E3S Web of Conferences **30**, 03005 (2018) https://doi.org/10.1051/e3sconf/20183003005
Water, Wastewater and Energy in Smart Cities

Sewage sludge conditioning with the application of ash from biomass-fired power plant

Marta Wójcik[1,*], *Feliks* Stachowicz[1] , and *Adam* Masłoń[2]

[1]Rzeszow University of Technology, Department of Materials Forming and Processing, Powstańców Warszawy 8, 35-959 Rzeszow, Poland
[2] Rzeszow University of Technology, Department of Chemistry and Environmental Engineering, Powstańców Warszawy 6, 35-959 Rzeszow, Poland

Abstract. During biomass combustion, there are formed combustion products. Available data indicates that only 29.1 % of biomass ashes were recycled in Poland in 2013. Chemical composition and sorptive properties of ashes enable their application in the sewage sludge treatment. This paper analyses the impact of ashes from biomass-combustion power plant on sewage sludge dewatering and higienisation. The results obtained in laboratory tests proved the possitive impact of biomass ashes on sewage sludge hydration reduction after dewatering and the increase of filtrate volume. After sludge conditioning with the use of biomass combustion by-products, the final moisture content decreased by approximatelly 10÷25 % in comparison with raw sewage sludge depending on the method of dewatering. The application of biomass combustion products in sewage sludge management could provide an alternative method of their utilization according to law and environmental requirements.

1 Introduction

Biomass plays a special importance amongst renewable energy sources. It is estimated that biomass energy constituted approximately 53 % of world renewable energy production in 2010 [1]. Hydrogeological location of Poland prevents a significant share of renewable energy from natural sources, for example: from wind and sun and for this reason, biomass energy is becoming more and more popular in Poland. For heating purposes, it is particularly used forest or agricultural biomass [2]. The main sources of biomass in Poland are energetic crops, for example: straw and willow *Salix viminalis*. The largest share of whole energetic plants has a willow tree. In Poland, there are approximately 780 willow plant plantations with a surface area of 9480 ha which contains approximately 95 % of perennial plants cultivation [3].
Biomass comprises components which are contained in organs, for example: proteins, fat and lignin and structural material of biomass: polymerized carbonohydres, lignin and cellulose. The definite advantage of biomass combustion is “zero emission” of carbon dioxide. During the biomass burning, only so much carbon dioxide is emitted as a plant

* Corresponding author: m.wojcik@prz.edu.pl

takes from the atmosphere by photosynthesis when the plants grow [4]. Therefore, biomass could be treated as a source of clean energy.
The biomass consumption is systematically growing what is confirmed by the available data. In Poland the biomass consumption was 9 317 763 GJ in coal-burning power plants in 2005. For comparison, the use of biomass grew to 42 917 011 GJ in 2013. In 2013 the biomass consumption was 26 275 970 GJ in biomass-burning power plants [2]. During the biomass burning, there are formed combustion by-products, such as fly and bottom ashes. The increasing share of biomass in final energy production causes the problem with the ash utilization. Available data indicates that only 29.1 % of biomass ashes were recycled in Poland in 2012 [5]. Specific properties of biomass combustion products, for example: high losses of ignition and the content of chlorine, prevent their application in many sectors of economy. The main destination of biomass ashes is agriculture which applied them as a valuable fertilizer improving the plant growth [5].
Sewage sludge is a by-product of sewage treatment which contains mineral and organic compounds. Due to the connection of new areas to the sewerage, the amount of sludge is systematically growing. According to the Central Statistical Office Report [6], there were produced 556 Mg dry mass of municipal sewage sludge in Poland in 2014. Before the land application of sewage sludge, there have to be processed in order to decrease the health risk. Additionally, the effective dewatering could reduce the transport cost of sewage sludge. Raw sewage sludge has a stable structure with a low dewatering and sedimentation capacity. For this reason, sludge dewatering is enhanced by conditioning with the use of mineral and organic reagents. Recently, the application of polyelectrolytes is very popular in treatment plants. The disadvantages of aforementioned reagents are their high cost. What is more, high amounts of polyelectrolytes are required for effective dewatering. The alternative solution for popular organic flocculants might be combustion by-products. Biomass ashes might be used as a conditioner [8]. Powdered materials with a diameter below 300 μm are the weights of sewage sludge flocs [9]. In the wake of incorporation of ash in sludge flocs, the shape, dimension and structure of flocs are altered. Ashes are integrated in sludge floc matrix, what could improve sewage sludge dewatering [10].
The aim of this study was to determine the influence of ash from biomass combustion on the effectiveness of sewage sludge dewatering.

