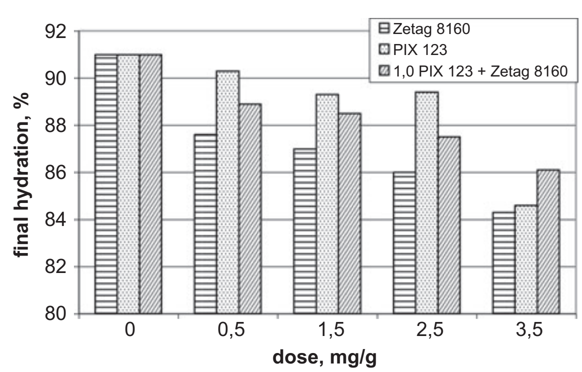

Fig. 8. The effect of chemical reagents dose on the changes of OP sludge final hydration in the process of pressure filtration.

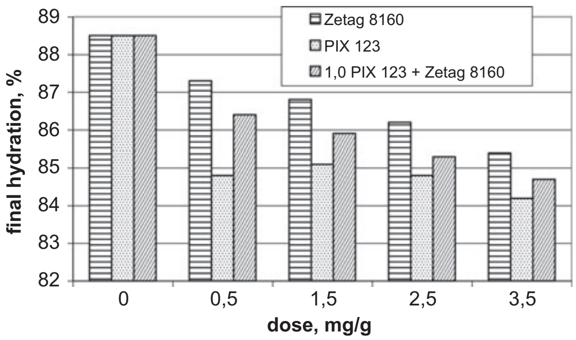

Fig. 9. The effect of chemical reagents dose on the changes of final hydration of ON sludge sonicated within 60 s and with $A = 15.25$ µm.

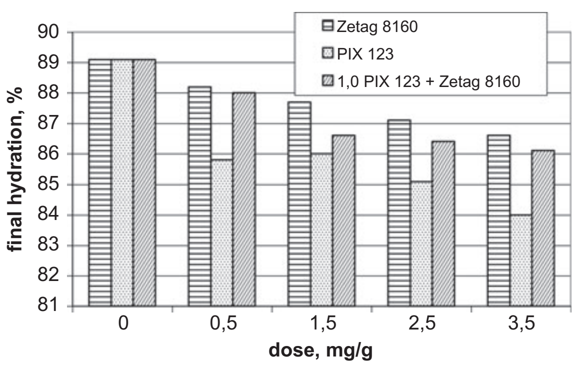

Fig. 10. The effect of chemical reagents dose on the changes of final hydration of ON sludge sonicated within 120 s and with $A = 15.25$ µm in the process of pressure filtration.

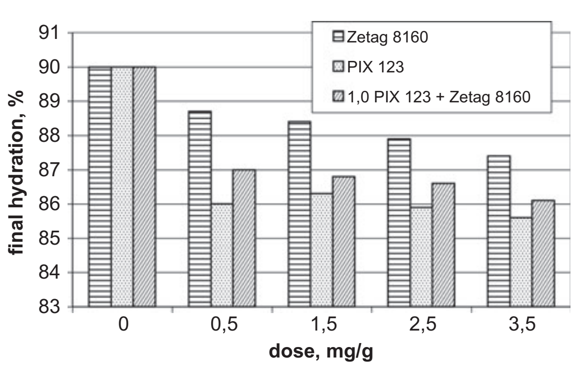

Fig. 11. The effect of chemical reagents dose on the changes of final hydration of ON sludge sonicated within 180 s and with $A = 15.25$ µm in the process of pressure filtration.

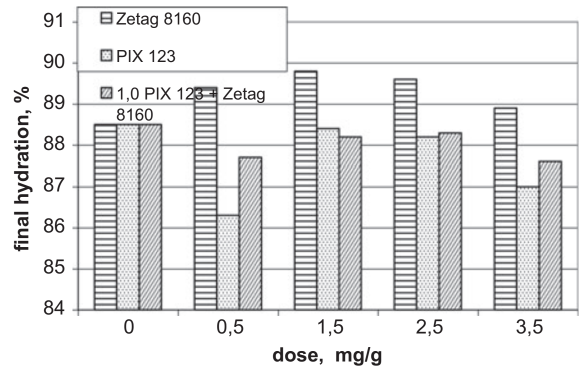

Fig. 12. The effect of chemical reagents dose on the changes of final hydration of ON sludge sonicated within 60 s and with $A = 30.5$ µm in the process of pressure filtration.

