www.czasopisma.pan.pl PAN www.journals.pan.pl
POLSKA AKADEMIA NAUK

Archives of Environmental Protection
Vol. 44 no. 3 pp. 51–57

PL ISSN 2083-4772
DOI 10.24425/aep.2018.122290

Possibility of recycling the biomass ashes in sewage sludge management

Marta Wójcik*, Feliks Stachowicz, Tomasz Trzepieciński,
Adam Andrzej Masłoń, Ireneusz Opaliński

Rzeszow University of Technology, Poland

*Corresponding author's e-mail: m.wojcik@prz.edu.pl

Keywords: sewage sludge, recycling, waste management, dewatering, biomass ashes.

Abstract: The article discusses the possibility of recycling the biomass ashes in a sewage sludge management. In laboratory tests, ashes from straw and beech wood combustion were used. The effectiveness of sludge conditioning was investigated by the capillary suction time (CST) measurement. The influence of straw and beech wood ashes on sewage sludge dewatering was examined by means of vacuum filtration for the vacuum pressure of 0.01 and 0.02 MPa. The laboratory tests showed that sewage sludge after conditioning with the use of biomass ash indicated a much stronger dewatering capacity than raw sewage sludge. The results proved the different influence of biomass ashes on the effectiveness of sludge dewatering. The best results were achieved for beech wood ash for the highest dosage of material (30 kg·m^{-3}). However, further detailed tests are needed in order to define the optimal dose of biomass ash.

Introduction

The literature review shows that raw sewage sludge is characterized by the high moisture content, over 90%, which corresponds to its big volume (Piotrowska-Cyplik and Czarnecki 2005). The high content of water generates significant operating costs in treatment plants connected with the transport and subsequent application of the sludge. Therefore, sewage sludge dewatering is an essential step is sewage sludge treatment. However, raw sewage sludge is characterized by a low-dewatering capacity and for this reason sludge conditioning with the use of different techniques is applied (Kuglarz et al. 2008, Wang and Virraghavan 1997, Yan et al. 2016). The aforementioned process contributes to the change of the structure and properties of sludge with the purpose of dewatering improvement. The improvement of dewatering properties might be achieved by means of chemical substances, such as polyelectrolytes. There are numerous papers available discussing the influence of organic flocculants on the effectiveness of sewage sludge dewatering. The use of chemical conditioning results in significant operating costs associated with the high doses of such materials (even EUR 12 000 per year) (Wójcik et al. 2017a). In order to decrease the costs of sludge conditioning by means of polyelectrolytes, physical conditioning with different materials is examined. In recent years, sludge conditioning by means of thermal methods and with the use of ultrasounds has been tested (Wolski and Zawieja 2012). Gypsum, lignite, coal fly ashes and even rice husk biochar are used for sewage sludge conditioning and dewatering on a laboratory scale (Chen et al. 2015, Yan et al. 2016). Kuglarz et al. (2008) proved that dual sewage sludge conditioning with the use of polyelectrolyte and coal fly ash could decrease the organic flocculants consumption by 30%.

Biomass is one of the main renewable energy sources and, therefore, its consumption is systematically growing. According to Konieczyński et al. (2017), solid fuels from agricultural and forestry biomass are the main renewable energy source in Poland. The increasing share of biomass in final energy production causes problems to ash utilization. The available data indicate that only approximately 29% of biomass ashes were recycled in Poland in 2012 (Jarema-Suchorowska 2015). Due to specific properties, ashes from biomass combustion could be managed in sewage sludge treatment. Wójcik et al. (2017b) investigated the influence of ashes obtained from willow ash on the effectiveness of sewage sludge dewatering. The aim of this study was to determine the effect of selected biomass ashes on dewatering properties of sewage sludge. The application of waste from biomass combustion in sewage sludge management could constitute a new method of its recycling in line with environmental, economical and law requirements.

