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Effect of the Addition of Coal Waste on the Process of Composting and Sorption Capacity of Composts

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1. Introduction

In the European Union countries, biological waste and biodegradable waste constitute from 30 to 40% of municipal solid waste (Kwarciak-Kozłowska & Bańka 2014). The provisions of the EU Landfill Directive (Council Directive 1999/31/EC) oblige Member States to gradually reduce the amount of biodegradable waste deposited in landfills.

Composting is a biological process in which thermophilic and mesophilic microorganisms transform organic matter into gaseous products (CO_2, H_2O, NH_4^+) and a stabilized organic substance, which is a precursor of humus (Bernal et al. 2009, He et al. 2009, de Guardia et al. 2010). Due to the variety of raw materials currently used and the resulting heterogeneity of the compost input, the process flow and conditions require continuous optimization (Himanen & Hänninen 2011).

One of the most important parameters of the efficient composting is the ratio of organic carbon to nitrogen, which determines susceptibility of organic substances to microbiological decomposition. The optimum C/N ratio can be controlled with carbon content by adding components rich in this element.

A very advantageous feature of compost is its high sorption capacity. Soil improvement with organic matter causes an increase in this parameter (Cuske & Karczewska 2016). This is particularly desirable when compost is used on soils contaminated with e.g. heavy metals. The positive effect of the addition of compost on the sorption properties of soils has been demonstrated in numerous studies (Greinert 2009, Bielińska & Mocek 2010, Kyzioł-Komosińska et al. 2011, Ciesielczuk & Rosik-Dulewska 2013). Compost mass is therefore a cheaper alternative to commercial mineral or organic sorbents, whose production is energy-intensive, expensive and requires the use of non-renewable natural resources

(Koh & Dixon 2001). The studies have confirmed the phenomenon of reduction in the migration of heavy metals to soil solution following the addition of stabilized compost to contaminated soils. This concerns in particular the application of compost with other sorbents, e.g. active carbon (Beesley et al. 2010, Karami et al. 2011). The introduction of substances which may increase the sorption capacity (zeolites, diatomites) into the soil reduces the amount of phytoavailable forms of heavy metals in the soil (Williamson et al. 2009, Farrell & Jones 2010).

The two aspects related to the waste composting process presented above, i.e. the possibility of correcting the C/N ratio and improving the sorption properties of composts, were the basis for determination of the scope of the study. The authors assumed that coal sludge generated in the processes of hard coal enrichment, often treated as waste, may be useful in correcting of the C/N ratio and the improvement of the sorption capacity of composts. This sludge is characterized by a carbon content of up to 30% (Sobik-Szołtysek 2006) and high sorption capacity due to a significant share of clay minerals in their composition.

2. Materials and methods

2.1. Analytical methods

Substrates selected for the study, compost mixtures made using these substrates and composts obtained were analyzed according to the following procedures:

- analytical moisture content according to PN-EN 14346:2011,
- pH in distilled water according to PN-Z-15011-3:2001,
- organic matter content according to PN-EN 15169:2011,
- nitrogen content by the Kjeldahl method according to PN-Z-15011-3:2001 and internal procedure for the SpeedDigester K-439 device,
- determination of the total specific surface area by the methylene blue sorption method according to PN-B-04481:1988,
- metal content in the samples after mineralization - ICP-OES SPECTRO ARCOS spectrometer,
- organic matter content as residue on ignition according to PN-EN 15169:2011.

All analyses were performed in three repetitions and the result was presented as an arithmetic mean.

The organic carbon content was calculated using the formula developed by Haug (1993):

$$\%\,C = \frac{(100 - ash)}{1{,}8} \tag{1}$$

2.2. Substrates for research

The usefulness and the potential of using different substrates in the composting process is determined primarily by their proper moisture content, optimal C/N ratio and proper structure, forming an environment with good oxygenation. The characteristics of the materials used in the tests are presented in Table 1. All the materials were designated specific symbols, used further in this study. The following determinations were made for the selected substrates: moisture content, organic carbon and nitrogen content, and the C/N ratio (Table 2).

The high moisture content observed for grass and organic fraction of municipal waste was caused by the fact that these components were dosed into the mixtures in the "fresh" form, while the remaining substrates were dosed in the air-dry state. All substrates, except for coal sludge, were characterized by a high content of organic carbon, with the highest values obtained for structure-forming additives such as barley straw and energy willow. The nitrogen content observed for grass higher compared to the literature data, was due to the fact that it was collected in the home garden intensively fertilized with mineral fertilizers rich in nitrogen. High nitrogen content in this substrate resulted in the lowest C/N ratio. The maximum values of this parameter, exceeding 100 (-), were found for barley straw, which was characterized by high carbon content at very low nitrogen content.

