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The Possibility of Sewage Sludge Conditioning and Dewatering with the Use of Biomass Ashes

Możliwość kondycjonowania i odwadniania osadów ściekowych z zastosowaniem popiołów ze spalania biomasy

The wastewater treatment produces a huge amount of excess sludge which has to be removed in line with ecological and legal requirements. Raw sewage sludge is characterized by the high moisture content, over 90 % and the microbiological activity. The high content of water in sewage sludge results in its big volume and generates significant problems with transport and further utilization. As the high moisture content in raw sewage sludge generates significant costs in treatment plants, it is essential to provide effective dewatering. In order to improve the sewage sludge dewatering, conditioning by means of different materials is applied. Chemical conditioning with the application of organic polymers is used in treatment plants more often than any other methods. The drawback of the aforementioned process is the high cost of chemical reagents and for this reason, it is necessary to find inexpensive and effective conditioners. The aim of this paper is the possibility of sewage sludge dewatering after conditioning with the use of biomass ash derived from the biomass-fired power plant. The effectiveness of the aforementioned process was based on the capillary suction time (CST) measurement. After conditioning with the use of biomass ash, the article goes on to describe dewater-ability of sewage sludge by vacuum filtration. The results showed that the sewage sludge moisture content decreased as a dosage of biomass ash increased. Mechanical conditioning with the use of biomass ash influenced the increase of filtrate volume after dewatering. Additionally, the application of biomass ash in sewage sludge management confers the earthen structure of sludge which is suitable to the transport and application in the environment. The mixture of ash and sewage sludge might be used as a valuable fertilizer in perennial plants plantations. Owing to agricultural utilization of sewage sludge, fertilizing properties of sludge are used without a minimal risk to human health.

Keywords: **sewage sludge, biomass ash, sludge conditioning, dewatering, recycling**

Introduction

With the number of new residents attached to a sewage system, the amount of produced sewage sludge is systematically growing. Therefore, a proper utilization of sewage sludge is required. Ineffective waste management activities prevent the circulation of elements in a local ecosystem. Additionally, the hazardous substances in sewage sludge will bring to not only environmental pollution, but also unexpected ecological disasters. In accordance with the new Polish Act on Waste of 2012 [1], sewage sludge has to be treated by means of physical, chemical and microbiological methods before its application in agricultural purposes. These practices aim to prevent the environmental contamination.

Raw sewage sludge is characterized by the high content of water, over 90 % and the microbiological activity [2]. The high moisture content results in its big volume and generates the significant operating costs in treatment plants connected with the transport and later application of sludge [3]. Therefore, sewage sludge dewatering is a very important step is sewage sludge treatment. Because raw sewage sludge creates a relatively stable system with low dewatering capacity, the sludge conditioning is commonly used. Sewage sludge conditioning comprises physical and chemical treatment in order to change the structure of sludge. The conditioning contributes to the change of properties of sewage sludge with the purpose of sedimentation and dewatering improvement [4]. The methods of sewage sludge conditioning are presented in Table 1. An effective conditioner should neutralize the electric charge of sludge particles and destroy the gelatinous structure of sludge which facilitates the dehydration [5].

Table 1. **Methods of sewage sludge conditioning**

Sewage sludge conditioning				
Chemical conditioning		Physical conditioning		
Addition of organics	Addition of inorganic substances	Mechanical methods	Thermal methods	Other
– polyelectrolytes	– ferric salts	– coal	– heating – cooling	– bathing
	– lime	– fly ashes		– ultrasound
	– alum salts	– sawdust		– electromagnetic field

