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The impact of coagulant PIX 113 modified by ultrasonic field on sewage sludge dewatering

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ABSTRACT

Sewage sludge dewatering processes can be very costly and difficult to solve at the wastewater treatment plants all over the world. Sludge includes substances that do not dehydrate easily, and without initial proper preparation, the effects of its dehydration and the degree of separation are very low. The degree of dehydration of sewage sludge is significant, because it is associated with energy consumption and costs of drying the sludge. The aim of the research was to determine the influence of combined activity of PIX 113 coagulant (non-sonicated and sonicated) and Zetag 8160 polyelectrolyte on pressure filtration parameters of digested sewage sludge. A technique based on the preparation of coagulant PIX 113 with ultrasound waves was used in an unconventional way. The combination of physical and chemical sludge conditioning was intended to improve the sludge dewatering process. The sludge for tests was collected after the digestion process. The use of the non-sonicated and sonicated PIX 113 in combination with the polyelectrolyte Zetag 8160 resulted in a decrease of capillary suction time (CST) value in relation to CST of the untreated sludge. Applied dosages of chemical reagents, such as PIX 113 and Zetag 8160, have improved the values of final hydration of sludge in the process of pressure filtration. The lowest final hydration of sludge was obtained when sludge was prepared with sonicated PIX 113 and Zetag 8160. Thus, the use of ultrasonic wave for the modification of the PIX 113 coagulant improved results of sludge dewatering process during pressure filtration.

Keywords: Sewage sludge; Pressure filtration; Polyelectrolyte; Coagulant; Ultrasonic field

1. Introduction

Regardless of its capacity, each sewage treatment plant applies mechanical dewatering of sewage sludge in its sludge management. Mechanical dewatering is becoming more and more important, because it is increasingly more difficult for sewage treatment plants to find recipients and users of the remaining sludge. Many studies and publications concerning the process of dewatering of sewage sludge in Poland and abroad [1–5] show that it is one of the most difficult and expensive problems connected with sludge processing in sewage treatment plants. These difficulties result from the properties of sludge, particularly from the high content of water, which occurs in different forms and is hard to remove. Water bound biologically by microorganisms is especially significant because of high cell hydration and water-binding forces. In practice, it is only possible to remove such water partially, and only after destroying the cell, or rather cell membrane, using, for example, thermal processes. A considerable part of pellicular water is water bound by colloids [6]. Water bound this way may account for a considerable part of different forms of water occurring in sludge. So it is not the quantity itself but the mutual relationship of proportion of waters occurring in sludge that determines its dehydration [7].

Sewage sludge may contain from 99% to 95% of water after gravity concentration [8], and after dehydration, approximately 75%. Thus, sludge includes substances that do not dehydrate easily, and without initial proper preparation,

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the effects of its dehydration and the degree of separation are very low. Besides, sludge properties change with the change in sewage composition, so the choice of a single method or a single chemical to condition them is not easy [9–11]. The effectiveness of mechanical dehydration of sludge is also largely dependent on filtration capacity of solid substances in the dehydrated sludge, as well as on the conditions of the whole process. The process of flocculation depends on the dosage and properties of chemicals, sludge composition, and the characteristics of the dehydrating device [4,8,12]. The degree of dehydration of sewage sludge is significant, because it is associated with energy consumption and costs of drying the sludge, and it facilitates transportation. Hence, many different variables have an influence on the effect of sludge dehydration at each stage. Regardless of the ultimate use of the sludge, it is crucial to remove as much water as possible from it. The aim of the research was to determine the influence of combined activity of PIX 113 coagulant (non-sonicated and sonicated) and Zetag 8160 polyelectrolyte on pressure filtration parameters of digested sewage sludge.

2. Materials and methods

2.1. Research material

The analysis involved sewage sludge after the process of methane fermentation in closed digesters. The sludge originated from a municipal sewage treatment plant with population equivalent (PE) > 100,000, which is a mechanical biological plant that biologically removes nitrogen and phosphorus compounds.