Materials and methods

In this research, selected biomass ashes from wheat straw (WSA) and pure beech wood (BWA) (combustion temperature 250÷300°C) were used. Ashes were obtained from domestic boiler produced by the Ogniwo Company. Due to the fact that ash was not sieved before laboratory tests, there were some coarse particles in the material. By means of that, the usage of biomass ashes in sewage sludge management without previous preparation might be assessed.

Sewage sludge used in laboratory tests was obtained from the thickening tank in Municipal Wastewater Treatment Plant (WWTP) in Świlcza in the Podkarpackie region. The characteristics of the aforementioned materials are shown in Table 1, Table 2 and in Figure 1. The pH was analyzed with pH-meter HACH HQ40d according to PN-EN 15933:2013-02. The dry mass was determined by weighing according to PN-EN 15934:2013-02. The CST was measured by means of quantitative method with CST meter in accordance with PN-EN 147011:2007.

The laboratory tests of sewage sludge conditioning and dewatering with the application of biomass ashes were carried out in three series. The scope of the research included, depending on the amount of biomass ashes, the following: the capillary suction time (CST) of sewage sludge measurement after its conditioning and the analysis of sludge dewaterability with the use of vacuum filtration for two vacuum pressure values (0.01 MPa and 0.02 MPa). The effectiveness of sewage sludge dewatering was assessed by the moisture content reduction and the changes of CST after vacuum filtration. As comparison criteria, the results for non-conditioned sewage sludge were used. The obtained results have been presented in diagrams below.

Table 1. Characteristics of raw sewage sludge

Parameter	Unit	Average value
pH	–	5.74 ± 0.14
Dry mass	%	3.16 ± 0.13
CST	s	140.53 ± 10.90

Table 2. Characteristics of tested biomass ashes

Parameter	Unit	Average value	
		WSA	BWA
d_{10}	μm	11.243±1.030	2.868±1.190
d_{50}	μm	42.072±2.480	20.032±1.870
d_{90}	μm	104.165±2.410	82.991±2.230
SMD	μm	19.211±2.190	6.417±0.260
VMD	μm	60.901±3.510	44.941±2.970
C_u	–	4.035±0.150	8.480±0.230
C_c	–	1.126±0.170	1.217±0.180
Specific surface area BET	m^2/g	11.904±1.110	79.073±3.550
Chemical composition			
Fe_2O_3	%	45.05 ± 0.10	5.892 ± 0.070
Al_2O_3	%	36.29 ± 0.10	8.509 ± 0.030
SiO_2	%	10.05 ± 0.09	3.128 ± 0.050
P_2O_5	%	2.781 ± 0.050	2.964 ± 0.040
CaO	%	2.418 ± 0.050	45.87 ± 0.20
MnO	%	1.49 ± 0.04	4.817 ± 0.060
SO_3	%	1.093 ± 0.030	1.521 ± 0.040
MgO	%	0.2046 ± 0.0100	5.036 ± 0.070
K_2O	%	0.1752 ± 0.0100	19.41 ± 0.10
Na_2O	%	0.1207 ± 0.0100	0.143 ± 0.010
ZnO	%	0.037 ± 0.006	0.083 ± 0.009
CuO	%	0.010 ± 0.003	0.032 ± 0.050
NiO	%	–	0.023±0.020
TiO_2	%	–	0.235±0.010
SrO	%	–	1.550±0.010
BaO	%	–	0.321±0.030
Cl	%	–	0.466±0.010

WSA – wheat straw ash; BWA – beech wood ash; SMD – Surface Mean Diameter; VMD – Volume Mean Diameter; C_u – Uniformity coefficient; C_c – Coefficient of curvature; d_{10} – Diameter at which 10% of the sample's mass is comprised of particles with a diameter less than this value; d_{50} – Diameter of the particle that 50% of a sample's mass is smaller than and 50% of a sample's mass is larger than; d_{90} – Diameter at which 90% of the sample's mass is comprised of particles with a diameter less than this value