In wastewater treatment plants, chemical conditioning by means of polyelectrolytes is commonly. The addition of chemical reagents enhances the sewage sludge dewater-ability across resulting larger flocs in comparison to raw sludge [6]. The main disadvantages of chemical conditioning are the high doses of polyelectrolytes and the cost of these substances (even 50 000 PLN per year) [7]. Due to the high operating costs of sludge conditioning with organic flocculants, physical conditioning with different substances is examined. Gypsum, lignite and coal fly ashes are used for sewage sludge conditioning and dewatering in a laboratory scale [8]. Jun et al. [9] investigated the influence of alum sludge from water treatment plant on sewage sludge dewatering. Yan et al. [10] added the rice husk biochar in order to improve the effectiveness the sewage sludge dewatering. Unconventional methods of sewage sludge conditioning, for example: with the use of dry ice, are also investigated [11]. The impact of dual conditioning with polyelectrolyte and coal fly ash on sewage sludge dewatering was also assessed [12]. The addition of physical substances creates the rigid lattice structure and the sewage sludge cake remain permeable during the filtration process.

In this paper, the influence of sewage sludge conditioning with use of biomass ash from the biomass-fired power plant was examined. After discussing conditioning with biomass ash, the dewater-ability of sewage sludge by vacuum filtration was investigated. The findings could provide a new approach for sewage sludge and biomass ashes utilization in regards to ecological and economical requirements.

1. Materials

1.1. Sewage sludge

Sewage sludge used in laboratory tests was gathered from the thickening tank from Świlcza - Kamyszyn wastewater treatment plant (Podkarpackie region, Poland). Sewage sludge was characterized by brown colour and earthy smell. The parameters of sample sewage sludge are presented in Table 2. All experiments were completed in a day after sampling in order to minimize changes in sludge characteristics due to microbial activity. Sewage sludge was stored at room temperature.

Table 2. **Characteristics of raw sewage sludge**

Parameter	Unit	Average value
pH	–	6.40
Initial hydration	%	97.48
Dry mass	%	2.52
Capillary suction time (CST)	s	130.89

1.2. Biomass ash

Biomass ash was derived from electrostatic precipitations from "Łężańska" Power Plant in Krosno (Podkarpackie region, Poland). In power plant, there is mainly used biomass from timber industry for biomass combustion, Organic Rankine Cycle (ORC) technology is used. The simultaneous transport heat from biomass combustion into electricity and thermal power is the main advantage of ORC technology.

The SEM image of ash is shown in Figure 1. The analysis of SEM microscopy showed that tested biomass ash contains irregular sharp and spongy particles. The chemical composition of ash is presented in Table 3.

Table 3. **Chemical composition of tested biomass ash**

Compound	Unit	Value
CaO	%	45.64
SiO_2	%	15.17
K_2O	%	9.78
SO_3	%	7.58
P_2O_5	%	4.59
MgO	%	4.25
Al_2O_3	%	4.14
Fe_2O_3	%	3.85
MnO	%	1.61
ZnO	%	0.37
Na_2O	%	0.20

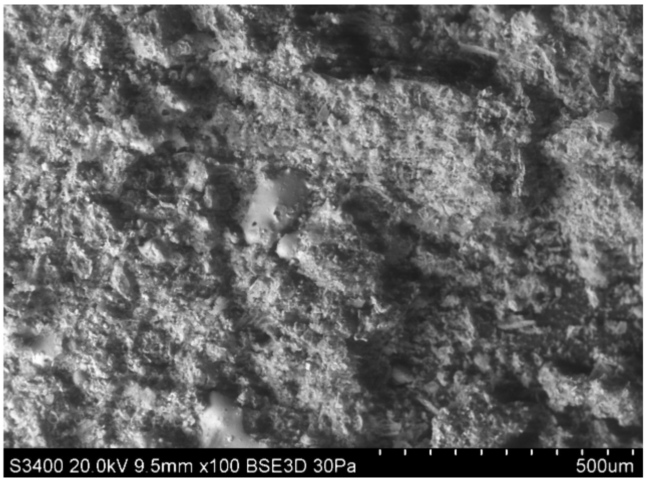

Fig. 1. SEM image of biomass ash used in laboratory tests

2. Methodology

The scope of the research encompassed: the analysis of raw sewage sludge, the choice of an optimal dose of ash and the determination of the influence of biomass ash on vacuum filtration. The whole experiment was done at room temperature. Laboratory tests of sewage sludge conditioning and dewatering with application of biomass ash were carried out in three series.