The following conditioners were used in the research:

- 10% solution of PIX 113 coagulant and
- 0.1% solution of Zetag 8160 polyelectrolyte.

PIX 113 coagulant is ferric sulfate. It is a dark brown water solution of ferric sulfate, in which the total iron (Fe) content is 11.4%–12.2%, density at the temperature of 20°C is 1,500–1,570 kg/m^3, and viscosity at 0°C is 100 mPa s and at 20°C is 60 mPa s.

The study also involved testing a polyelectrolyte with the commercial name Zetag 8160 from BASF SE (Ludwigshafen, Germany). This polyelectrolyte has a unique molecular architecture. Zetag 8160 is a synthetic polyacrylamide with a high molecular mass. It is provided as loose white powder. The molecule size is 98% < 1,750 μm and bulk density is 0.7 g/cm^3. Zetag 8160 is a cation polyelectrolyte. In order to obtain a solution of Zetag 8160 polyelectrolyte, it was thoroughly mixed with water. After 120 min of mixing, the solution was mature and ready to use.

During the study, PIX 113 coagulant was first dosed, followed by Zetag 8160 polyelectrolyte. PIX neutralizes electric charges on the surface of sludge molecules, thus ensuring better conditions for their joining. The polyelectrolyte added later acts as a bridging and networking agent, forming large, durable flocculi that can be separated in the process of concentration or dehydration. Both reagents are then used to the full and influence each other [13].

2.2. Procedure

The study included two stages (Table 1). The first stage was the study of digested sludge assisted by the combination of two selected chemical substances: PIX 113 (at three different doses selected in preliminary studies) and Zetag 8160 polyelectrolyte (in changing doses). At the second stage, PIX 113 was additionally sonicated to modify the coagulant so as to achieve better effects of sludge conditioning, and then the sewage sludge was prepared with the sonicated coagulant (in a constant dose) and non-sonicated polyelectrolyte (in changing doses). Optimum doses of PIX 113 coagulant were chosen for sonication: 4.5, 5.0, and 5.5 mg/g dry organic mass (d.o.m.).

PIX 113 coagulant was sonicated in static conditions, with a constant sample volume of 200 mL. A high power microprocessor-based ultrasonic processor Sonics VC750 with automatic tuning, the frequency of 20 kHz (Fig. 1) and amplitude of 30.5 μm (corresponding to the 50% amplitude) was used to sonicate the samples. The variable of the sonication process was the disintegration time t = 2, 4, 6, 8, and 10 s.

The sludge was mixed with selected chemicals with a magnetic stirrer MMS-3000N from Biosan, Medical-Biological Research & Technologies (Riga, Latvia). After adding PIX 113 to the sludge, first it was stirred quickly for 60 s (200 rpm) in order to mix the whole volume thoroughly, and then slowly for 14 min (30 rpm), which ensured the formation of flocculi that made larger agglomerates. Then, a specific dose of Zetag

Table 1
Research stages

Stage I		Stage II	
Non-sonicated PIX 113 (mg/g d.o.m.)	Zetag 8160 (mg/g d.o.m.)	PIX 113 sonicated (mg/g d.o.m.)	Zetag 8160 (mg/g d.o.m.)
4.5/5.0/5.5	0.5	4.5/5.0/5.5	0.5
	1.0		1.0
	1.5		1.5
	2.0		2.0
	2.5		2.5
	3.0		3.0
	3.5		3.5
	4.0		4.0
	4.5		4.5
	5.0		5.0

Fig. 1. Sonics VC750 ultrasonic processor.

8160 polyelectrolyte was added, and after 2 min the whole sample was stirred (30 rpm) thoroughly again for 2 min.

The scope of the study was to select the doses of chemicals using the capillary suction time (CST) test, to determine the dehydration parameters during pressure filtration (final hydration and filtration resistance), and to analyze the structure of the sludge under a microscope.