Table 1. Materials used in the composting process

Type of materials	Substrate with designation	Material origin and description
Green waste	Grass (T)	Household garden subject to standard treatments. Chopped grass, with natural moisture, taken from the basket of the mechanical mower.
Structure-forming materials	Barley straw (SJ)	Purchased directly from farmers after summer harvesting, air-dry state, fragmented before application
	Energy willow (WE)	A commercial product sold as an alternative fuel, air-dry state, fine texture.
Coal waste	Coal sludge (M)	Filtration presses for water and sludge circulation in hard coal mines, air-dry state, crushed before application.
Municipal waste	Organic fraction of municipal waste (OFOK)	Crushed household material: residues of fruit, vegetables, pasta, rice, coffee and tea grounds, egg shell, without animal products and citrus fruits.

Table 2. Selected physical and chemical properties of the substrates

Parameter	Unit	Component				
		OFOK	T	SJ	WE	M
Moisture content	wt% dry weight	82.0	75.2	4.7	6.4	1.8
C	wt% dry weight	52.4	48.7	54.1	54.2	27.8
$N_{Kjeldahl}$	wt% dry weight	1.6	3.7	0.4	0.8	0.5
C/N	(-)	32.8	13.2	135.3	67.8	55.6

Due to the potential of composts for agricultural use, the content of selected heavy metals in all substrates was analyzed (Table 3). Low content of analyzed metals was found, so there was no risk of exceeding the permissible values for compost specified in the regulations (Ordinance 2008).

Table 3. Content of selected metals in components for composting

Metal	Unit	Component					Permissible content (Ordinance 2008)
		OFOK	T	SJ	WE	M	
Zn	mg/g	0.0164	0.06	0.013	0.083	0.09	-
Pb	mg/g	0.011	0.011	0.0047	0.0037	0.04	0.140
Cd	mg/g	<0.001	0.0006	<0.0005	0.0011	<0.001	0.005
Cr	mg/g	0.088	0.0083	0.0072	0.0023	0.044	0.100
Ni	mg/g	0.0036	0.0039	0.0017	0.0014	0.0168	0.060

2.3. Research stand

The composting process was conducted in cylindrical, isolated bioreactors with a capacity of 5 dm^3 (Fig. 1). The upper cover was equipped with a ventilation opening to drain the gases, while the bottom of the bioreactor is equipped with a moisture removal system in the form of a water-permeable sieve that retains substrate particles. An aeration hose was put on the sieve, connected with a pump (AIRFISH 5W) with a maximum capacity of 4.5 dm^3/min. A temperature sensor configured with a computer program CoolTerm Win, allowing to record and archive temperature measurements every 1 hour, was installed in the bioreactor.

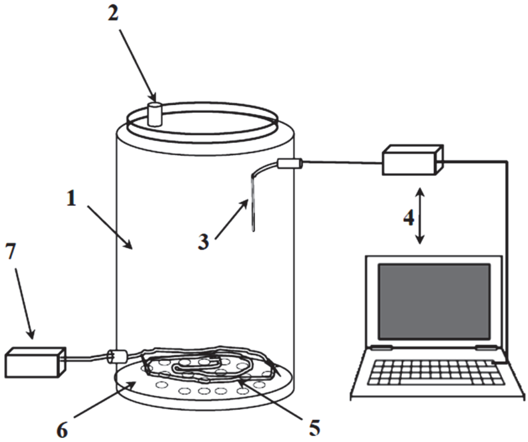

Fig. 1. Research stand: 1 – bioreactor, 2 – gas outlet, 3 – temperature gauge, 4 – temperature recording system, 5 – aeration hose, 6 – perforated spacer, 7 – aeration pump

The composting process was carried out in two research series: series 1, for composts marked as 1, 2 and 3, and series 2, for composts marked as 4, 5 and 6. Since an increase in temperature of only slightly more than 40°C was achieved during the thermophilic phase of the first series, the bioreactors in the second series were additionally insulated to better stabilize the temperature. The thermal insulation was made of 5 cm thick expanded polystyrene, whereas the space between the bioreactor and the walls was filled with expanded polystyrene balls. The bioreactors were then covered with a plastic cover and, additionally, a cover made of expanded polystyrene of the same thickness.