2 Materials and Methodology

2.1 Materials

The academic research concerning the influence of biomass ash on sewage sludge dewatering was performed under laboratory conditions. Sewage sludge used in tests was obtained from the inlet of the thickening tank from Świlcza WWTP (Podkarpackie region, Poland). Sewage sludge was taken during summer/autumn and was characterized by grey-brown colour and earthy smell. The physical and chemical properties of unconditioned sludge were as follows: pH = 6.40 ± 0.44; the moisture content = 97.48 ± 0.81%; the capillary suction time (CST) = 130.89 ± 28.71 s.
In laboratory research, ash from "Łężańska" Power Plant in Krosno (Podkarpackie region, Poland) was used. The biomass ash was characterized by particles in the range of 0.399 ÷ 399 μm. Due to the fact that ash was not sieved before laboratory research, there were some coarse particles above 300 μm. The biomass ash contains the following types of particles: irregular sharp, polyhedral and highly porous (Fig. 1).
The chemical composition of ash was determined by means of Energy Dispersive Spectroscopy (EDS). The results of EDS analysis showed that the ash comprises mainly the

following compounds: Ca, O, S, and Cl. The significant amount of Ca and S could classify the tested ash as a calcium and sulphate ash. Due to the biomass combustion from surrounding timber industry, ash from power plant also contains molybdenum. The phase composition of biomass ash was as follows: SiO_2 (α-quartz), Fe_2O_3 (hematite), CaO, Na_2O_2, SO_2, Na_2O, P_2O_5 and KO_2 (Table 2).

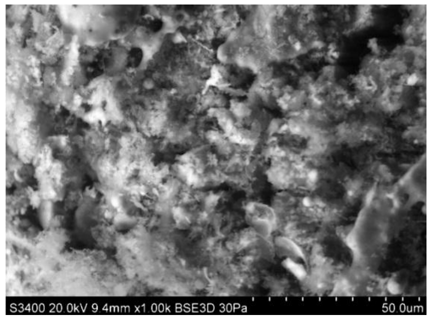

Fig. 1. SEM image of biomass ash.

Table 1. Chemical composition of tested biomass ash.

Element	Content [%]
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

2.2 Laboratory experiments

Laboratory tests of sewage conditioning and dewatering were carried out in tree series. The sewage sludge conditioning was carried out as follows: five beakers with a volume of 1 dm^3 were filled with 500 cm^3 of raw sewage sludge. To four beakers with sludge, there are applied appropriate dosages of biomass ash: 5; 7.5; 15 and 30 $g \cdot dm^{-3}$. The dosages of biomass ash were expressed as the weight ratio of ash to sewage sludge dry mass: 1:4; 1:3; 1:2 and 1:1, respectively. Firstly, mixtures were rapidly stirred with a speed of 200 rpm for

1 minute and after that, they were stirred with a speed of 50 rpm for 15 minutes. In sewage sludge after conditioning, pH and capillary suction time (CST) were determined.

2.3 Analytical methods

All parameters of sewage sludge after dewatering and conditioning were investigated in line with the applicable research procedure.
CST was measured by means of the CST meter ProLabTech in accordance with PN-EN 147011:2007. In sewage sludge, the pH was analyzed with pH-meter HACH HQ40d in line with PN-EN 15933: 2013-02. After that, for prepared samples of sewage sludge, the dewatering capacity was investigated. Mechanical dewatering process was done in a Büchner funnel and in a centrifuge. The vacuum filtration was done under 0.01 and 0.02 MPa vacuum pressure for approximately 15 minutes. Centrifugation of sewage sludge was done for two rotation speeds: 2000 and 2500 rpm for 5 minutes in a laboratory centrifuge (MPW-350). After mechanical dewatering, the moisture content was determined according to PN-EN 15934: 2013-02.

3 Results and discussion

This study showed different efficiencies in the improvement of sewage sludge dewatering, depending on the amount of biomass ash.
The impact of sludge conditioning on dewatering was assesed by means of CST measurement. The obtained results have shown that the biomass ash influenced the improvement of sewage sludge dewatering in various ways, depending on the amount of ash (Fig. 2). The best result was achieved for a dose of 30 g·dm^{-3} and for this reason, this amount of ash was considered as an optimal dosage. Detailed information concerning the influence of biomass ashes on CST value are presented in [12]. Similar results of sludge conditioning were achieved by Piotrowska-Cyplik and Czarnecki [10] for cationic polyelectrolyte F-410. Wójcik et al. [7] also proved that the addition of willow ash in the dosage of 30 g·dm^{-3} could decrese the CST value of sewage sludge by approximately 55%.