The water removal capacity of the sludge was measured using the CST. Mechanical dewatering of the sludge, that is, pressure filtration, took place at the laboratory pressure filtration station (Fig. 2). The applied pressure was 0.5 MPa. The fabric used for filtration was a polyester fabric ET 18II.

The structure of the sludge was inspected using image analysis software (Quick Photo Camera) and a digital camera Olympus WZ 7070 with an optical microscope Olympus BX41. The magnification of the structure photos was 100:1.

The outcome of the experiments is presented on charts as an arithmetic mean made up of three repetitions.

3. Results and discussion

The physical–chemical characteristics of digested sludge are given in Table 2. The sludge has neutral pH, greyish-black color, and sallow smell. The initial hydration of the sludge is around 98%, and the filtration hydration after pressure filtration is 89%. Digested sludge is a type of sludge that is hard to dehydrate, which is proved by CST measurement (2,565 s).

CST of digested sludge decreases as the dose of PIX 113 increases (Fig. 3). Significant changes in CST occurred in the dose range of 4.0–5.5 mg/g d.o.m.; but the next doses of the coagulant did not cause any significant improvement in dehydration rate. The lowest CST value was 67.5 s at the dose 5.5 mg/g d.o.m., which meant 97.4% reduction. Doses of PIX 113, 4.5, 5.0, and 5.5 mg/g d.o.m., were chosen for further experiments because they are within the range

Fig. 2. Pressure filtration station.

Table 2
Physical–chemical characteristics of sewage sludge

Determination	Value
Color	Greyish black
Smell	Sallow
pH	6.8
Initial hydration, %	98
Final hydration, %	89.9
Dry remains, g/dm³	23.4
Mineral compounds content, %	34.5
Organic compounds content, %	65.5
CST, s	2,565

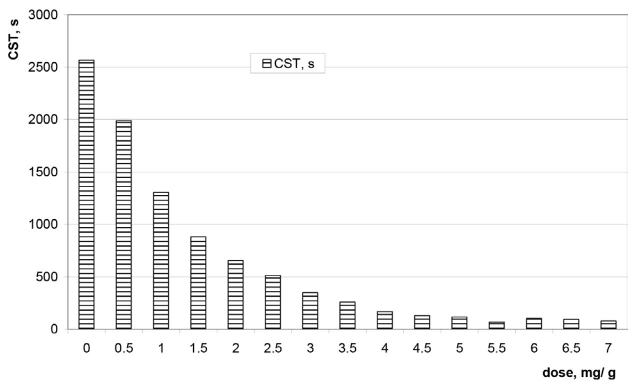

Fig. 3. Influence of PIX 113 coagulant dose on capillary suction time (CST) of digested sludge.

of optimum doses and for financial reasons connected with the consumption of the conditioner. The exceeded dose of polyelectrolyte may cause the decrease of sludge dewatering efficiency. Optimal selection of polyelectrolyte dose for sludge dewatering requires a detailed analysis of product performance and it is also important to take into consideration the quality of sludge leachate. A turbid solution or suspension in the leachate may indicate a malfunctioning of the polyelectrolyte.

Direct effect of ultrasound on flocculating compounds may vary [14]. Modification of PIX 113 coagulant with ultrasonic field may result in improved conditioning of digested sludge. Fig. 4 presents the chart of dependence of sonication time of PIX 113 on CST. Based on the lowest CST value, the sonication time of 6 s was chosen to prepare the PIX 113 coagulant and to use it in further experiments.

Fig. 5 shows the influence of a constant non-sonicated dose of PIX 113 coagulant (4.5, 5.0, 5.5 mg/g) and a changing dose of Zetag 8160 polyelectrolyte on CST of digested sludge: the higher the dose of the coagulant, the lower the value of CST. Fig. 6 shows a similar relationship. Based on the charts from Fig. 5, the following doses of Zetag 8160 polyelectrolyte were chosen for further experiments: 2.5, 3.0, and 3.5 mg/g d.o.m.