2.1. Conditioning procedure

The sewage sludge conditioning was carried in the following manner: five beakers with a volume of 1 dm^3 were filled with 500 cm^3 of raw sewage sludge.

The appropriate dosages of ash: 5, 7.5, 15 and 30 g·dm^{-3}, were added to four of the beakers. The doses of biomass ash were calculated as the weight ratio of ash to the content of sewage sludge dry mass: 170; 250; 500 and 1000 g·kg^{-1} d.m., accordingly. The mixtures were rapidly stirred with a speed of 250 rpm for 1 minute and then, they were mixed with a speed of 50 rpm for 15 minutes. After mechanical conditioning with the use of biomass ash, capillary suction time (CST) was determined in accordance with Baskerville and Gaulle method. CST was based on the wetting time measurement. The wetting time was measured as long as a filtration layer covered the area between the circles of 32 and 45 mm (Fig. 2).

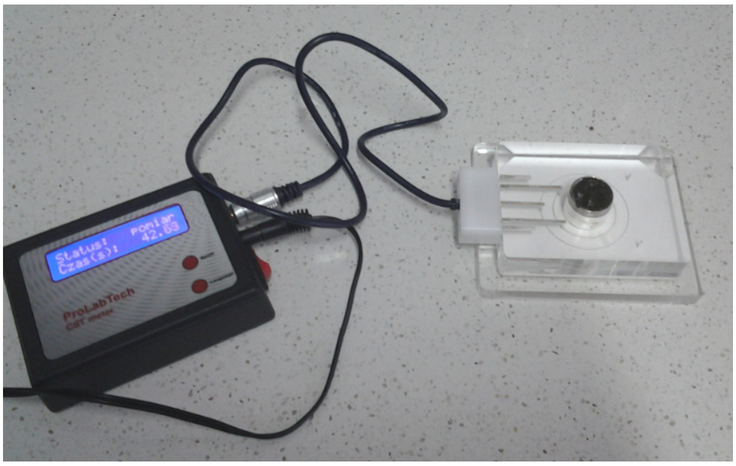

Fig. 2. CST measurement in laboratory conditions

2.2. Vacuum filtration process

After mechanical conditioning, the samples of sewage sludge were examined in terms of their dewater-ability with the application of vacuum filtration under two vacuum pressure values: 0.01 and 0.02 MPa. The research was carried out in accordance the following rules: 50 cm^3 of conditioned sewage sludge was poured into the Büchner funnel. After that, the vacuum pump was switched on to generate the appropriate vacuum pressure and the dewater-ability of sludge was investigated (Fig. 3). In order to determine the influence of biomass ash on sludge dewatering, the vacuum filtration was also performed for non-conditioned sewage sludge. The results of aforementioned process were used to calculate the moisture content reduction.

In order to determine the sewage sludge moisture content, such obtained sewage sludge cake was dried at 105°C. The sewage sludge moisture content (W) before and after filtration process, was calculated as shown by the following equation:

$$W = \frac{(m_1 - m) - (m_2 - m)}{m_1 - m} \cdot 100\%$$

where:
m - weight of dish, g,
m_1 - weight of sewage sludge + dish, g,
m_2 - weight of dried sewage sludge + dish, g.

