Experimental Research of Sewage Sludge Conditioning with The Use of Selected Biomass Ashes

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Abstract. The high content of water in sludge results in its big volume and contributes to the high operating costs of wastewater treatment plants. Chemical conditioning is commonly used in order to improve mechanical dewatering in treatment plants. The cost of chemical reagents is significant, thus it is important to find effective and inexpensive conditioners.
This paper presents the improvement of sewage sludge dewatering with the use of biomass ashes. In laboratory tests, ashes from willow tree and beech wood combustion were used.The results have shown that the sewage sludge moisture content decreased with the addition of ash. The best results were obtained for the 30 g·dm^{-3} of biomass ash in both cases. With a 30 g·dm^{-3} dosage of ash, the moisture content decreased by approximately 9 ÷ 17% for willow ash and about 9 ÷ 21% for beech wood ash, depending of the method of dewatering.

1. Introduction

With the increase of wastewater treatment efficiency and the number of new residents attached to the sewerage system, the amount of produced sewage sludge is systematically growing. For this reason, sewage sludge management is a challenging issue for treatment plants. The high content of water in sewage sludge, over 95% results in its big volume and impedes the final utilization of sludge [1]. Additionally, the high moisture content of sewage sludge generates the significant operating costs in municipal sewage sludge [2].
Sewage sludge conditioning and dewatering are the most important steps in sewage sludge treatment. Raw sewage sludge creates a relatively stable system with low dewatering capacity and for this reason, chemical conditioning with organic flocculants is commonly used in treatment plants [2]. It is well-known that the addition of chemical reagents enhances sewage sludge dewater-ability to a certain extent.Sewage sludge conditioning with the use of polyelectrolytes involves two mechanisms: charge neutralization and interparticle bridging. J Kleimann et al. [3] showed that the addition of polyelectrolytes brought the zeta potential close to zero. The optimal dosage of polyelectrolyte also causes the destruction of gelatin structure and enables the aggregation of sewage sludge particles in larger flocs [4]. The literature review [5, 6] confirms that the chemical conditioning with the use of polyelectrolytes could increase the effectiveness of sludge dewatering in a significant way. K B Thapa et al. [5] showed that the addition of polyelectrolytes ZETAG7501 in the dosage of 10.8 g/kg could decrease the sludge hydration by approximately 85% in comparison to raw sewage sludge. S R Gray

and C B Ritche [6] also proved that the application of polyelectrolytes influenced on the higher strength of flocs in comparison to non-conditioned sludge. On the other hand, the main disadvantage of chemical conditioningis the high dosages of such reagents which translates into high operating costs of treatment plants.

In order to decrease polyelectrolytes consumption in treatment plants, mechanical conditioning by means of different substances is examined. Gypsum, lignite and coal fly ashes are used for sewage sludge conditioning and dewatering in a laboratory scale. The application of aforementioned materials led to the formation of more ridged lattice structure and by means of that, sewage sludge cake remains permeable during the filtration process. For this reason, sewage sludge dewatering is improved in comparison with raw sludge. In order to achieve better results of sludge dewatering, the modification of mechanical conditioners is investigated. Z Chen et al. [7] proved that the addition of coal fly ash modified by sulfuric acid improved sewage sludge dewater-ability to a greater extent than raw ash. M Wójcik et al. [8, 9] investigated the impact of willow ash and straw ash on sewage sludge dewatering. W Yan et al. [10] also examined the influence of rice husk biochar modified by the addition of ferric chloride on sewage sludge dewatering.

Biomass ash is the powdery residue produced as a result of burning of fuel that is captured from exhaust fumes by means of electrostatic precipitators (fly ashes) or is discharged from fluidized bed (bottom ashes). Because the biomass consumption in energy sector is systematically growing, the proper utilization of biomass combustion by-products is required. Available data indicate that only 29% of generated biomass ashes are recycled in Poland every year [8]. Due to the content of nutrient for plants, biomass ashes have been used in agriculture as a valuable fertilizer [11]. The chemical composition (the content of chlorine and alkaline) and high losses of ignition lead to the fact that most of biomass ashes fail to fulfill standard requirements as a component of cement and concrete production [8].