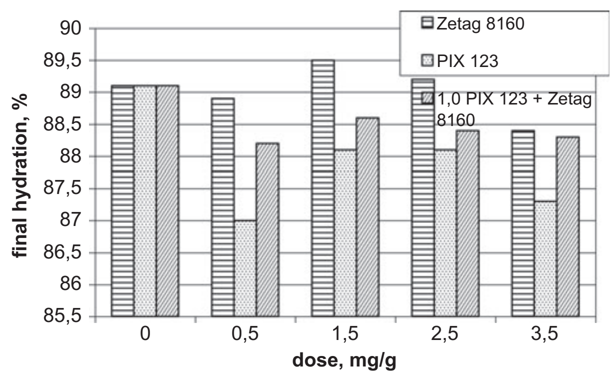

Fig. 13. The effect of chemical reagents dose on the changes of final hydration of ON sludge sonicated within 120 s and with $A = 30.5$ µm in the process of pressure filtration.

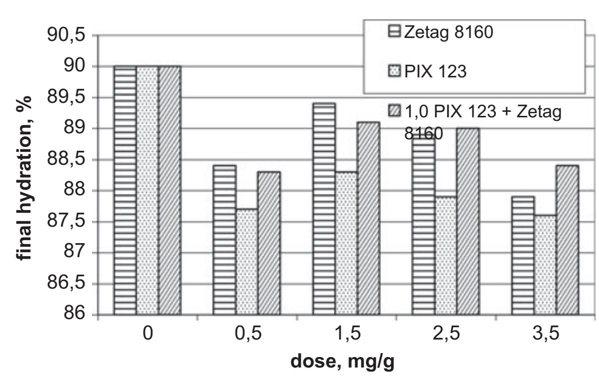

Fig. 14. The effect of chemical reagents dose on the changes of final hydration of ON sludge sonicated within 180 s and with $A = 30.5$ µm in the process of pressure filtration.