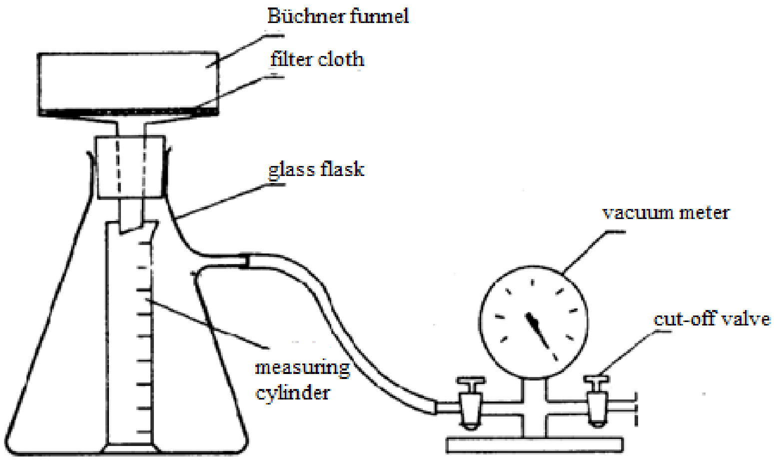

Fig. 3. Scheme of vacuum filtration process in laboratory conditions [12]

3. Results and discussion

The laboratory test showed that mechanical conditioning of sewage sludge with the use of biomass ash could improve the sewage sludge dewatering. The improvement of sewage sludge dewater-ability has been observed depending on the amount of biomass ash that was applied. The efficiency of process was the highest for the dosage of 30 $g\cdot dm^{-3}$ and for this reason, this amount of ash was considered as an optimal dose.

The effectiveness of sewage sludge conditioning with the application of biomass ash was done by CST measurement. The obtained results have shown that the biomass ash improved sewage sludge dewatering in various ways. CST of raw sewage sludge was 130.89 s which shows poor dewater-ability of sludge. The application of biomass ash resulted in the decline of the parameter with the increase of the dosage of ash (Fig. 4). The lowest dose of biomass ash reduced the CST of approximately 18% to the value of 108.54 s. The 7.5 and 15 $g\cdot dm^{-3}$ dosages of reagent reduced the CST value of about 41 and 73% which corresponds to the value of 77.43 and 34.76 s, respectively. CST after conditioning with the biomass ash in the highest dose (30 $g\cdot dm^{-3}$) was 20.08 s. This enables the reduction of examined parameter of approximately 85% in comparison with raw sewage sludge. The analysis of results showed that the use of biomass ash has resulted in the decline of CST within the whole range of the agent used. The similar results were obtained by other researchers for the application of medium cationic polyelectrolytes [13].

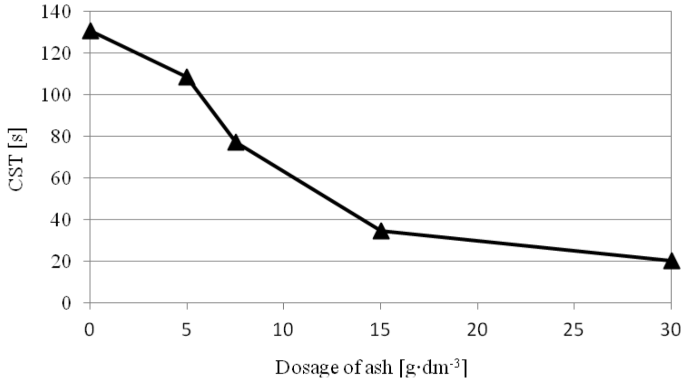

Fig. 4. Influence of biomass ash from biomass-fired power plant on CST of sewage sludge

In order to determine the influence of biomass ash on sewage sludge dewatering, conditioned sludge was dewatered with the use of vacuum filtration. The aforementioned process was done under 0.01 and 0.02 MPa vacuum pressure. The efficiency of conditioned sewage sludge dewatering was compared with the results of raw sludge. The measure of effectiveness was the sewage sludge moisture content and the filtrate volume after vacuum filtration. The addition of biomass ash to sewage sludge decreased the final moisture content due to the forming the special skeleton builder for sludge particles. Depending on the amount of biomass ash, the sewage sludge moisture content had differential values.