2.4. Sorption tests

The use of composts as sorbents for many different substances described in the literature (Ciesielczuk et al. 2011) is confirmed by the evaluation of their sorption capacity. Since compost is used for the sorption of dyes from aqueous solutions (Jóźwiak et al. 2013), a method of methylene blue (Bhattacharyya & Sharma 2005) was chosen to determine the sorption capacity of the composts. Sorption capacity was calculated from the formula:

$$\mathrm{MBC} = \frac{100\ \mathrm{m}}{2\ m_s}(\mathrm{V_i} + \mathrm{V_{i-1}}) \qquad (2)$$

where:

MBC – sorption capacity of compost compared to methylene blue according to trihydrate substance per 100 g of dry matter of material,

m – mass of methylene blue contained in 1 cm^3 of solution, calculated per trihydrate substance, g,
m_s – mass of compost used for the determination calculated per dry matter at temperature of 105–110ºC, g,
v_i – volume of solution at which sorption capacity was exceeded, cm^3,
V_{i-1} – volume of solution corresponding to the penultimate portion of the methylene blue solution before exceeding the sorption capacity, cm^3.

The specific surface area was calculated according to the formula:

$$S_t = k_1 \cdot MBC \tag{3}$$

where:
k_1 – coefficient with the value adopted as 20.94 m^2/g,
MBC – sorption capacity of compost compared to methylene blue according to trihydrate substance per 100 g of dry matter of material.

In order to confirm sorption capacity of the obtained composts, zinc sorption from aqueous solutions was carried out by batch method (Roy et al. 1991) in a constant liquid-solid contact ratio of 1:20. A base solution of 10 g/L Zn^{2+} was obtained by dissolution of the calculated stoichiometric reaction of $ZnCl_2$ mass (Chempur reagent, analytical grade) in distilled water. A solution with initial concentration of Zn^2+ 100 mg/L and compost dried to solid mass at the temperature of about 60°C, crushed and passed through a sieve with a mesh diameter of 0.1 mm, was used. The mixtures were shaken for 24 hours and then filtered. The content of Zn^{2+} ions in the obtained eluate was determined by inductively coupled plasma atomic emission spectroscopy (ICP).

Sorption efficiency (S) was calculated from the formula:

$$S = \frac{(C_0 - C_k)}{C_0} \times 100, \% \tag{4}$$

where:
C_0 – initial concentration of zinc in the solution, mg/L,
C_k – equilibrium concentration of zinc in solution, mg/L.

2.5. The course of research

The composition of mixtures subjected to the composting process was selected based on the results of analyses of individual substrates (Table 2). The parameter determining the share of individual initial substrates (OFOK, T, WE, SJ) was C/N ratio. Mixtures with the same proportion of basic substrates were modified by adding coal sludge (M) in doses of 10 and 25wt%. The symbols and the composition of individual mixtures are presented in Table 4.

Table 4. Percentage of basic substrates in the tested compost mixtures

Mixture number	Composition of a compost mixtures *
1	T_{40}+SJ_{20}+$OFOK_{40}$
2	T_{40}+WE_{20}+$OFOK_{40}$
3	T_{50}+SJ_{15}+$OFOK_{10}$+M_{25}
4	T_{60}+SJ_{10}+$OFOK_{20}$+M_{10}
5	T_{50}+WE_{15}+$OFOK_{10}$+M_{25}
6	T_{60}+WE_{10}+$OFOK_{20}$+M_{10}

* the subscripts denote wt% of the basic component

The prepared compost mixtures were subjected to the testing procedure using the following stages:

- performing determinations (moisture, content of organic matter, organic carbon and nitrogen) for prepared compost mixtures - initial state,
- composting in bioreactors for a period of 4 weeks (stage 1),
- compost collection after 4 weeks and performing analysis (moisture, organic matter, organic carbon and nitrogen content),
- compost maturation in natural conditions for the next 4 weeks (Stage 2),
- sampling and analysis of compost (moisture content, organic matter, organic carbon and nitrogen content) after 8 weeks of the experiment.

3. Results and discussion

3.1. Analysis of the initial properties of compost mixtures

Samples were obtained from the compost mixtures prepared for the experiments, for which the analyses and calculations presented in Table 5 were performed.

The values of optimal moisture content for compost mixtures in the literature range from 45 to 70% (Richard et al. 2002, Jędrczak 2007, Ozimek & Kopec 2012). All analyzed mixtures met this condition, with the highest values of this parameter obtained for mixtures 1, 2, 4 and 6. Numbering and composition of compost mixes in accordance with Table 4. This was a result of high moisture content of two basic substrates, i.e. grass and organic fraction of municipal waste, whose total share in these mixtures amounted to 80% by weight. The application of large contents of these substrates resulted from the analysis of literature reports in which the dependence of obtaining high temperatures in the thermophilic phase on their content in the compost was indicated (Bień et al. 2011).