Final hydration rate was used to determine the susceptibility of sewage sludge to dehydration during pressure filtration (Fig. 7). The final hydration of non-prepared sludge was 89.9%. Changes in final hydration obtained for sludge samples prepared with non-sonicated and sonicated PIX 113 plus Zetag 8160 polyelectrolyte after pressure filtration were in the range of 84.3%–88.9% (Fig. 7). The lowest value of final hydration (84.3%) was obtained for sludge prepared only with PIX 113 in the dose of 5.5 mg/g d.o.m. and 84.4% was obtained for sludge prepared with sonicated PIX 113 in the dose of 5.0 mg/g d.o.m. plus Zetag 8160 in the dose of 2.5 mg/g d.o.m. Besides, it was found that lower values of final hydration were obtained for sludge conditioned with sonicated PIX 113 and then with Zetag 8160 as compared with the same doses but with non-sonicated PIX 113 and Zetag 8160.

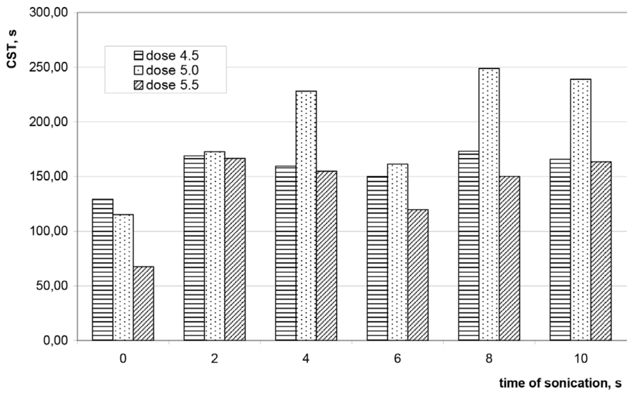

Fig. 4. Influence of PIX 113 coagulant sonication time on capillary suction time (CST) of digested sludge.

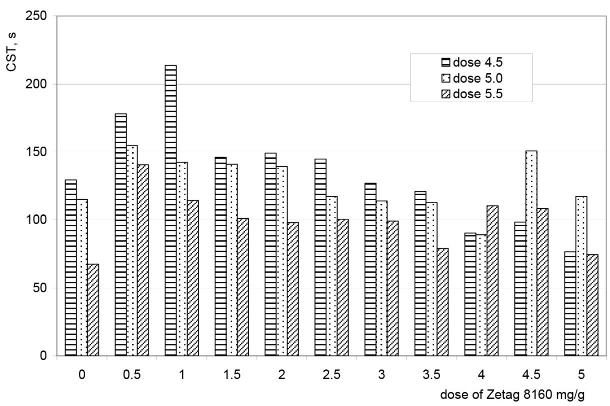

Fig. 5. Influence of a constant non-sonicated dose of PIX 113 coagulant (4.5, 5.0, 5.5 mg/g) and a changing dose of Zetag 8160 polyelectrolyte on capillary suction time of digested sludge.

Microscopic photos of the structure of pre-prepared sewage sludge before its dehydration allow to assess the changes in the structure of the sludge. The analysis shows that different doses of both non-sonicated and sonicated PIX 113 and Zetag 8160 affect the changes occurring in the sludge. For the constant PIX 113 dose of 4.5 mg/g d.o.m. and growing doses of Zetag 8160 polyelectrolyte administered to the sludge, we found an increase in the size of flocculated molecules in comparison with sludge that was not prepared with digested sludge (DS) (Fig. 8).