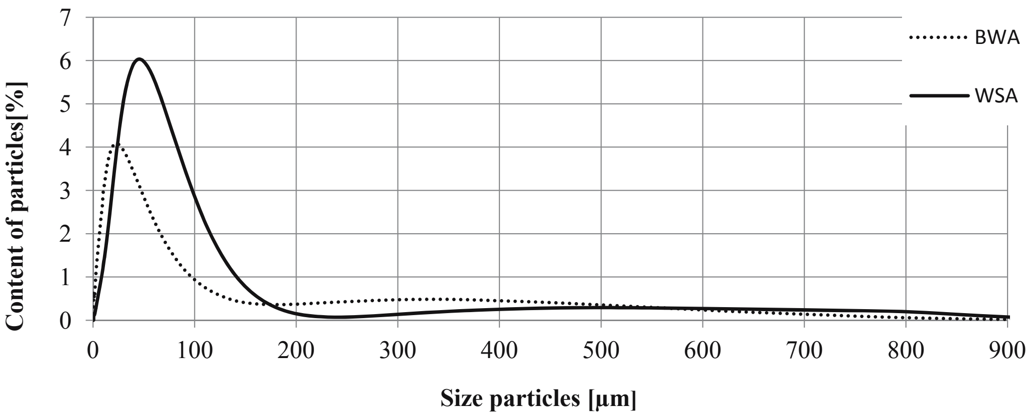

Fig. 1. The granulometric analysis of tested biomass ashes

The following laboratory research was carried out: five beakers with a volume of 1dm^3 were poured with 500 cm^3 of raw sewage sludge. The appropriate dosages of ash: 5 (2); 7.5 (3); 15 (4) and 30 kg·m^{-3} (5) were added to four beakers. The reference level (1) was a sample without the addition of ash. The dosages of wheat straw and beech wood ashes were determined on the basis of literature review (Changya et al. 2010) as the weight ratio of ash to sewage sludge dry mass approximately: 1:4; 1:3, 1:2 and 1:1.

Firstly, beakers were placed in a mechanical stirrer and mixtures were rapidly stirred with a speed of 200 rpm (1 minute) and after that, they were stirred with a speed of 50 rpm (15 minutes). The effectiveness of sewage sludge conditioning with the aforementioned ashes has been determined by CST measurement using the CTS meter (ProLabTech). Secondly, for the prepared samples of sewage sludge, the dewatering capacity with the application of Büchner funnel was investigated. The sewage sludge dewatering was carried out as follows: 50 cm^3 of sewage sludge was poured into a Büchner funnel. The process was done under 0.01 and 0.02 MPa vacuum pressure for approximately 15 minutes. After vacuum filtration, the sewage sludge moisture content and CST were determined.

Results and discussion

The laboratory tests showed different efficiencies of sewage sludge dewatering, depending on the type and amount of ashes applied. It was observed that conditioned sewage sludge, especially with the use of the highest dosages of ashes, indicated much better dewatering properties in comparison with raw sludge. What is more, filtration time for conditioned sewage sludge was shorter than that for non-condition sludge and the whole effectiveness of the process increased.

The effectiveness of sewage sludge conditioning with the use of biomass ash was evaluated by the CST measurement. The analysis of the obtained results showed that mechanical conditioning influenced the improvement of sewage sludge dewatering, as evidenced by reduced CST. The impact of biomass ashes on CST value was shown in Figure 2. The CST of non--conditioned sewage sludge was 140.5 s on average which shows poor dewaterability of sludge. The application of biomass ash resulted in the decline of the aforementioned parameter with the increase of the dosage of biomass ashes. The lowest dosage of ash decreased the CST by only about 6% to the value of 129.3 s for WSA and by approximately 5% to the value of 141.3 s for BWA. The 7.5 and 15 kg·m^{-3} dosages of the aforementioned materials reduced CST by approximately 9 and 10% for SWA and of about 23 and 36% for BWA. These results correspond to CST value of 120.3 and 119.6 s for WSA and 114.3 and 94.8 s for BWA, respectively. But the best results were obtained for the highest applied dosage (30 kg·m^{-3}) and for this reason, this amount was considered as an optimal dosage. CST after conditioning with the biomass ash in the highest dose was 114.9 s for WSA and 62.9 s for BWA which corresponds to the reduction of the aforementioned parameter by approximately 14 and 58%, accordingly. The results showed significantly higher effectiveness of sewage sludge conditioning with the use of beech wood ash. Similar results were obtained by Wójcik et al. (2017b) for sewage sludge conditioning by means of willow ash. The addition of wheat straw ash could decrease CST slightly. Bohdziewicz et al. (2008) proved that the addition of coal fly ash in a dosage of 10% d.m. could decrease the CST value by approximately 30%. Additionally, low dosages of tested ashes influenced the effectiveness of sludge conditioning and dewatering to a small extent.