Table 5. Initial conditions for compost mixtures

Mixture number	Moisture content	Organic matter content	C	N Kjeldahl	C/N
	% by weight	% by weight	% by weight	% by weight	(-)
1	64.9	92.8	51.7	1.74	29.7
2	65.1	91.4	50.8	1.89	26.9
3	49.1	75.8	42.1	1.49	28.3
4	62.3	78.5	43.6	1.63	26.7
5	50.5	75.3	41.8	1.58	26.4
6	63.5	82.5	45.7	1.79	25.5

The C/N ratio, which according to Jędrczak (2007) should be in the range of 25-35, is given as the basic parameter characterizing the optimal composition of the compost mixture. Other authors (Mustin 1987, Dach 2010) demonstrated that the ratio should range from 20 to 30. Comparison of the obtained results with the literature data reveals that all the tested mixtures reached the recommended C/N ratios. The use of municipal organic waste fraction (OFOK) in compost improves the C/N ratio due to the high content of organic carbon (Siebielska and Janowska 2011).

A higher content of organic matter and organic carbon can be observed in the mixtures without the use of coal sludge (mixtures 1-2) compared to mixtures with this addition. This is due to the high content of inorganic carbon in coal sludge.

The nitrogen content was determined primarily by the grass content, because this substrate was characterized by the highest content of this element (3.7% by weight).

3.2. Temperature changes during composting

Figures 2 and 3 show the temperatures measured during composting in bioreactors (first 4 weeks). Mixtures 1-3 (the first series of experiments) were composted without thermal insulation, whereas mixtures 4-6 – with thermal insulation (the second series of experiments).

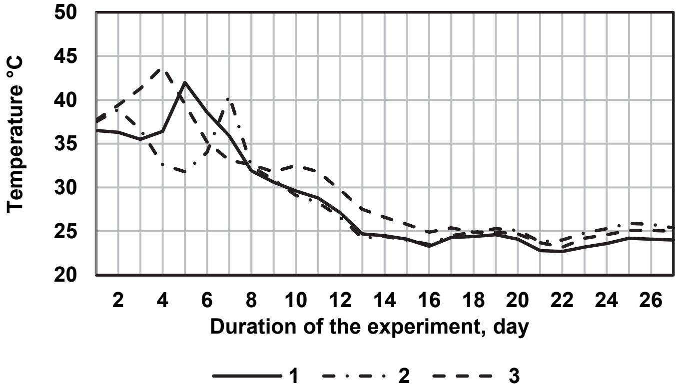

Fig. 2. Mean daily temperature values for mixtures 1-3 (the first series of experiments)

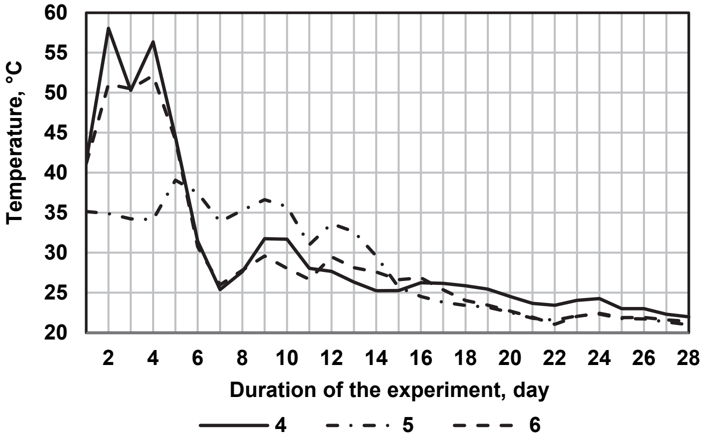

Fig. 3. Mean daily temperatures for mixtures 4-6 (the second series of experiments)

According to literature (Richard 1992), composting is most effective in the temperature range 45-55°C, while an increase in temperature of above 60°C causes the death of microorganisms, which results in a decrease in the rate of decomposition of organic matter. This can cause odors to be emitted into the environment and reduce the quality of the compost. A further increase in temperature to 75°C causes denaturation of protein and consequently the complete stopping the biological processes during composting. At temperatures below 20°C, microorganisms do not proliferate, which also slows down the rate of transitions. Succession of mesophilic and thermophilic microorganisms in the composted material, related to temperature changes, is an indicator of the correct course of the composting process (Ishii et al. 2000).