4. Conclusions

With regard to problems connected with dehydration of sewage sludge, we studied the application of selected conventional and unconventional methods of sludge conditioning in order to intensify the dehydration process. Digested sludge was prepared with a combination of sonicated and/or non-sonicated coagulant PIX 113 and Zetag 8160 polyelectrolyte. The unconventional part was the use of the technique based on preparing the PIX 113 coagulant with an

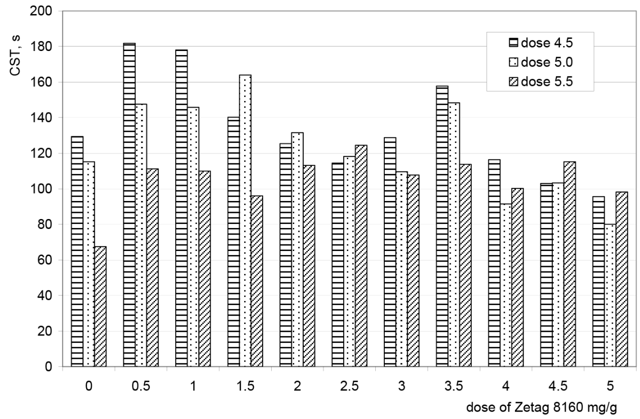

Fig. 6. Influence of a constant sonicated dose of PIX 113 coagulant (4.5, 5.0, 5.5 mg/g) and a changing dose of Zetag 8160 polyelectrolyte on capillary suction time of digested sludge.

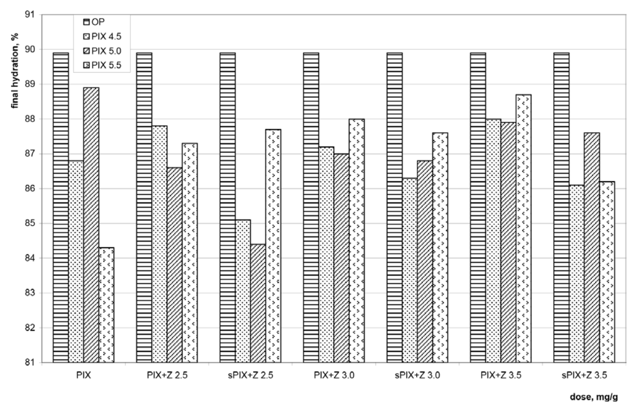

Fig. 7. Changes in final hydration of sludge prepared with non-sonicated and sonicated constant dose of PIX 113 and a changing dose of Zetag 8160 in the process of pressure filtration.