The influence of mechanical conditioning with the use of biomass ashes on sewage sludge dewatering was evaluated on the basis of the results of vacuum filtration. The analysis of the results confirmed the differentiated influence of biomass ashes on final sludge hydration, depending on the amount and sort of ash.

Non-conditioned sewage sludge decreased its moisture content to the value of 91.22% on average for 0.01 MPa. Slightly better results were obtained for a higher vacuum pressure value. Raw sewage sludge moisture content after dewatering under 0.02 MPa vacuum pressure was approximately 90.66%. The research proved that the application of biomass ashes influenced the effectiveness of sewage sludge filtration. By means of that, the hydration of sewage sludge decreased as the dosage of ash increased. The influence of wheat straw and beech wood ashes on the effectiveness of vacuum filtration for 0.01 and 0.02 MPa vacuum pressure was shown in Figure 3 and Figure 4. The final sewage sludge moisture content for 5; 7.5; 15 and 30 kg·m^{-3} doses of WSA was at the level of: 91.05; 90.75; 90 and 84.87% for the vacuum pressure of 0.01 MPa and 90; 89.34; 88.12 and 82.74% for the vacuum pressure of 0.02 MPa. These results correspond to the moisture content reduction of approximately: 6.0; 6.3; 7 and 12.3% (0.01 MPa) and of: 7; 7.7; 9 and 14.5% (0.02 MPa). The addition of BWA in the same doses resulted in the decrease of moisture content to the value of: 87.61; 86.67; 82.32 and 78.52% for the vacuum pressure of 0.01 MPa and to: 86.99; 85.55; 80.30 and 78.22% for the vacuum pressure of 0.02 MPa. The aforementioned dosages of beech wood ash allow for the moisture content reduction at the level of: 9.5; 10.5; 15 and 19% (0.01 MPa) and of: 10.2; 11.7; 17.1 and 19.2% (0.02 MPa), accordingly. The research has shown that low dosages of biomass ashes influenced the improvement of dewatering to a small extent. Only the addition of higher dosages of ashes caused the whole process to be more intensified. On the basis of the obtained results, the higher moisture content reduction was observed for beech wood ash. Yan et al. (2016) achieved comparable results of vacuum filtration for sewage sludge modified by means of rice husk biochar. Changya et al. (2010) also indicated that the application of coal fly ash in sludge dewatering could reduce the moisture content below 80%. Sewage sludge conditioning with the use of wheat straw ash influenced the improvement of vacuum filtration to a lesser extent.