Due to the specific physical characteristic, mainly the high porosity and the big specific surface area, biomass ashes might be useful in sewage sludge management [12]. But there are any articles concerning the mechanical conditioning of sewage sludge with the use of biomass combustion by-products. Additionally, the use of biomass ashes in sewage sludge conditioning might be a promising alternative of its utilization.In contrast, biomass ashes comprises heavy metals, especially Zn, Cr and Pb and for this reason, their application in sewage sludge management should be control. The final product of sludge dewatering, namely the mixture of sewage sludge and ash should be checked in terms of chemical and microbiological characteristics.

This paper is going to present sewage sludge conditioning with the use of selected biomass ash: willow ash and beech ash. After the discussion of conditioning with biomass ash, the dewater-ability of sewage sludge by centrifugation and vacuum filtration was investigated. After dewatering, the changes of sewage sludge cake moisture content and capillary suction time (CST) were investigated. The results obtained in research confirms the effectiveness of the application of biomass ashes in sewage sludge management.

2. Materials

2.1. Sewage sludge

Sewage sludge was obtained from the inlet of thickening tank from the communal municipal wastewater treatment plant (WWTP) in Świlcza-Kamyszyn (Podkarpackie Province, Poland). Sewage sludge was taken during summer/autumn. The main sewage sludge characteristics were as follows: pH = 6.62 ± 0.04; the moisture content = 97.16 ± 0.47%; capillary suction time (CST) = 145.36 ± 5.46s.

2.2. Biomass ashes

Ashes from willow (WA) and beech combustion (BA) used in laboratory tests were obtained from the domestic central heating boiler. Tested biomass ashes were not sieved before the laboratory research.

There is the reason why the particle size of biomass ashes was distributed within the range of 0.4÷900 μm. The chemical composition of sample biomass ashes was presented in table 1.

Table 1. Chemical composition of tested biomass ashes.

	Ca [%]	K [%]	Mg [%]	Fe [%]	Mn [%]	Si [%]	S [%]
WA[a]	50.37±0.10	25.53±0.10	4.95±0.07	2.03±0.04	0.73±0.03	1.39±0.04	1.71±0.04
BA[b]	35.87±0.20	18.41±0.10	5.04±0.07	4.89±0.07	3.82±0.06	3.13±0.05	1.52±0.04

[a] Willow ash
[b] Beech wood ash

3. Methodology

Laboratory tests were done for every biomass ash separately. The appropriate doses of biomass ash: 5; 7.5; 15 and 30 g·dm^{-3} were added into 500 cm^3 of raw sewage sludge. The dosages of aforementioned materials corresponded to the weight ratio of ash to the content of sewage sludge dry mass (d.m.): 170; 250; 500 and 1000 g·(kg d.m.)$^{-1}$, 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 with the use of flocculator. After mechanical conditioning, capillary suction time (CST) was determined. CST was measured by means of ProLabTech CST meter in accordance with PN-EN 147011:2007.

Secondly, the samples of conditioned sewage sludge were examined in terms of their dewater-ability with the application of vacuum filtration and centrifugation. 50 cm^3 of sewage sludge was put into a Büchner funnel and the effectiveness of dewatering was investigated. The vacuum filtration was done under 0.01 MPa and 0.02 MPa vacuum pressure. Additionally, 50 cm^3 of conditioned sewage sludge was poured into centrifuge tubes. Centrifugation of sewage sludge was conducted for two rotation speeds: 2000 and 2500 rpm for 5 minutes.

The sewage sludge dewater-ability was evaluated by means of CST measurement and the sewage sludge cake moisture content. CST was measured using CTS meter (ProLabTech). In order to determine the moisture content, the samples of sludge cakes were dried to the constant weight at 105°C in line with PN-EN 15934:2013-02 [8].