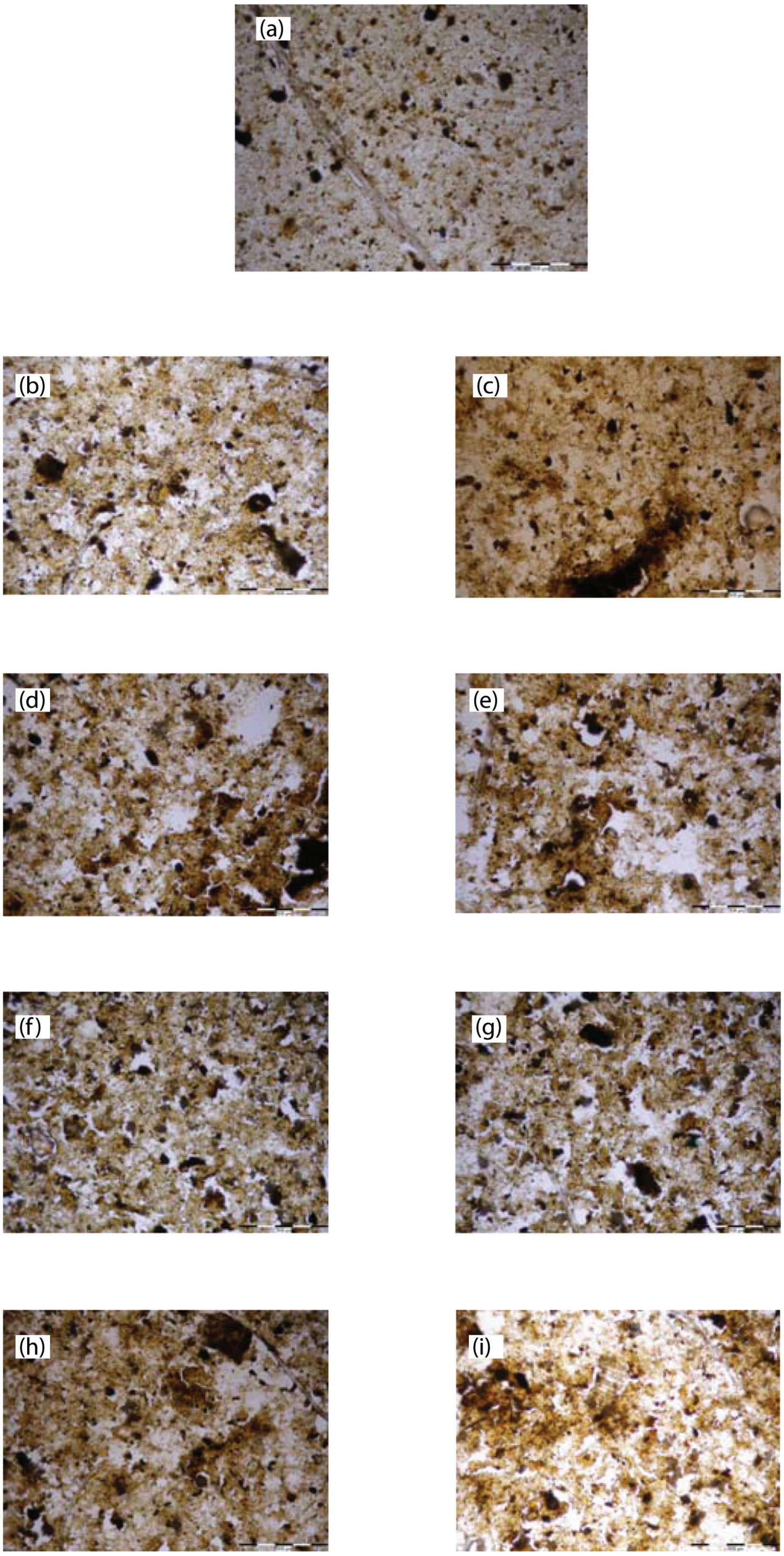

Fig. 8. Microscopic structure of digested sludge (DS) flocculi (a) prepared with non-sonicated PIX 113 in the dose of 4.5 mg/g d.o.m. plus a changing dose of Zetag 8160: (b) DS + PIX4.5, (c) DS + PIX4.5 + Z2.5, (d) DS + PIX4.5 + Z3.0, and (e) DS + PIX4.5 + Z3.5; and sonicated PIX 113 in the dose of 4.5 mg/g d.o.m. plus a changing dose of Zetag 8160: (f) DS + sPIX4.5, (g) DS + sPIX4.5 + Z2.5, (h) DS + sPIX4.5 + Z3.0, and (i) DS + sPIX4.5 + Z3.5.

ultrasonic wave. Sonication of the PIX 113 coagulant causes lower energy consumption than the application of ultrasonic field for the whole volume of the sludge sample.

Using this method, we determined the influence of preparation of the sludge with the use of sonicated PIX 113 coagulant combined with Zetag 8160 polyelectrolyte, which additionally improved the conditioning of digested sludge in the process of pressure filtration. The combination of physical and chemical conditioning of the sludge was expected to improve the dehydration process.