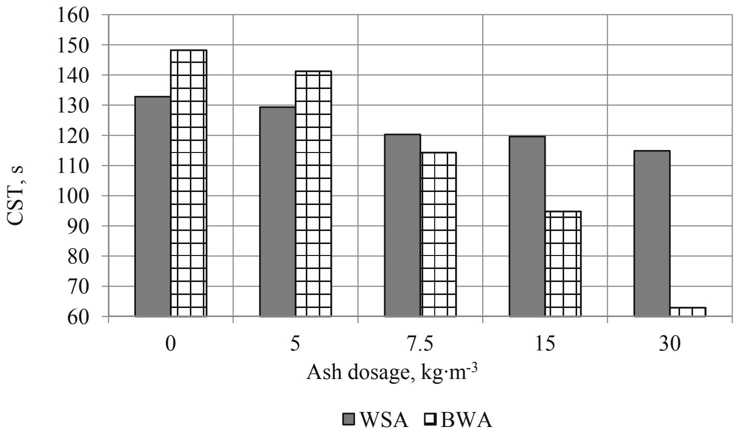

Fig. 2. Influence of tested biomass ashes on CST value of sewage sludge

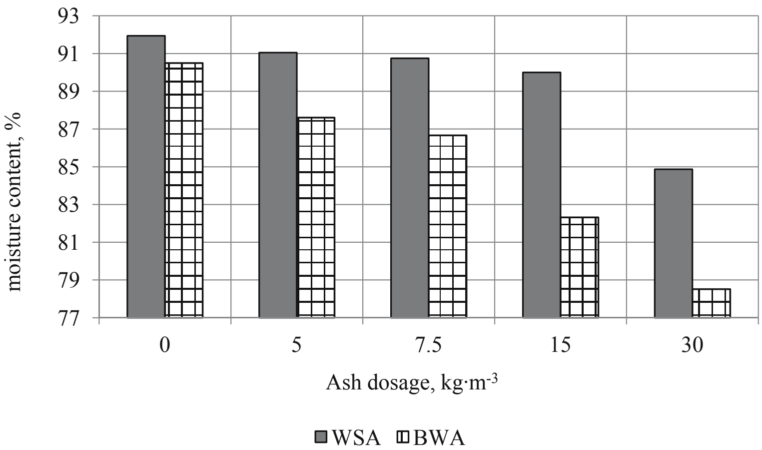

Fig. 3. Influence of biomass ashes on the sewage sludge moisture content under 0.01 MPa vacuum pressure

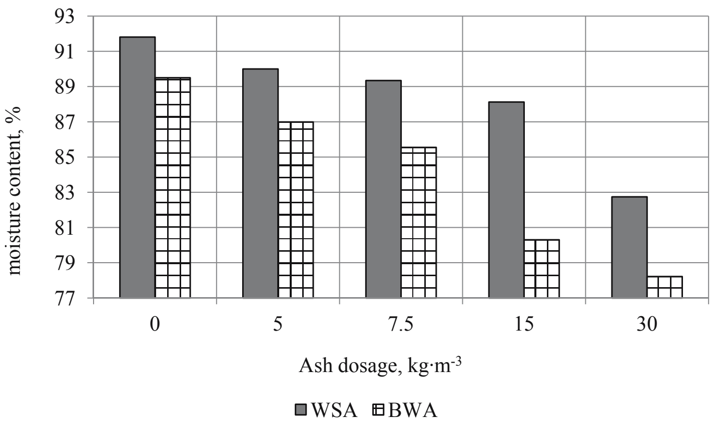

Fig. 4. Influence of biomass ashes on the sewage sludge moisture content under 0.02 MPa vacuum pressure

For sewage sludge cake after dewatering, CST was measured. The analysis of results showed that CST for raw sewage sludge after vacuum filtration was 1395 s (0.01 MPa) and 1626 s (0.02 MPa) on average. Depending on the type and dosage of biomass ashes, CST value for dewatered sewage sludge (under 0.01 MPa vacuum pressure) amounted to 1957.2 ÷ 2967.3 s for WSA and 2056.3÷3986.8 s for BWA (Fig. 5).

By comparison, CST for 0.02 MPa was in the range of 2170.5÷3269.9 s for WSA and 2654.7÷4357.8 s for BWA (Fig. 6). Higher values of CST were obtained for beech wood ash and under higher vacuum pressure, which confirmed a better influence on the improvement of sewage sludge filtration. A similar influence of biomass ashes on CST value after dewatering was proved by Wójcik et al. (2017d) for sewage sludge conditioning by means of ash derived from power plant in Krosno.

Sewage sludge conditioning with the use of different fractions of waste was also tested by other researchers. In research, the different materials and methods were examined. The influence of waste on sewage sludge dewatering by means of different methods is presented in Table 3.