4. Results and discussion

4.1. Sewage sludge conditioning with the use of biomass ashes

At the beginning, sewage sludge was tested as a conditioner. The influence of biomass ashes on CST was shown in figure 1. It was observed that CST value decreased in the whole range of agent used. 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 ash dosage. The 5 g·dm^{-3}dosage of ash reduced the CST approximately by only4% to the value of 143.11 s for WA and by about 6% to the value of 133.52 s for BA. The 7.5 and 15 g·dm^{-3} dosages of reagent reduced the CST value by about 18 and 35% for WA and by approximately 22 and 43% for BA. However, the best results were achieved for the 30 g·dm^{-3}dosage of ash. CST after conditioning with the biomass ash in the dose of 30 g·dm^{-3} was 61.19 s for WA and 66.77 s for BA which was approximately 56% lower in comparison with non-conditioned sewage sludge. The comparison ofobtained results and the literature reviewproved that the addition of biomass ashes influenced on CST value after conditioning to a lesser extent in comparison to the polyelectrolytes. B Bień [13] showed that the chemical conditioning with the use of Praestol 644BC in the dosage of 4 mg·(g d.m.)$^{-1}$ decreased the CST by approximately 96%. M Kuglarz et al. [14] proved that the addition of Praestol 2540 in the dosage of 2 mg·(g d.m.)$^{-1}$ resulted in the decrease of CST by approximately 80% in comparison to raw sludge. The higher influence of polyelectrolytes on the CST after conditioning is associated with the other conditioning mechanism. The chemical conditioning causes the neutralization of zeta potential and sludge particles bridging [15]. The addition of biomass ashes only causesan improvement in porosity and strength of sewage sludge flocs [16].

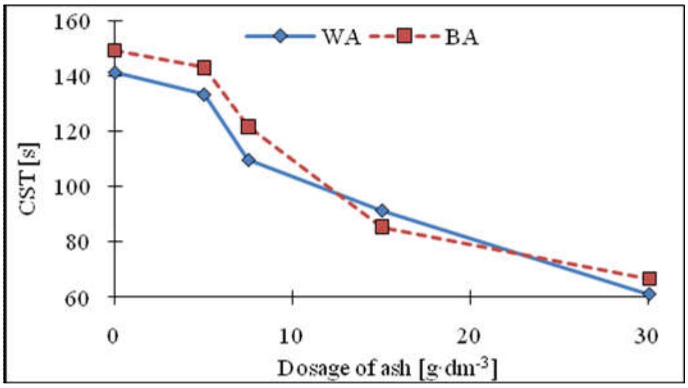

Figure 1. The influence of sewage sludge conditioning with willow ash and beech ash on CST.

4.2. Sewage sludge dewatering by means of centrifugation and vacuum filtration

After mechanical conditioning with the application of biomass ashes, sewage sludge was dewatered by means of centrifugation.The academic results showed a different influence of biomass ash on the moisture content reduction, depending on the amount of the agent and the rotation speed. The filter cake moisture decreased with an increase of biomass ash dosage. Figure 2 indicates the effect of biomass ash application on sewage sludge dewatering for the rotation speed of 2000 rpm.The moisture content of raw sewage sludgeafter centrifugation was 93.35% on average. The application of biomass ash in dosages of: 5; 7.5; 15 and 30 g·dm^{-3} reduced the sewage sludge moisture content by approximately: 4.2; 4.8; 6.7 and 9% for WA and of about: 6; 7; 7.3 and 9% for BA. The addition of mentioned doses of biomass ashes could lead to obtaining the final hydration of sewage sludge at the levels of: 92.25; 91.29; 88.65 and 85.77% for WA and 90.95; 89.64; 88.42 and 85.94% for BA.