In the first series of studies, temperatures assumed to be optimal were not obtained. However, no temperature drop below the critical level (20°C) was observed. The highest temperature was reached by a mixture 3 containing a 25% admixture of coal sludge. Starting from the 13th day of the experiment, the temperature stabilized at a similar level. According to Sidełko et al. (2014), the temperature drop may be related to a reduction in microbiological activity due to the effect of a limiting factor, i.e. oxygen content in the compost pores, or to the depletion of organic compounds, which represent an easily accessible source of carbon. The use of additional insulation in the second series had a positive effect on mixtures 4 and 6. The temperatures observed on the first 5 days of the process reached a satisfactory level. The exception was mixture 5, for which the maximum temperature of 39.1°C was reached only on day 5. This mixture was characterized by the lowest initial content of moisture, organic matter and organic carbon. Insufficient water content in the compost can inhibit biological processes (Liang et al. 2003) because water is a transport medium for nutrients necessary for the proper course of active metabolic processes of microorganisms (McCartney & Tingley 1998). After 9 days, the temperature of composts decreased gradually and evenly. The obtained results confirmed that ensuring good thermal insulation allows for keeping the required temperature regime needed for both the course of the process and for the hygienization of compost. The effect of the amount of coal sludge added and the type of applied structure-forming material (SJ and WE) on the maximum temperatures was observed. If the same amount of coal sludge (25%) was used, higher temperatures were obtained for mixtures with barley straw, for which the C/N ratio is twice as high as for the WE mixture.

3.3. Analysis of the physicochemical properties of composts

3.3.1. Changes in organic matter content

The organic matter content decreases during the composting process. Research conducted by Sidełko (2009) showed that the content of organic matter in the compost decreased gradually, regardless of the duration of the composting cycle. It was found that the organic matter content decreased by 13-15%. Figure 4 shows changes in the organic matter content of compost during the experiment.

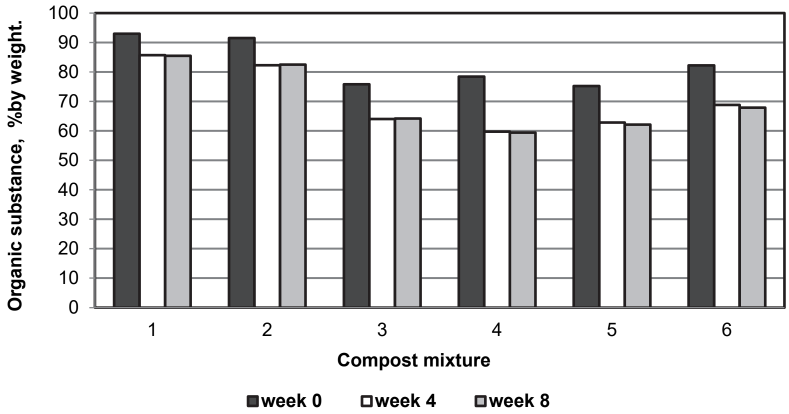

Fig. 4. Changes in organic matter content over 8 weeks of the experiment

A decrease in organic matter content of 7.85-23.85% was observed in all composts after 4 weeks of composting, with the smallest decrease in composts obtained without the addition of coal sludge but with the highest OFOK content (1 and 2). Furthermore, the greatest decrease in organic matter (by 20.1% on average) was observed in the mixtures with 10% coal sludge and 60% grass (composts 4 and 6). Changes in organic matter content after 8 weeks were very slight compared to those after 4 weeks. This indicates that the process of mineralization of organic compounds was inhibited. The downward tendencies in the content of organic matter in compost recorded during the research is consistent with the literature reports in this field.

3.3.2. C/N ratio changes

The C/N ratio usually decreases during composting if the initial C/N ratio is > 25. Mature compost should be characterized by a C/N ratio of < 20, which is indicative of an adequate degree of organic matter conversion. A higher nitrogen content in the compost guarantees obtaining better parameters required for organic fertilizers. Changes in the C/N ratio during the tests are presented in Figure 5.

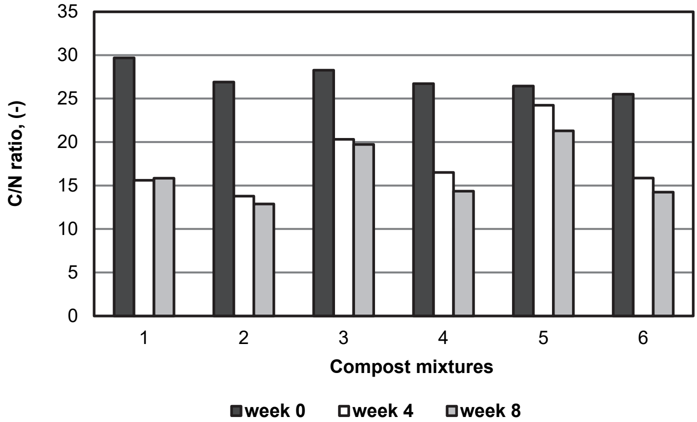

Fig. 5. Changes in the C/N ratio during 8 weeks of the experiment

After 4 weeks of the experiment, a significant decrease in C/N values was observed in all tested compost blends. During the next 4 weeks, the dynamics of changes in C/N values was low; after 8 weeks, almost all the mixtures, except for mixture 5, reached the value of C/N ratio below 20, which was characteristic of mature composts.