The research carried out at the laboratory showed that only raw sewage was characterized by a good susceptibility to dewatering. Non-conditioned sewage sludge reduced the final moisture content to the value of 88.21% for vacuum pressure of 0.01 MPa and to the value of 87.94% for vacuum pressure of 0.02 MPa. The application of ash from biomass combustion intensified the vacuum filtration process and for this reason, the hydration of sewage sludge decreased as the dosage of ash increased. The average sewage sludge moisture content for: 5; 7.5; 15 and 30 g·dm^{-3} doses of ash, was at the level of: 85.42; 84.19; 80.16 and 75.64% for the vacuum pressure of 0.01 MPa (Fig. 5). The aforementioned results corresponds to the moisture content reduction of approximately: 12, 13, 16 and 20%, respectively (Table 4).

Table 4. **Influence of biomass ash on the sewage sludge moisture content reduction after vacuum filtration process (0.01 MPa)**

Dosage of ash g·dm^{-3}	Sewage sludge moisture content reduction %
5.0	11.72
7.5	12.85
15.0	16.11
30.0	19.66
without biomass ash	9.51

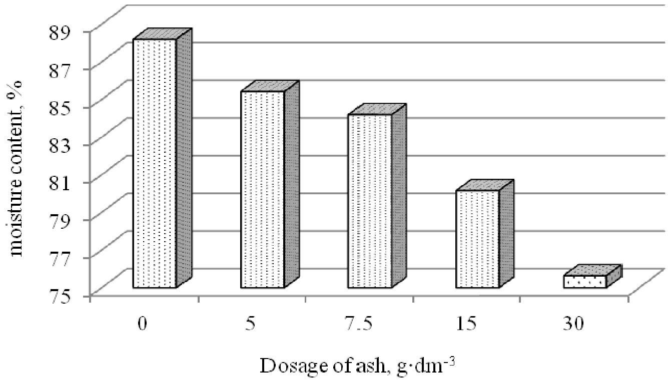

Fig. 5. Influence of biomass ash from biomass-fired power plant on sewage sludge moisture content after vacuum filtration (0.01 MPa)

Better results were obtained for the higher vacuum pressure value (0.02 MPa). The sewage sludge moisture content after dewatering for: 5; 7.5; 15 and 30 g·dm^{-3} dosages of ash, was: 83.07; 82.02; 76.07 and 70.91%, accordingly (Fig. 6). The application of such doses of biomass ash could reduce the moisture content of: 14, 15, 20 and 25%, respectively (Table 5). The similar results were obtained by Panyae et al. [14] for the application of coal fly ash.

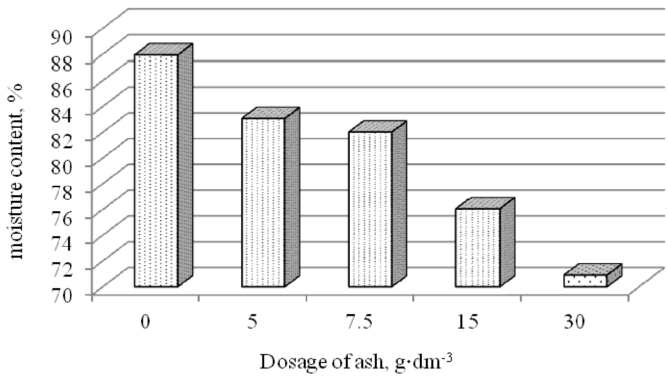

Fig. 6. Influence of biomass ash from biomass-fired power plant on sewage sludge moisture content after vacuum filtration (0.02 MPa)

Table 5. **Influence of biomass ash on the sewage sludge moisture content reduction after vacuum filtration process (0.02 MPa)**

Dosage of ash g·dm^{-3}	Sewage sludge moisture content reduction %
5.0	14.15
7.5	15.09
15.0	20.39
30.0	24.68
without biomass ash	9.79

The analysis of results has shown that the mechanical conditioning of sewage sludge with the use of biomass ash influenced the dewater-ability of sludge within the whole range of dosages. However, the best results were obtained for the highest dose of biomass ash. The application of 30 g·dm^{-3} of aforementioned reagent could lead to obtaining the sewage sludge cake of "mushy" consistence which was easily removable from the filter cloth.