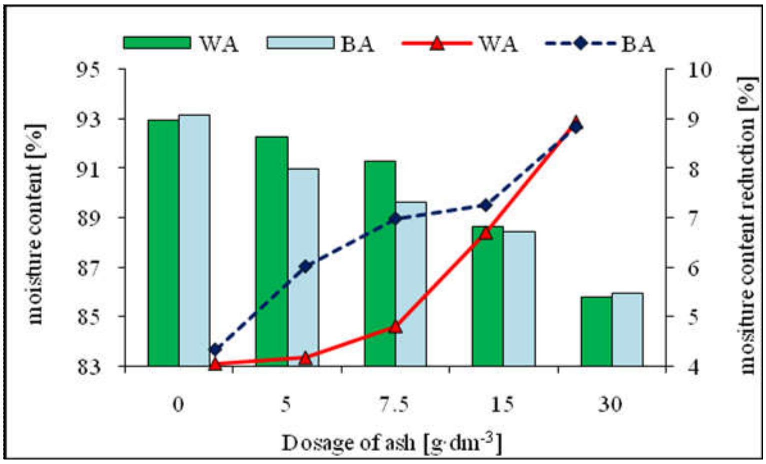

Figure 2. The influence of biomass ashes on the effectiveness of sludge centrifugation (2000 rpm).

Slightly better results were achieved for the higher rotation speed. The effectiveness of sewage sludge centrifugation with a rotation speed of 2500 rpm was shown in figure 3. After centrifugation with a rotation speed of 2500 rpm, non-conditioned sewage sludge reduced the final moisture content by approximately 5% to the value of 91.80%. The application of biomass ashes intensified the mechanical dewatering 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: 90.36; 89.24; 87.06 and 84.31% for WA and at the level of: 90.62; 88.87; 87.56 and 82.49% for BA. The results correspond to the moisture content reduction by approximately: 6.1; 7; 8.3 and 10.5% for WA and of about: 6.3; 7.7; 8.1 and 12.3% for BA.

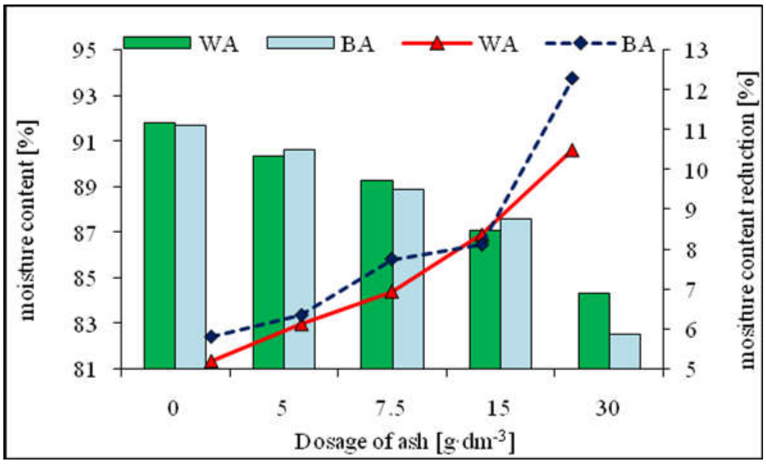

Figure 3. The influence of biomass ashes on the effectiveness of sludge centrifugation (2500 rpm).

Secondly, conditioned sewage sludge was dewatered by means of vacuum filtration. In comparison with the centrifugation, the vacuum filtration might serve to achieve better results of 10 % on average. The analysis of the results confirmed the differentiated influenceof biomass ashes on the final sludge hydration, depending on the amount and sort of ash.