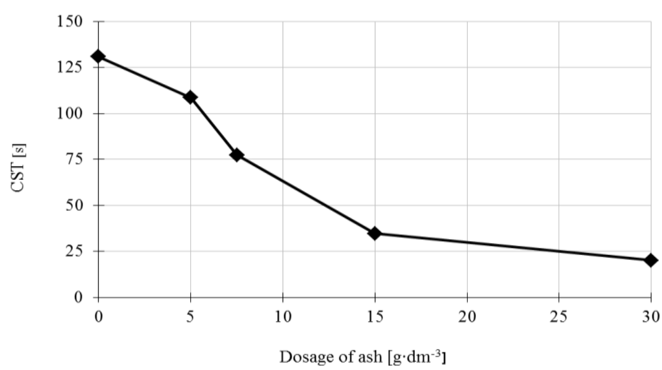

Fig. 2. Influence of sewage sludge conditioning by means of biomass ash on the CST [12]

Biomass ash might be an effective reagent in sewage sludge higienisation. The pH for raw sewage sludge was mean 6.40 and for sewage sludge after conditioning with biomass ash in dosage of 30 g·dm^{-3} was 12.24. The dosages of ash from 5 to 15 g·dm^{-3} could obtain the growth of the pH to the value: 7.38; 8.32 and 11.44, respectively (Fig. 3). The positive impact of biomass ash on the growth of pH is connected with the content of alkaline metals, such as: Ca and Na. In the case of high dosages, biomass ash might be an effective reagent in sewage sludge higienisation.

After conditioning, sewage sludge was dewatered by means of centrifugation. The research was carried out for two rotation speed: 2000 rpm and 2500 rpm. Results showed that the moisture content decreased with an increase of dosage of ash (Fig. 4). The best results were obtained for the highest amount of ash. With 30 g·dm^{-3} dosage of ash, the moisture content decreased from 92.71% (raw sewage sludge) to 84.52% (conditioned sewage sludge) for the rotation speed of 2000 rpm. Low dosages of ash influenced on the sludge moisture content in a lesser degree. Better results were obtained for the higher rotation speed. The application of 30 g·dm^{-3} dosage of biomass ash reduced the moisture content from 92.52% (raw sludge) to 76.21% (conditioned sludge). In comparison with raw sewage sludge, the highest dosage of biomass ash reduced the moisture content of approximately 19% for a rotation speed of 2500 rpm. In any case, low dosages of ash did not influence the reduction of moisture content in a significant way.

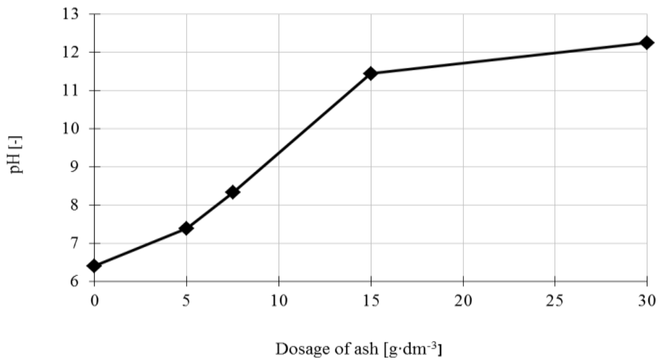

Fig. 3. Influence of sewage sludge conditioning by means of biomass ash on the pH of sewage sludge.

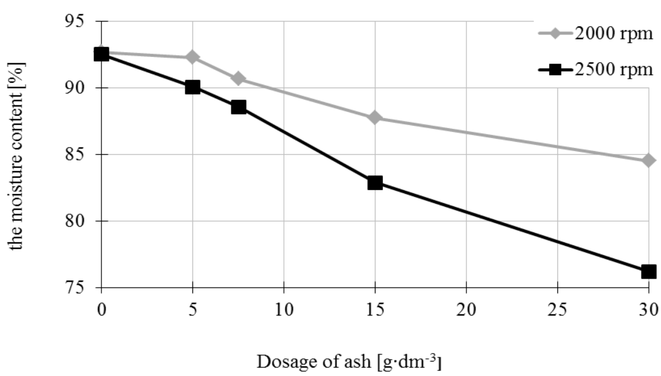

Fig. 4. Influence of biomass ash on the sewage sludge moisture content after centrifugation.