Additionally, the vacuum filtration process for conditioned sewage sludge was more rapid in comparison with raw sewage sludge. The influence of biomass ash on the filtrate volume after vacuum filtration under 0.01 and 0.02 MPa vacuum pressure are shown in Figure 7. Although, the filtered water volume did not change significantly, but the time of filtration process was shorten. In order to produce 10 cm^3 filtered water from 50 cm^3 raw sewage sludge, the filter duration of approximately 100 s was needed. The application of biomass ash in the dosage of 30 g·dm^{-3} could shorten the necessary time to approximately 10 s.

The effectiveness of sewage sludge conditioning with ash results from the special structural properties of ash. Sewage sludge has a negative charge and creates a stable system with low-sediment and low-dewatering capacity. After conditioning with biomass ash, the sludge particles congregated around the ash microspheres and flocs were formed. When the raw sewage sludge was compressed, a highly compressible sludge might deform under pressure. The biomass ash acts as skeleton builders and formed a permeable and rigid lattice structure. Opposite to raw sewage sludge, conditioned sludge remained porous under high pressure [15].

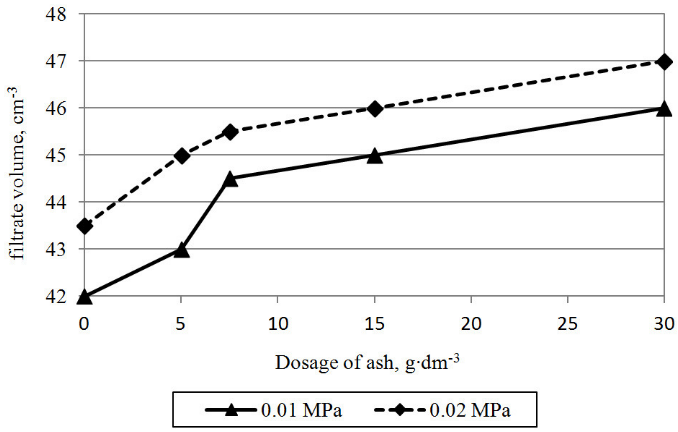

Fig. 7. Influence of biomass ash from biomass-fired power plant on filtrate volume after vacuum filtration

Conclusions

Raw sewage sludge is characterized by the high content of water and for this reason, it is necessary to intensify the sewage sludge dewatering. In order to improve the sewage sludge dewatering, sludge conditioning by means of different materials is applied [5]. In order to reduce the cost of reagents, new sludge conditioning methods are developed.

The alternative solution for popular organic flocculants might be ashes. According to Masłoń [7], ashes with a diameter below 300 μm are the weights of sewage sludge flocs. In the wake of incorporation of ash in sludge flocs, the shape, dimension and structure of flocs are altered. Ashes are integrated in sewage sludge floc matrix, what can improve the sewage sludge dewatering.

The laboratory test showed that sewage sludge conditioning with the use of biomass ash can improve dewater-ability of sludge. For every dosage of ash, there could be observed a reduced sewage sludge moisture content. But the highest decline in water content was attained for the highest dosage of biomass ash. With a 30 $g \cdot dm^{-3}$ amount of biomass ash, the sludge cake moisture content decreased at approximately 12÷25%, depending on the method of dewatering. The effectiveness of sewage sludge conditioning with biomass ash also confirms the increase of filtrate volume in comparison with raw sewage sludge.