The test carried out in the laboratory showed that only raw sewage was characterized by a good susceptibility to dewatering. Non-conditioned sewage sludge reduced the final moisture content by approximately 10% to the value of 88.58% on average. The application of biomass ashes intensified the vacuum filtration and for this reason, the hydration of sewage sludge decreased as the dosage of ash increased. The results of conditioned sewage sludge dewatering for two vacuum pressure values were presented in figure 4 and figure 5. The average sewage sludge moisture content for: 5; 7.5; 15 and 30 g·dm^{-3} doses of willow ash, was at the level of: 87.10; 86.30; 83.27 and 78.61%for the vacuum pressure of 0.01 MPaand 85.86; 83,76; 80.32 and 75.80% for the vacuum pressure of 0.02 MPa. These results correspond to the moisture content reduction of approximately: 9.50; 10; 12 and 17 % (0.01 MPa) and of: 11; 13; 15 and 20 % (0.02 MPa). In the case of application of beech wood ash at the same doses, the moisture content decreased to: 83.90; 81.97; 79.80 and 75.83 % for the vacuum pressure of 0.01 MPa and to: 82.27; 81.04; 77.57 and 74.57 % for the vacuum pressure of 0.02 MPa. The aforementioned dosages of beech ash enable the moisture content reduction at the level of: 13; 15; 17 and 20% (0.01 MPa) and of: 15; 16; 19 and 21% (0.02 MPa). Z Panyue et al. [17] obtained a similar results for sewage sludge conditioned by means of coal fly ash in the dosage of approximately 50 g·dm^{-3}.

The analysis of obtained results showed that the mechanical dewatering by means of vacuum filtration was effective within the whole range of dosages. However, the best results were obtained for the 30 g·dm^{-3} dose of biomass ash.

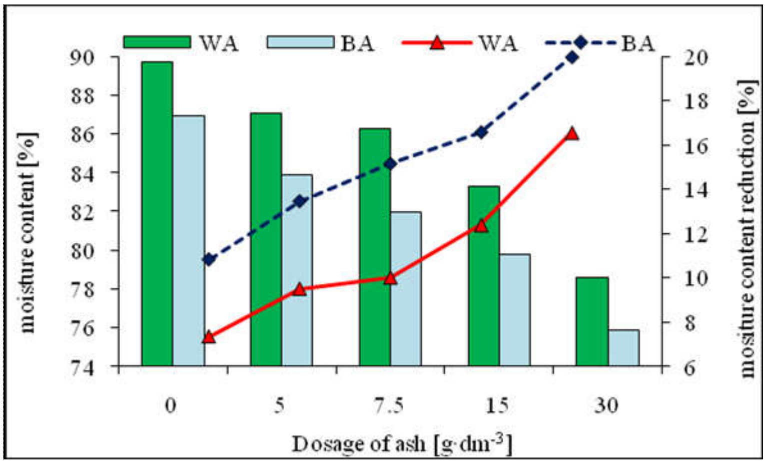

Figure 4. The influence of biomass ashes on the effectiveness of sludge vacuum filtration (0.01 MPa).

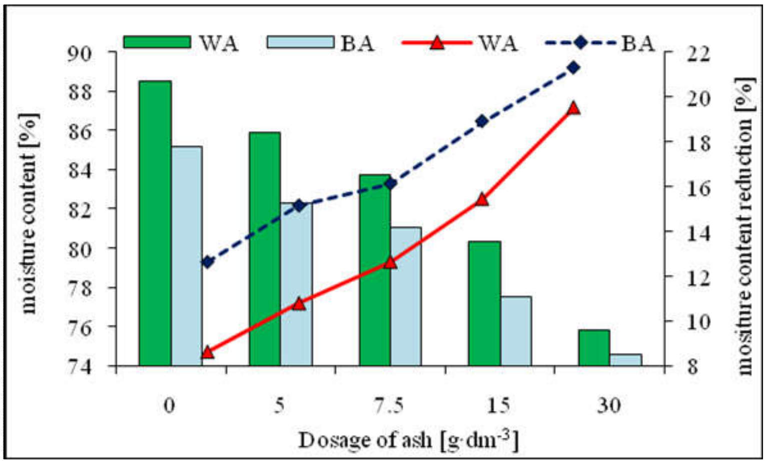

Figure 5. The influence of biomass ashes on the effectiveness of sludge vacuum filtration (0.02 MPa).