The literature review confirms a different influence of waste materials on sewage sludge dewaterability, depending on the dewatering technique and the sort of reagent. In each case, the best results of dewatering were achieved for the highest dosage of waste. But any material intensified the effectiveness of sewage sludge dewatering in comparison to raw sewage sludge. The results of laboratory tests proved the comparable efficacy of biomass ashes to other waste materials. Additionally, biomass combustion by-products are inexpensive and easy-obtained material, especially in industrial areas. For this reason, sewage sludge conditioning with the use of ashes is a cheaper alternative to the use of chemical conditioners.

Conclusions

The analysis of results indicated that the most effective material was beech wood ash for which a dosage of 30 kg·m^{-3} resulted in the highest reduction of sewage sludge moisture content. The application of beech wood ash reduced the aforementioned parameter by 19% for the vacuum pressure of 0.01 MPa and by 19.2% for the vacuum pressure of 0.02 MPa. For wheat straw ash, the improvement of sewage sludge dewaterability was smaller. The addition of the highest dosage of straw ash could reduce the sewage sludge moisture content of approximately 12% (0.01 MPa) and 14.5% (0.02 MPa). In terms of the effectiveness, biomass ashes could be established as follows:

BWA (30 kg·m^{-3}) > BWA (15 kg·m^{-3}) > WSA (30 kg·m^{-3}) > BWA (7.5 kg·m^{-3}) > > BWA (5 kg·m^{-3}) > WSA (15 kg·m^{-3}) > WSA (7.5 kg·m^{-3}) > WSA (5 kg·m^{-3}).

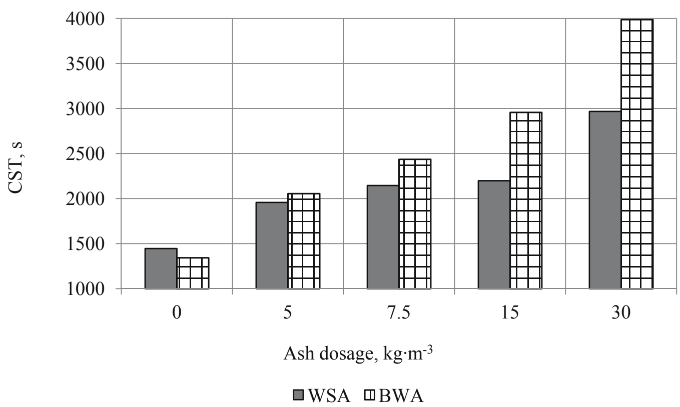

Fig. 5. Influence of biomass ashes on CTS of sewage sludge after dewatering (0.01 MPa)

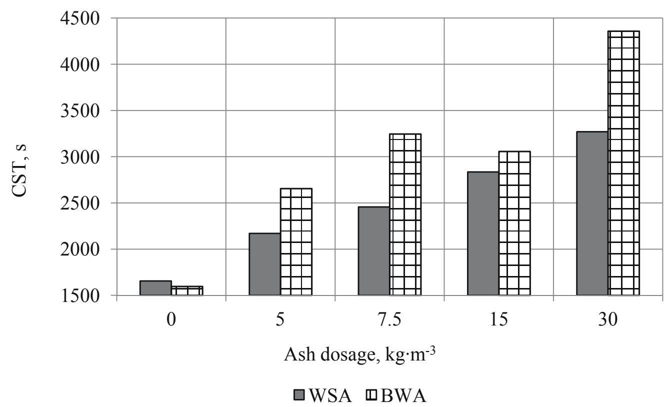

Fig. 6. Influence of biomass ashes on CTS of sewage sludge after dewatering (0.02 MPa)

Table 3. Influence of waste materials on the effectiveness of sewage sludge dewatering