The highest declines after week 4 (Fig. 6) were observed for mixtures without coal sludge (mixtures 1 and 2) and amounted to 47.5 and 48.7%, respectively.

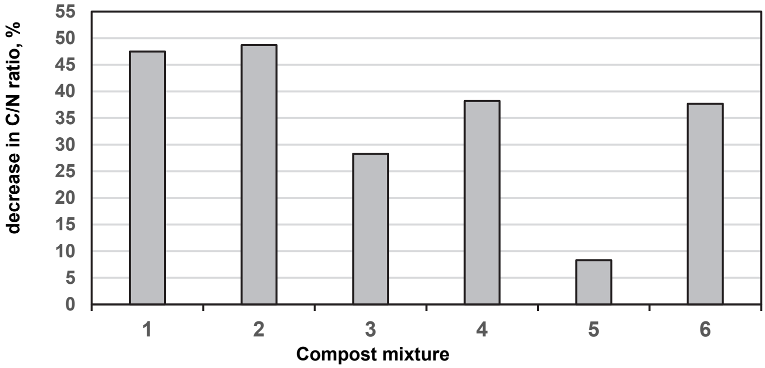

Fig. 6. Decrease in C/N ratio after 4th week of composting (stage 1) with respect to initial value

For mixtures with coal sludge, a decrease in C/N value was observed in the range from 28.3 to 38.2%. The exception was mixture 5, for which this decrease was only 8.3%. This mixture was characterized by the lowest maximum temperature reached in the thermophilic phase, resulting in lower activity of microorganisms responsible for changes in carbon content. An effect of the amount of coal sludge added on the amount of C/N decrease can be observed, with the lowest values observed for 25% content of this component in the mixture. Therefore, the change in the C/N ratio depends mainly on the coal sludge content, since the content of nitrogen in these mixtures remained at a similar level.

3.3.3. Evaluation of sorption capacity of compost

Compost from municipal and green waste has been commonly used to remediate soils contaminated with heavy metals (Bolan et al. 2014). The transformation of organic matter during the composting process changes the speciation of heavy metals (He et al. 2009), whereas the degree of leaching and bioavailability to plants depends on the degree of maturity of the compost applied to the contaminated soil (Weber et al. 2007). Figure 7 shows the size of the compost specific surface area and the Zn^{2+} ion removal efficiency obtained for the compost. The specific surface area was determined by means of the methylene blue sorption method, whereas the efficiency of zinc ion sorption was evaluated using the batch sorption method.

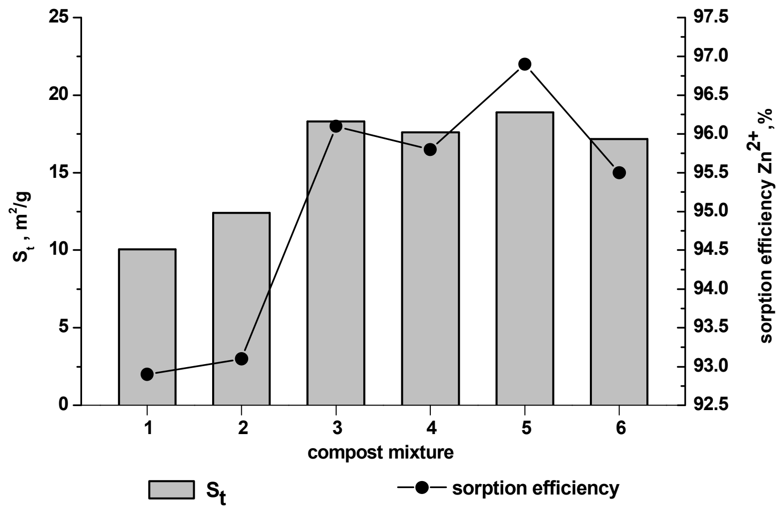

Fig. 7. Specific surface area and efficiency of zinc ion sorption for the composts obtained

In all composts with addition of coal sludge (3-6), the specific surface area has increased compared to composts without this addition (1 and 2). This is due to the presence of clay minerals in this component, which have a strongly developed specific surface area. The largest surface on which the sorption process occurs was found for composts 5 and 3, containing 25% of coal sludge. The values of this parameter were 18.9 and 18.3 m^2/g, respectively. The specific surface area of composts with 10% of coal sludge was slightly lower, at the level of over 17 m^2/g. These values are higher than the values presented in literature reports in which the specific surface area of composts was determined as 14.54 m^2/g (Kyzioł-Komosińska et al. 2011).