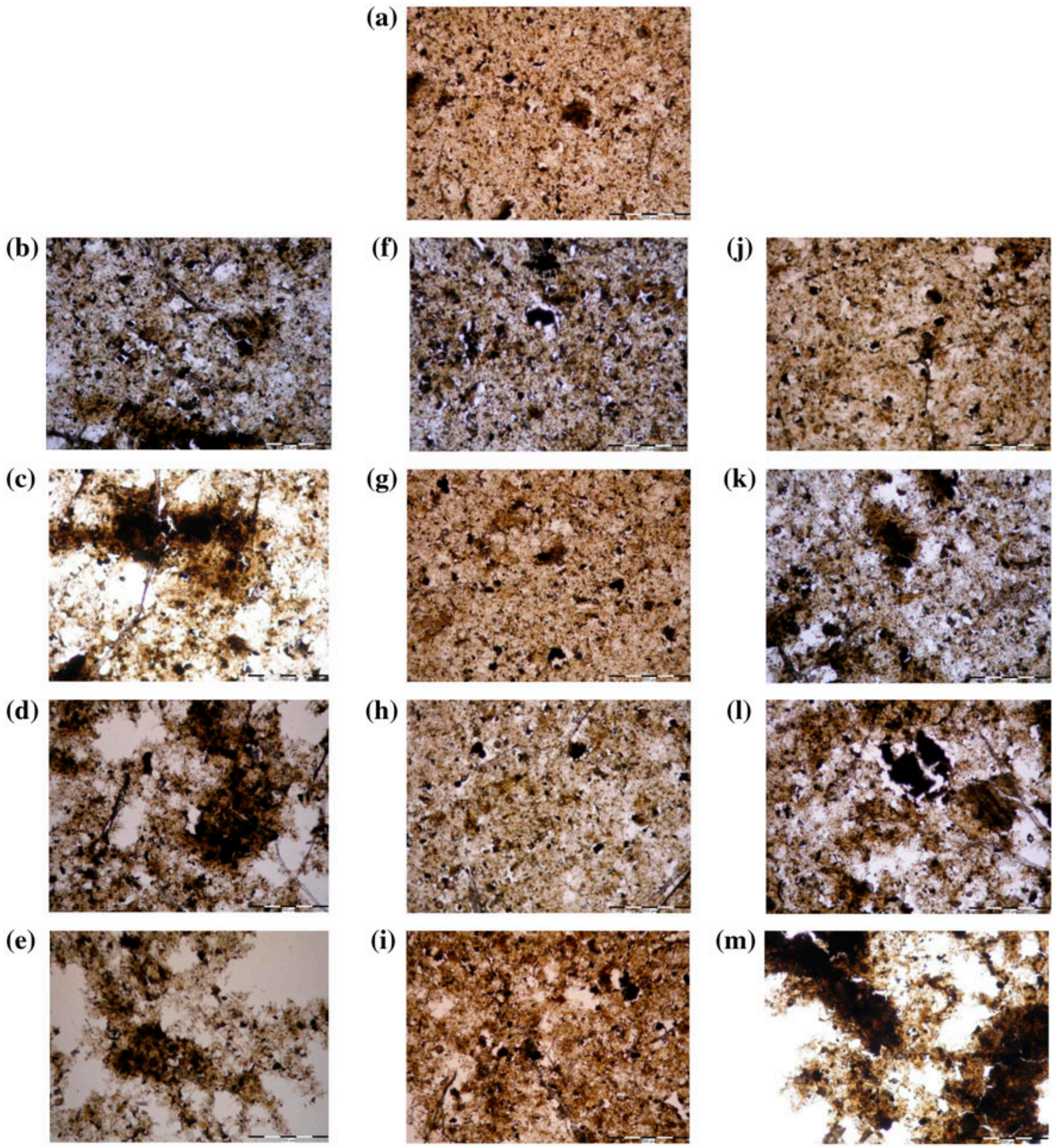

Fig. 15. The microscopic structure of sewage sludge sonicated and conditioned. (a) OP + 120 s; (b) OP + 120 s + 0.5 Zetag 8160; (c) OP + 120 s + 1.5 Zetag 8160; (d) OP + 120 s + 2.5 Zetag 8160; (e) OP + 120 s + 3.5 Zetag 8160; (f) OP + 120 s + 0.5 PIX 123; (g) OP + 120 s + 1.5 PIX 123; (h) OP + 120 s + 2.5 PIX 123; (i) OP + 120 s + 3.5 PIX 123; (j) OP + 120 s + 1.0 PIX 123 + 0.5 Zetag 8160; (k) OP + 120 s + 1.0 PIX 123 + 1.5 Zetag 8160; (l) OP + 120 s + 1.0 PIX 123 + 2.5 Zetag 8160; (m) OP + 120 s + 1.0 PIX 123 + 3.5 Zetag 8160.

sonication, similar relationships between the doses of chemical reagents used in experiments and the CST for both sonicated and non-sonicated sludge were observed (Figs. 2–4). However, in the case, while amplitude of 30.5 μm was used for sludge sonication and next Zetag 8160 or PIX 123 were applied to sludge better results were achieved for sludges prepared by PIX 123 (Figs. 5–7). The reason is that PIX-123 combines smaller particles effectively.

The final hydration of a filter cake for sonicated and prepared sludge in the process of pressure filtration was determined during experiments (Figs. 8–14). The final hydration of non-prepared sludge was 91%. For sonicated sludge, it was between 88.5 and 90%. It was observed that the higher dose of the chemical reagent was used for non-sonicated sludge, the better result in the final hydration was achieved. The best result of the final hydration for non-sonicated sludge