Material	Dewatering method	Material dosage	Initial moisture content	Final moisture content	Sewage sludge moisture reduction	References
[–]	[–]	[% d.m.]	[%]	[%]	[%]	[–]
coal fly ash	vacuum filtration (0.03 MPa)	0 273 455 636 827 1000	98.74	86.90 62.61 56.52 about 53.00 about 48.00 about 46.00	11.99 36.59 42.76 46.32 51.39 53.41	Changya at al. (2010)
wood chips	plate-and-frame filter press	0 50 80 1000	98.00	93.00 91.28 89.00 88.45	5.10 6.86 9.18 9.74	Ding et al. (2014)
coal fly ash	piston type dewatering device	0 30 50	97.70	80.00 77.20 74.80	18.12 20.98 23.44	Lee et al. (2010)
rice husk biochar	vacuum filtration (0.03 MPa)	0 40 60	98.60	96.69 94.70 77.97	1.94 3.96 20.92	Yan et al. (2016)
willow tree ash	vacuum filtration (0.02 MPa)	0 17 25 50 100	96.83	88.47 85.86 83.76 80.32 75.80	8.63 11.33 13.50 17.05 21.72	Wójcik et al. (2017b)
wheat straw ash	vacuum filtration (0.02 MPa)	0 13 20 40 80	96.69	89.09 86.37 84.17 83.06 76.19	7.86 10.67 12.95 14.10 21.20	Wójcik et al. (2017c)
wheat straw ash	pressure filtration (0.1 MPa)	0 13 20 40 80	96.69	94.04 93.98 92.69 90.87 89.10	2.74 2.80 4.14 6.02 7.85	Wójcik et al. (2017c)
biomass ash from power plant	pressure filtration (0.1 MPa)	0 17 25 50 100	96.69	94.12 91.89 89.87 87.04 83.40	2.66 4.96 7.05 9.98 13.74	Stachowicz et al. (2017)
biomass ash from power plant	vacuum filtration (0.02 MPa)	0 17 25 50 100	96.69	87.94 83.07 82.02 76.07 70.19	9.05 14.09 15.17 21.33 27.41	Stachowicz et al. (2017)
wheat straw ash	vacuum filtration (0.01 MPa)	0 17 25 50 100	96.84	91.22 91.05 90.75 90.00 84.87	5.80 5.98 6.29 7.06 12.36	This study
wheat straw ash	vacuum filtration (0.02 MPa)	0 17 25 50 100	96.84	90.66 90.00 89.34 88.12 82.74	6.38 7.06 7.74 9.00 14.58	This study
beach wood ash	vacuum filtration (0.01 MPa)	0 17 25 50 100	96.84	91.22 87.61 86.67 82.32 78.52	5.80 9.53 10.50 14.99 18.92	This study
beach wood ash	vacuum filtration (0.02 MPa)	0 17 25 50 100	96.84	90.66 86.99 85.55 80.30 78.22	6.38 10.17 11.66 17.08 19.23	This study

References

Bohdziewicz, M., Bohdziewicz, J. & Przywara, L. (2008). The influence of dual conditioning methods on sludge dewatering properties, *Architecture Civil Engineering Environment,* 3, pp. 103–106.

Changya, C., Panyue, Z., Guangming, Z., Jiuhua, D., Yu, Z. & Haifeng, L. (2010). Sewage sludge conditioning with coal fly ash modified by sulfuric acid, *Chemical Engineering Journal*, 158, 3, pp. 616–622.

Chen, Z., Zhang, W., Wang, D., Ma, T. & Bai, R. (2015). Enhancement of activated sludge dewatering performance by combined composite enzymatic lysis and chemical re-flocculation with inorganic coagulants: kinetics of enzymatic reaction and re-flocculation morphology, *Water Research*, 83, pp. 367–376.

Ding, A., Qu, F., Liang, H., Guo, S., Ren, Y., Xu, G. & Li, G. (2014). Effect of adding wood chips on sewage sludge dewatering in a pilot-scale plate-and-frame filter press process, *RSC Advances*, 4, pp. 24762–24768.

Jarema-Suchorowska, S. (2015). Biomass ashes, (http://www.kierunekenergetyka.pl/magazyn, popioly-z-biomasy.html/ (01.05.2017). (in Polish)

Konieczyński, J., Komosiński, B., Cieślik, E., Konieczny, T., Mathews, B., Rachwał, T. & Rzońca, G. (2017). Research into properties of dust from domestic central heating boiler fired with coal and solid biofuels, *Archives of Environmental Protection,* 43, 2, pp. 20–27.