The conclusions from the experiment are as follows:

- The use of non-sonicated and sonicated PIX 113 together with Zetag 8160 polyelectrolyte caused a reduction in the value of the basic indicator of sludge dehydration rate, CST, in comparison with non-prepared sludge, in which case CST was 2,565 s.
- The used doses of the chemical reagents (PIX 113 and Zetag 8160) improved the final hydration rate of sludge in the process of pressure filtration.
- Lower values of final hydration in the process of pressure filtration were obtained for sludge conditioned with sonicated PIX 113 and then with Zetag 8160 as compared with the same doses but with non-sonicated PIX 113 and Zetag 8160. Thus, the application of an ultrasonic wave to modify the PIX 113 coagulant in most cases caused the reduction in the value of final hydration, and thus led to better results of sludge dehydration in the process of pressure filtration.
- The analysis of microscopic structure of the sludge allows to observe the changes occurring in the structure of the flocculus. As the dose of conditioners rose, the volume of flocculi increased and their compressibility decreased. Sonication of the coagulant not only improved the connection of the flocculi, but also improved their density visible in Figs. 8(f)–(i) in the form of separate clusters.

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References

[1] P. Ginisty, J. Olivier, J. Vaxelaire, S. Fortuny, Influence of Flocculation on Sewage Sludge Thickening and Dewatering, 3rd European Conference on Sludge Management, Leon, Spain, 2012. Available at: http://hal.archives-ouvertes.fr/hal-01294328/document

[2] S. Glendinning, J. Lamont-Black, C.J.F.P. Jones, Treatment of sewage sludge using electrokinetic geosynthetics, J. Hazard. Mater., 139 (2006) 491–499.

[3] C. Chen, P. Zhang, G. Zeng, J. Deng, Y. Zhou, H. Lu, Sewage sludge conditioning with coal fly ash modified by sulfuric acid, Chem. Eng. J., 158 (2010) 616–622.

[4] J. Vaxelaire, J. Olivier, Conditioning for municipal sludge dewatering. From filtration compression tests to belt press, Drying Technol., 24 (2006) 1225–1233.

[5] Q. Guan, M. Tang, H. Zheng, H. Teng, X. Tang, Y. Liao, Investigation of sludge conditioning performance and mechanism by examining the effect of charge density on cationic polyacrylamide microstructure, Desal. Wat. Treat., 57 (2016) 12988–12997.

[6] Available at: http://e-czytelnia.abrys.pl/wodociagi-kanalizacja/2013-12-725/raport-wod-kan-8443/odwadnianie-osadow-sciekowych-wybrane-zagadnienia-17156 (Accessed 01.02.2017).

[7] J. Podedworna, K. Umiejewska, Sewage Sludge Technology, Publishing House of the Warsaw University of Technology, 2008 (in Polish).

[8] H. Saveyn, S. Meersseman, O. Thas, D.M.P. Van, Influence of polyelectrolyte characteristics on pressure-driven physicochemical dewatering, Colloids Surf., A, 262 (2005) 40–51.

[9] B. Bień, J. Bień, Coagulant and polyelectrolyte application performance testing in sonicated sewage sludge dewatering, Desal. Wat. Treat., 57 (2016) 1154–1162.

[10] T.A. Mohammad, E.H. Mohamed, M.J.M.M. Noor, A.H. Ghazali, Dual polyelectrolytes incorporating *Moringa oleifera* in the dewatering of sewage sludge, Desal. Wat. Treat., 55 (2015) 3613–3620.

[11] J. Hussain, M.S. Jami, S.A. Muyibi, Enhancement of dewatering properties of kaolin suspension by using cationic polyacrylamide (PAM-C) flocculant and surfactants, Aust. J. Basic Appl. Sci., 6 (2012) 70–73.

[12] Z. Chen, W. Zhang, D. Wang, T. Ma, R. Bai, Enhancement of activated sludge dewatering performance by combined composite enzymatic lysis and chemical reflocculation with inorganic coagulants: kinetics of enzymatic reaction and reflocculation morphology, Water Res., 83 (2015) 367–376.

[13] M. Ciborowski, The possibility of non-organic coagulant application for sewage sludge conditioning before its thickening and dewatering, Gas Water Sanit. Eng., 12 (2006) 34.

[14] L. Wolny, Ultrasounds in the Process of Sewage Sludge Preparation before Dewatering, Monography No. 104, University of Czestochowa, Czestochowa, 2005 (in Polish).