The obtained results of laboratory tests allow us to draw the following conclusions:

1. Ash from the biomass-fired power plant could be an effective reagent in sewage sludge conditioning and dewatering. The effectiveness of sewage sludge conditioning by means of biomass ash depends on the amount of ash applied. The improvement of sewage sludge dewatering was observed with the increase of the dosage of ash.
2. The application of biomass ash in sewage sludge confers the earthen structure of sludge which is suitable to the application in the environment. This structure eliminates the possible leakage of sludge during the transport.
3. In order to the low cost and high prevalence, biomass ash might be an effective reagent in sewage sludge treatment in comparison with polyelectrolytes. Before the application of biomass ash in treatment plants, the previous test is required in order to select the optimal dosage of ash.
4. Additionally, the mixture of sewage sludge and ash might be applied in agricultural practices, especially in fertilizing of perennial plants plantations. Due to the non-consumable character of biomass, the influence of toxic elements containing in sewage sludge on human health is reduced significantly.
5. The application of biomass ashes in sewage sludge treatment is the new ash recycling method in accordance with law, economic and environmental requirements.

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Streszczenie

Procesy oczyszczania ścieków powodują wytwarzanie ogromnych ilości osadów ściekowych, które wymagają odpowiedniego unieszkodliwiania zgodnie z wymogami ekologicznymi, ekonomicznymi, społecznymi i prawnymi. Surowe osady ściekowe charakteryzują się wysokim uwodnieniem, powyżej 90%, oraz aktywnością mikrobiologiczną. Wysoka zawartość wody w osadach ściekowych przekłada się na ich znaczną objętość, co generuje problemy z transportem i utylizacją osadów. Ze względu na fakt, że wysokie uwodnienie osadów ściekowych generuje wysokie koszty eksploatacyjne oczyszczalni ścieków, niezbędna jest intensyfikacja procesu odwadniania osadów. W celu poprawy efektywności odwadniania osadów ściekowych stosuje się proces kondycjonowania z zastosowaniem różnych substancji. Powszechnie w oczyszczalniach ścieków stosowane jest kondycjonowanie chemiczne z zastosowaniem polielektrolitów. Wadą powyższej metody są wysokie koszty związane z zakupem organicznych flokulantów, co wymusza potrzebę poszukiwania tanich i skutecznych środków kondycjonujących. Celem prezentowanego artykułu jest zbadanie możliwości kondycjonowania osadów ściekowych z zastosowaniem popiołu, pochodzącego ze spalania biomasy w elektrociepłowni. Do oceny skuteczności zaproponowanej metody kondycjonowania osadów ściekowych zastosowano pomiar czasu ssania kapilarnego (CSK). Osady ściekowe po procesie kondycjonowania zbadano pod kątem poprawy efektywności procesu odwadnia-

nia za pomocą filtracji próżniowej, dla dwóch wartości próżni: 0,01 i 0,02 MPa. Uzyskane rezultaty wykazały spadek uwodnienia końcowego osadów ściekowych wraz ze wzrastającą dawką popiołu. Mechaniczne kondycjonowanie osadów ściekowych z użyciem popiołu ze spalania biomasy wpłynęło również na wzrost objętości filtratu uzyskanego po procesie filtracji próżniowej. Dodatkowo, zastosowanie popiołu ze spalania biomasy w gospodarce osadowej nadaje osadowi ziemistą strukturę, dogodną do transportu i aplikacji w celach przyrodniczych. Wytworzona mieszanina osadu ściekowego i popiołu może znaleźć zastosowanie jako wartościowy nawóz na plantacjach roślin wieloletnich. Dzięki wspomnianej metodzie zagospodarowania osadów ściekowych możliwe jest wykorzystanie właściwości nawozowych osadów przy minimalnym poziomie zagrożenia dla zdrowia i życia ludzi.

Słowa kluczowe: osady ściekowe, popioły ze spalania biomasy, kondycjonowanie, odwadnianie, recykling