CST increased with the rise of dosage of biomass ash (Fig. 5). It was observed that CST depends on the sewage sludge moisture content. The higher value of CST could mean that sewage sludge has a more consistent structure. In the wake of elimination of excessive water, sludge is resistant to further dewatering. Higher values of CST were obtained for the rotation speed of 2500 rpm what corresponds to the better effectiveness of centrifugation.

Additionally, the centrifugation of conditioned sewage sludge was more efficient in comparison with raw sewage sludge, as witnesses by the liquid volume after dewatering. The water volume was approximately 27 cm^3 for raw sewage sludge and in the range of 31÷34 cm^3 (2000 rpm) and 32÷34 cm^3 (2500 rpm) for conditioned sewage sludge in different dosages of ash (Fig. 6). Although the water volume did not change significantly, the dividing line between sludge and liquid was clearer than for raw sewage sludge.

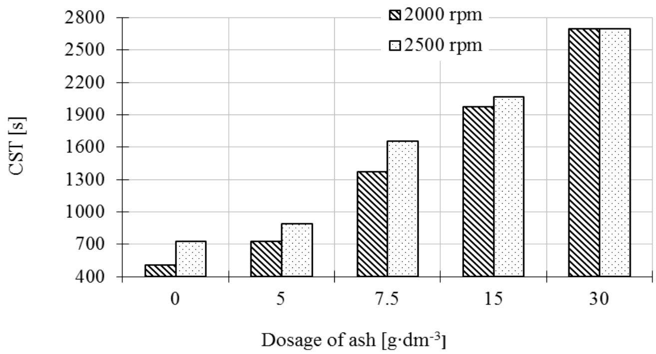

Fig. 5. Influence of biomass ash on the CST after centrifugation.

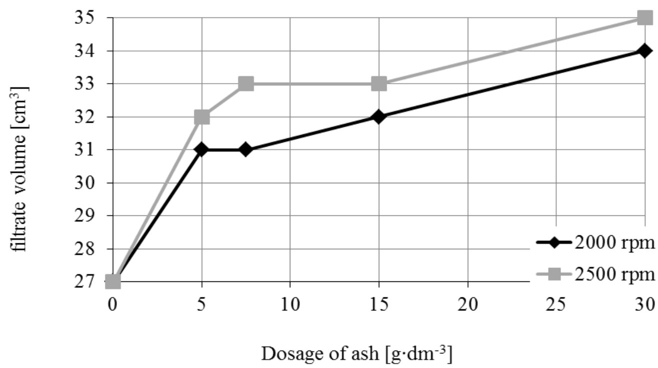

Fig. 6. Influence of biomass ash on the filtrate volume after centrifugation.

The vacuum filtration provided the best results of sewage sludge dewatering (Fig. 7). The hydration of sewage sludge decreased as the dosage of ash and the vacuum pressure increased. The application of biomass ash in a dose of 30 g·dm^{-3} reduced the moisture content of approximately 20% for a vacuum pressure of 0.01 MPa and about 25% for a vacuum pressure of 0.02 MPa. Detailed information concerning the influence of biomass ashes on CST value are presented in [12]. Similar results were achieved by Changya et al. [9] for sewage sludge with the addition of coal fly ash in the dosage of 300% d.m. Likewise, Wójcik et al. [7] investigated that the addition of willow ash in the dosage of 30 g· dm^{-3} could decrease the sewage sludge hydration by approximatelly 13% for the vacuum pressure of 0.01 MPa and 14% for the vacuum pressure of 0.02 MPa.
Increasing both biomass ash dosage and the vacuum pressure caused an increase of CST. In comparison with the results for centrifugation, CST after the vacuum filtration was approximately 50% higher. The higher value of CST is a result from the better effectiveness of sewage sludge dewatering in vacuum filtration (Fig. 8).