Kuglarz, M., Bohdziewicz, J. & Przywara, L. (2008). The influence of dual conditioning methods on sludge dewatering properties, *Architecture Civil Engineering Environment*, 3, pp. 103–106.

Lee, J.E., Lee, J.K. & Kim, D.S. (2010). A study of the improvement in dewatering behavior of wastewater sludge through the addition of fly ash, *Korean Journal of Chemical Engineering,* 27, 3, pp. 862–867.

Piotrowska-Cyplik, A. & Czarnecki, Z. (2005). Determination of the capillary suction time (CST) as a method for estimation of optimal dose of flocculants supporting dewatering of municipal sewage sludge, *Journal of Research and Applications in Agricultural Engineering*, 50, 1, pp. 21–23. (in Polish)

Stachowicz, F., Wójcik, M., Trzepieciński, T. & Masłoń, A. (2017). The cost-effectiveness analysis of biomass ashes application in sewage sludge Management, *Papers of International Multidisciplinary Conference 12th Edition Baia Mare – Nyiregyháza*, pp. 87–92.

Wang, S. & Viraraghavan, T. (1997). Wastewater sludge conditioning by fly ash, *Waste management,* 17, 7, pp. 443–450.

Wolski, P. & Zawieja, I. (2012). Effect of ultrasound field on dewatering of sewage sludge, *Archives of Environmental Protection*, 38, 2, pp. 25–31.

Wójcik, M., Stachowicz, F. & Masłoń, A. (2017a). The possibility of the application of fly ashes in order to the improvement of sewage sludge dewatering, *Journal of Civil Engineering, Environment and Architecture JCEEA*, 64, 1, pp. 337–393. (in Polish)

Wójcik, M., Stachowicz, F. & Masłoń, A. (2017b). The application of biomass ashes for improvement of sewage sludge dewatering, *E3S Web of Conferences*, 17, pp. 1–8.

Wójcik, M., Stachowicz, F. & Masłoń, A. (2017c). Ocena skuteczności kondycjonowania osadów ściekowych popiołami ze spalania biomasy, *Inżynieria i Ochrona Środowiska*, 20, 3, pp. 295–304. (in Polish)

Wójcik, M., Stachowicz, F. & Masłoń, A. (2017d). The possibility of sewage sludge conditioning and dewatering with the use of biomass ashes, *Inżynieria i Ochrona Środowiska,* 20, 2, pp. 153–164.

Yan, W., Panyue, Z., Haibo, Z., Guangming, Z., Jianbo, L., Jie, Y., Wei, F. & Xiying, G. (2016). Possibility of sludge conditioning and dewatering with rice husk biochar modified by ferric chloride, *Bioresource Technology,* 205, pp. 258–263.

Propozycja recyklingu popiołów ze spalania biomasy w gospodarce osadami ściekowymi

Streszczenie: Artykuł przedstawia propozycję recyklingu popiołów ze spalania biomasy w gospodarce osadami ściekowymi. W badaniach laboratoryjnych zastosowano popioły ze spalania słomy oraz drewna bukowego. Skuteczność kondycjonowania osadów ściekowych z użyciem ubocznych produktów spalania biomasy oceniono na podstawie pomiaru czasu ssania kapilarnego (CSK). Wpływ popiołów ze spalania biomasy na proces odwadniania osadów ściekowych zbadano za pomocą filtracji próżniowej dla wartości podciśnienia 0,01 i 0,02 MPa. Badania laboratoryjne wykazały większą podatność kondycjonowanych osadów ściekowych na procesy odwadniania w porównaniu do surowego osadu ściekowego. Uzyskane wyniki potwierdziły zróżnicowany wpływ popiołów z biomasy na efektywność procesu odwadniania. Najlepsze rezultaty uzyskano dla osadów kondycjonowanych popiołem ze spalania drewna bukowego w najwyższej dawce (30 kg·m^{-3}). Niemniej jednak niezbędne jest przeprowadzenie dalszych badań w celu wyznaczenia optymalnej dawki reagenta.