The influence of biomass ashes on the effectiveness of sewage sludge dewatering is closely related with the change of sludge structure. Sewage sludge has a negative charge and creates a stable system with low-sediment and low-dewatering capacity. The effectiveness of sewage sludge conditioning with ash results from the special structural properties of ash. 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 [17, 18, 19].R N Cogger and H M Merker [20] also proved that sewage sludge containing biomass ash remains permeable and porous under high pressure.

Both ashes influenced on the improvement of sewage sludge dewatering, but slightly better results were achieved for beech wood ash. It might be associated with the fact that beech wood is a better quality fuel than willow tree. The differences between biomass species influence on the properties of ashes and consequently on the effectiveness of sewage sludge dewatering.

The literature review confirms the high effectiveness of biomass ashes in the dosage of 30 $g \cdot dm^{-3}$ on sludge dewatering in comparison to the application of polyelectrolytes. B Bień [13] showed that the chemical conditioning with the use of Praestol 644MB in the dosage of 4.5 $mg \cdot (g\ d.m.)^{-1}$ could decrease the hydration of sewage sludge after vacuum filtration by approximately 10% in comparison

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to non-conditioned sludge. M Kuglarz et al. [14] achieved the sewage sludge moisture content reduction at the level of 16% after the addition of Praestol 610BC in the dosage of 2 mg·(g d.m.)$^{-1}$.

4.3. The influence of biomass ashes on CST after sewage sludge dewatering

The application of biomass ashes resulted in the increase of CST after dewatering. CST for raw sewage sludge after centrifugation was 1170 s (2000 rpm) and 2501 s (2500 rpm) on average. For the rotation speed of 2000 rpm, the addition of biomass ash in dosages of: 5; 7.5; 15 and 30 g·dm^{-3} resulted in the increase of CST to the value of approximately: 1638; 1874; 2469 and 3047 s for WA and to the value of: 803; 1285; 1607 and 2248 s for BA (figure 6a). For the higher rotation speed, CST for the same dosages of ashincreased to: 1826; 2179; 2801 and 3441 s for WA and to: 960; 1380; 1955 and 2756 s for BA (figure 6b). According to M Wójcik [21], lower values of CST indicate a higher sludge susceptibility to further elimination of water.

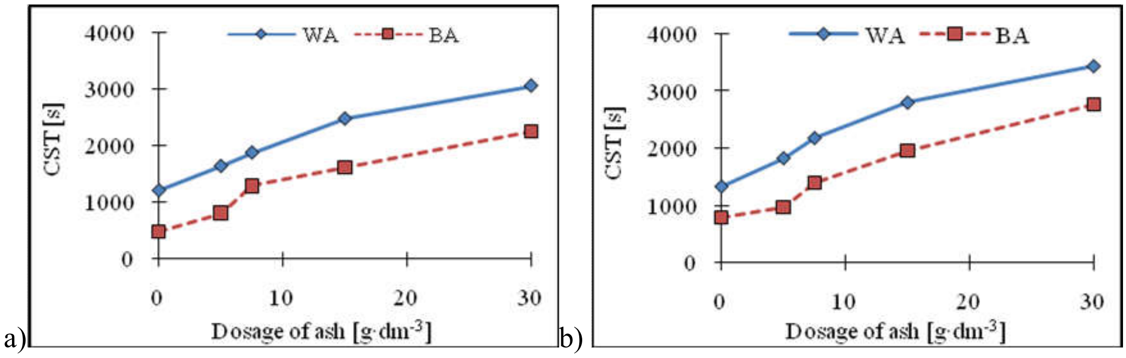

Figure 6. The influence of biomass ashes on CST after centrifugation with a rotation speed of 2000 rpm (a) and 2500 rpm (b).