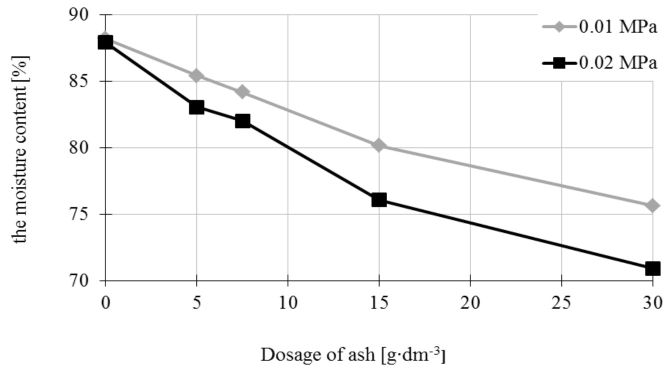

Fig. 7. Influence of biomass ash on the sewage sludge moisture content after vacuum filtration [12].

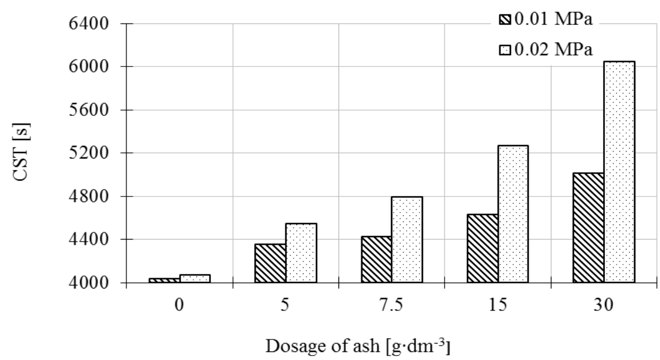

Fig. 8. Influence of biomass ash on the CST after the vacuum filtration.

The effectiveness of vacuum filtration was also done by the measurement of filtrate volume (Fig. 9). Although the filtered water volume did not change significantly, the sludge filtration was more rapid in comparison with raw sewage sludge. With 30 g·dm^{-3} dosage of ash, the filter duration reduced from 200 s to about 60 s [12].

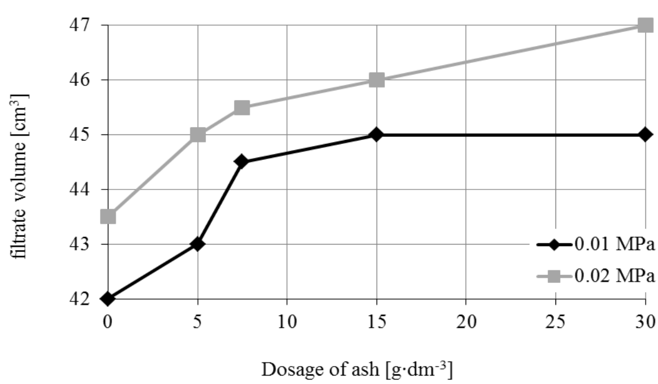

Fig. 9. Influence of biomass ash on the filtrate volume after the vacuum filtration [12].

4 Summary

The biomass ash is problematic waste which has to be managed in line with environmental and law requirements. Stringent requirements prevent biomass ashes from being used as a component in concrete and cement production. For this reason, the new biomass ash utilization methods are developed.
According to the specific physico-chemical properties, biomass ashes could be used as a sewage sludge conditioner. Sewage sludge after conditioning with ash showed a much stronger dewatering capacity than raw sewage sludge. The main sludge conditioning mechanisms with application of biomass ash can improve the floc formation and provide the water transmitting passages by skeleton builder [8, 11].
The obtained results of laboratory tests allow us to draw the following conclusions:

1. The application of biomass ash has a positive impact on sewage sludge dewatering what is confirmed by the measurement of CST. Aforementioned parameter decreased with the increase of dosage of ash.
2. The analysis of results has shown that the addition of biomass ash can improve the capacity of sewage sludge dewatering. The application of higher doses of ash yielded better results which are confirmed by the filtrate volume and moisture content after dewatering. With a 30 $g \cdot dm^{-3}$ dosage of biomass ash, the sewage sludge moisture cake content decreased of approximately 10 ÷ 25 %, depending on the method of dewatering. The best results of sewage sludge dewatering were obtained for vacuum filtration for 0.02 MPa vacuum pressure. The addition of low dosages of biomass ash could slightly improve the sewage sludge dewatering.
3. The application of ash from biomass-fired power plant might raise the pH of conditioned sewage sludge. For this reason, it is possible to reduce the amount of pathogens and achieve the partial higienization of sewage sludge.

The confirmation of the effectiveness of biomass ashes in sewage sludge conditioning might reduce the consumption of polyelectrolytes and contribute to the reduction of operating costs of treatment plants.

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