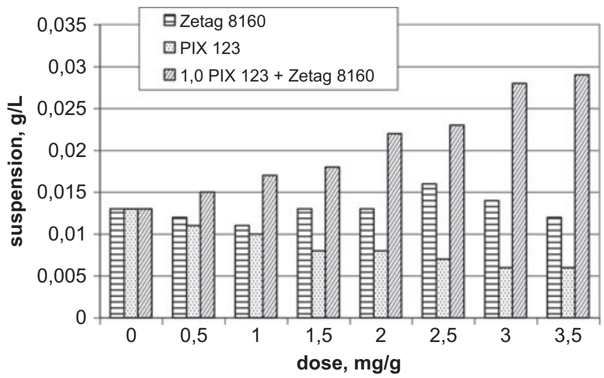

Fig. 16. The effect of chemical reagents dose on the quality of OP sludge supernatant.

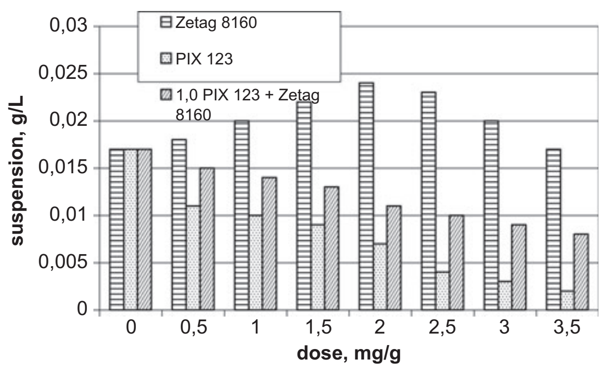

Fig. 17. The effect of chemical reagents dose on the quality of sludge supernatant (ON sludge sonicated for 120 s; A = 15.25 μm).

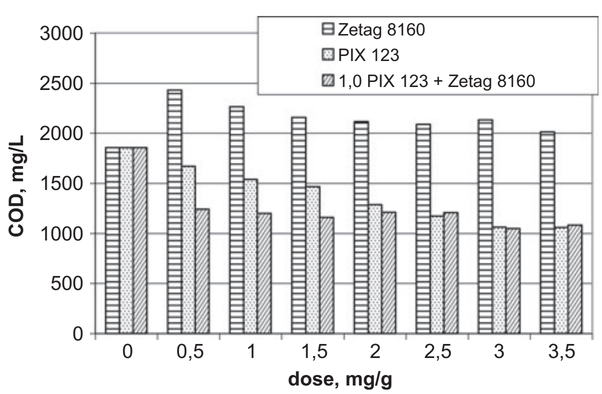

Fig. 18. The effect of chemical reagents dose on the COD of OP sludge supernatant.

was determined when sludge was prepared with Zetag 8160. It was 84.3% (Fig. 8).

For sonicated sludge, the highest drop in the final hydration was obtained when PIX-123 was used for sludge preparation, regardless of wave amplitude (Figs. 9–14). The lowest value of the final hydration was 84% for sludge sonicated for 120 s with an amplitude of $A = 15.25$ μm and prepared with PIX-123 (Fig. 9). The effect of the final hydration reduction for sonicated sludge and a sludge prepared with Zetag 8160 was not satisfactory. The application of PIX-123 at a dose of 1.0 mg/g and Zetag 8160 combination gives better results in comparison, while only polyelectrolyte Zetag 8160 was used for sludge preparation.

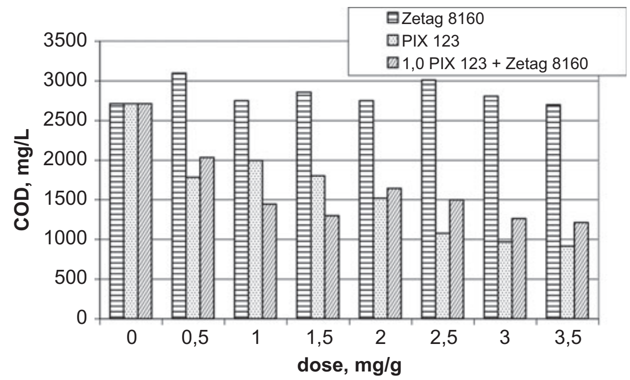

Fig. 19. The effect of chemical reagents dose on the COD of sludge supernatant. ON sludge sonicated for 120 s; A = 15.25 μm.