CST for raw sewage sludge after vacuum filtration was 1170 s (0.01 MPa) and 2501 s (0.02 MPa) on average. For the vacuum filtration with the vacuum pressure of 0.01 MPa, the addition of biomass ash in dosages of: 5; 7.5; 15 and 30 g·dm^{-3} resulted in the increase of CST to the value of: 2143; 2804; 3497 and 4898 s for WA and to the value of: 2339; 2741; 3139 and 4113 s for BA (figure 7a). After the application ofthe higher vacuum pressure value, CST for the dosages of: 5; 7.5; 15 and 30 g·dm^{-3} increased to: 3326; 3968; 4718 and 6635 s for WA and to: 3598; 3953; 4317 and 5015 s for BA (figure 7b). Higher values of CST confirmed the better effectiveness of vacuum filtration in comparison with the centrifugation.

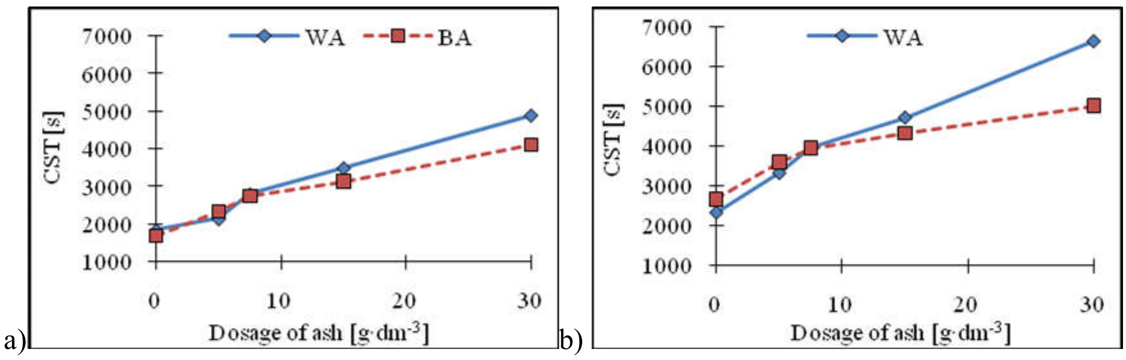

Figure 7. The influence of biomass ashes on CST of sludge after vacuum filtration for the vacuum pressure of 0.01 MPa (a) and 0.02 MPa (b)

5. Summary and conclusions

The results of laboratory tests allows to draw the following conclusions:

- The application of mechanical conditioning with the use of biomass ashes had a positive impact on sewage sludge. The results of laboratory tests confirmed the reduction of CST while increasing of the amount of biomass ash. The best results were achieved when the dosage of materials amounted to 30 g·dm^{-3}. But in comparison to the conditioning with the use of polyelectrolytes, biomass ashes influences on the decrease of CST in a lesser extent [12, 13].
- Both willow ash and beech wood ash influenced the effectiveness of sewage sludge dewatering. The aforementioned materials had a similar impact on sewage sludge treatment, but slightly better results were achieved for beech wood ash.It is associated with the different characteristics of aforementioned ashes which influences on the sludge dewatering.
- The application of biomass ashes improved the centrifugation and vacuum filtration parameters in comparison with raw sewage sludge. The addition of the 30 g·dm^{-3}dosage of ash resulted in the reduced sewage sludge moisture content in the range of 10 ÷ 25% for WA and of 10 ÷ 20% for BA.The literature review confirms the high effectiveness of the application of biomass ashes in comparison to chemical conditioning [12, 13].
- Sewage sludge conditioning with the use of biomass ashes resulted in the increase of CST after mechanical dewatering. The higher values of CST indicated the improvement of sludge dewater-ability in comparison with raw sewage sludge. Higher values of CST werecoincideswith the reduced sewage sludge moisture content.
- The use of biomass ashes in sewage sludge management might be a promising alternative for other chemical reagents. Biomass ash is a waste product of a problematic nature and requires proper utilization in line with environmental, law and economic requirements. The aforementioned proposition could help manage two problematic waste products: ashes and sewage sludge. Additionally, biomass ash is inexpensive, effective and an easily obtained reagent, especially in industry areas. Before the application of biomass ash in treatment plants, the previous test is necessary in order to select the optimal dosage of ash.

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