Microscopic images of sludge structure sonicated with an ultrasonic wave of $t = 120$ s, $A = 15.25$ μm, and prepared with chemical agents are presented in Fig. 15. The structure of sludge which was only sonicated is given in Fig. 15(a). Sonicated sludge has a uniform structure, which is slightly broken down into smaller particles. The effect of coagulant and polyelectrolyte application in different doses is given in Fig. 15 (b)–(m). It could be observed that a higher dose of polyelectrolyte reduced the compressibility of flocs, and as a result the volume of flocs increased. The best results were achieved with the highest dose of polyelectrolyte (3.5 mg/g). However, the best visible flocs were observed when the combination of inorganic coagulant PIX-123 and polyelectrolyte Zetag 8160 was used in the tests. The sludge flocs were well outlined. Coagulant neutralizes the electrical charges on the surface of solid particles more effectively than polyeletrolyte. In that way it creates more favorable condition for particles connection. While PIX-123 was added for conditioning, the sludge structure was more stable with less amounts of pores. The flocs structure had spatial arrangements of greater compressibility. The application of polyelectrolyte Zetag 8160 enabled the creation of large flocs.

Application of ultrasounds leads to destruction of sludge flocs and microbial cells. As a result, sludge flocs break into a fine suspension leading to deterioration in water clarity and an increase in COD. The longer sonication time the stronger disintegration was observed. The combined effect of inorganic coagulants and polyelectrolytes made it possible to reduce the amount of suspended solids and COD. The best results were achieved when sludge was prepared with PIX 123 (Figs. 16–19).

4. Conclusions

According to Directive 99/31/EC (CEC, 1999), which sets mandatory targets for the reduction of biodegradable waste to landfill; landfilling of sewage is bound to be completely banned. Consequently, some efficient methods of final sludge treatment are necessary. Dewatering of sludge is a very important stage because it makes it possible to reduce the volume of sludge. To obtain some good results of sludge dewatering its conditioning is necessary. In order to achieve that purpose, the combination of inorganic coagulant PIX-123 and polyelectrolyte Zetag 8160 was used in the research. Different doses of these reagents, different time of sonication as well as different amplitudes of ultrasonic waves were used to find the relationship between the method of sludge conditioning and the effect of its dewatering in the pressure filtration process. On the basis of research results the following conclusions were formulated:

(1) The application of an inorganic coagulant PIX-123 as well as polyelectrolyte Zetag 8160 caused a decrease in the CST value in the whole range of applied doses. For non-sonicated sludge, lower values of CST were obtained while polyelectrolyte was used for sludge conditioning. While an amplitude of ultrasonic wave of 15.25 μm was used during sonication, the relationship between the doses of chemical reagents and the CST was similar to non-sonicated sludge. However, while an amplitude of 30.5 μm was used for sludge sonication lower values of CST were achieved for sludge prepared by PIX 123.

(2) The best CST results were achieved for sludge preconditioning with an inorganic coagulant in a dose of 1.0 mg/g during the first stage and polyelectrolyte in different doses in the second stage.

(3) Sonification of sludge influences the final sludge hydration. The best effect was achieved while sonification within 60 s when an amplitude of 15.25 μm was applied. The final sludge hydration was 88%.

(4) Sonication of sludge with an amplitude of A = 15.25 μm gave better results in CST and the final sludge hydration, while sonication of sludge with an amplitude of A = 30.5 μm was applied.

(5) Applied doses of chemical reagents (PIX-123, Zetag 8160) allow to achieve lower final hydration in the process of pressure filtration. The most effective reagent was PIX-123—the lowest value of the final hydration was achieved (84%).

(6) Conditioning of sludge with both inorganic coagulant and polyelectrolyte allowed to reduce the amount of suspended solids and COD. The best results in suspension reduction were achieved when PIX-123 was used for conditioning. In the case of COD reduction similar effects were achieved when PIX-123 or the combination of PIX-123 and polyelectrolyte were used.

(7) Microscopic observations of sludge structure helped to determine the impact of chemical and physical conditionings.

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