The application of the batch method for the assessment of the sorption capacity of composts confirmed the relationship between the specific surface area of the material and its sorption properties. At the same initial zinc concentration (100 mg/dm^3), mixtures 5 and 3 also had the highest sorption efficiency. The percentage of sorption for them was 96.9 and 96.1%, respectively. The remaining two mixtures with 10% of coal sludge (compost 4 and 6) were characterized by similar high efficiency of Zn ion removal at the level of 95.5-95.8%. Therefore, it can be stated that the addition of coal sludge to the compost improves its sorption properties. However, the dose size in the range studied does not have a significant effect on the course of the sorption process.

4. Conclusion

Analysis of the results obtained during the experiment leads to the following conclusions:

- the use of thermal insulation of bioreactors stabilized and improves thermal conditions of the composting process,
- the effect of the amount of added coal sludge and the type of applied structure-forming material (SJ and WE) on the maximum temperatures was observed; the highest temperatures were obtained for mixtures with coal sludge and SJ admixture, which has twice as high C/N ratio as WE,
- after 4 weeks of composting, a decrease in organic matter content and C/N values was observed in all composts,
- the effect of the amount of coal sludge addition on the decrease of the C/N ratio value was observed, which was the lowest for 25% content of this component in the compost mixture; therefore, too high content of coal sludge in the compost mixture adversely affects the composting process and does not allow to reach the expected value of the C/N ratio for the mature compost,
- all composts prepared with the addition of coal sludge increased their sorption surface area and, consequently, their sorption capacity compared to composts

prepared without this addition; this was due to the presence of clay minerals with a strongly developed specific surface area in this component,

- a high capability of removing zinc ions (sorption above 92.9%) regardless of the type and proportion of individual substrates was found for all composts, However, the highest efficiency (over 96%) was observed in compost with 25% content of coal sludge.

In conclusion, the obtained results confirmed the beneficial effect of 10% of coal sludge addition on the course of the composting process, improvement of the sorption properties of composts, and the quality of the obtained final products. Research on the effect of the addition of coal waste on the course of the composting process and sorption capacity of composts needs to be continued, especially in terms of selection of an optimal dose of coal sludge, and the analysis of the effect of such composts on the phenomena occurring in soils due to human impacts.

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References

Beesley, L., Moreno-Jiménez, E., Gomez-Eyles, Jl. (2010). Effects of biochar and green-waste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environmental Pollution*, 158(6), 2282-2287.

Bernal, M.P., Alburquerque, J.A., Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment, A review. *Bioresource Technology*, 100, 5444–5453.

Bhattacharyya, K. G., Sharma, A. (2005). Kinetics and thermodynamics of methylene blue adsorption on Neem (Azadirachta indica) leaf powder. *Dyes and pigments*, 65(1), 51-59.

Bielińska, E., Mocek, A. (2010). Właściwości sorpcyjne i aktywność enzymatyczna gleb parków miejskich na terenach o zróżnicowanym wpływie antropopresji. *Journal of Research and Applications in Agricultural Engineering*, 55(3), 20-23.

Bień, J., Milczarek, M., Sobik-Szołtysek, J., Okwiet, T. (2011). Optymalizacja fazy termofilowej w procesie współkompostowania osadów ściekowych i odpadów komunalnych. *Nauka Przyroda Technologie*, 5, 4, #33.

Bolan, N., Kunhikrishnan, A., Thangarajan, R., Kumpiene, J., Park, J., Makino, T., Scheckel, K. (2014). Remediation of heavy metal(loid)s contaminated soils – To mobilize or to immobilize? *Journal of Hazardous Materials*, 266, 141-166.

Ciesielczuk, T., Karwaczyńska, U., Rosik-Dulewska, Cz. (2011). Możliwości zastosowania kompostu z odpadów do usuwania węglowodorów alifatycznych C_6-C_9 z roztworu. *Rocznik Ochrona Środowiska*, 13, 1301-1313.

Ciesielczuk, T., Rosik-Dulewska, Cz. (2013). Wykorzystanie kompostów z odpadów komunalnych i sorbentów handlowych do degradacji zanieczyszczeń ropopochodnych. *Rocznik Ochrona Środowiska*, 15, 766-779.

Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, Official Journal of the European Communities L 182/1.

Cuske, M., Karczewska, A. (2016). Wpływ materii organicznej na zmiany rozpuszczalności metali ciężkich w glebach zanieczyszczonych w świetle literatury. *Uniwersytet Zielonogórski, Zeszyty Naukowe*, 162, Nr 42, Inżynieria Środowiska, 39-59.

Dach, J. (2010). Wpływ poziomu C:N na wielkość emisji amoniaku z kompostowanych osadów ściekowych. *Journal of Research and Applications in Agricultural Engineering*, 55(2), 14-18.

Farrell, M., Jones, D.L. (2010). Use of composts in the remediation of heavy metal contaminated soil. *Journal of Hazardous Materials*, 175(1), 575-582.

Gilbert, O., Pablo, de J., Cortina, J.L., Ayora, C. (2005). Municipal compost-based mixture for acid mine drainage bioremediation: Metal retention mechanisms. *Applied Geochemistry*, 20, 1648-1657.

Greinert, A. (2009). Poprawa właściwości sorpcyjnych gleb jako warunek utrzymania w dobrym stanie terenów zieleni miejskiej. *Rocznik Gleboznawczy,* 60, 3, 75-83.

de Guardia, A., Mallard, P., Teglia, C., Marin, A., Le Pape, C., Launay, M., Benoist, J.C., Petiot, C. (2010). Comparison of five organic wastes regarding their behavior during composting: part 1, biodegradability, stabilization kinetics and temperature rise. *Waste Management*, 30, 402-414.

Haug, R.T. (1993). The practical handbook of compost engineering, Lewis Publishers, CRC Press Inc., Florida.

He, M.M., Tian, G.M., Liang, X.Q. (2009). Phytotoxicity and speciation of copper, zinc and lead during the aerobic composting of sewage sludge. *Journal of Hazardous Materials*, 163(2), 671-677.

Himanen, M., Hänninen, M. (2011). Composting of bio-waste, aerobic and anaerobic sludges – Effect of feedstock on the process and quality of compost. *Bioresource Technology*, 102, 2842-2852.

Ishii, K., Fukui, M., Takii, S. (2000). Microbial succession during a composting process as evaluated by denaturing gradient gel electrophoresis analysis. *Journal of Applied Microbiology*, 89, 768 777.

Jędrczak, A. (2007). Biologiczne przetwarzanie odpadów, Warszawa: PWN.

Jóźwiak, T., Filipkowska, U., Rodziewicz, J., Mielcarek, A., Owczarkowska, D. (2013). Zastosowanie kompostu jako taniego sorbentu do usuwania barwników z roztworów wodnych. *Rocznik Ochrona Środowiska*, 15, 2398-2411.

Karami, N., Clemente, R., Moreno-Jiménez, E., Lepp, NW., Beesley, L. (2011). Efficiency of green waste compost and biochar soil amendments for reducing lead and copper mobility and uptake to ryegrass. *Journal of Hazardous Materials*, 191(1), 41-48.

Koh, S.M., Dixon, J.B. (2001). Preparation and application of organo-minerals as sorbent of phenol, benzene and toluene. *Applied Clay Science*, 18, 111-122.

Kwarciak-Kozłowska, A., Bańka, B. (2014). Biofiltracja jako metoda unieszkodliwiania odorów powstających podczas kompostowania frakcji biodegradowalnej odpadów komunalnych i przemysłowych. *Inżynieria i Ochrona Środowiska*, 17, 4, 631-645.

Kyzioł-Komosińska, J., Rosik-Dulewska, Cz., Dzieniszewska, A., Pająk, M. (2011). Compost as biosorbent for removal of acid dyes from the wastewater generated by the textile industry. *Archives of Environmental Protection*, 37, (4), 3-14.

Liang, C., Das, K.C., McClendon, R.W. (2003). The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. *Bioresource Technology*, 86, 131-137.

McCartney, D., Tingley, J. (1998). Development of a rapid moisture content method for compost materials. *Compost Science & Utilization*, 6, 73-91.

Mustin, M. (1987). Le compost, gestion de la matiere organique, Edition Francois Dubuse.

Ordinance of the Minister of Agriculture and Rural Development on the implementation of certain provisions of the Act on fertilizers and fertilization, Dz.U. 2008 nr 119 poz. 765 (in polish).

Ozimek, A., Kopec, M., 2012, Ocena aktywności biologicznej biomasy na różnych etapach procesu kompostowania przy użyciu systemu pomiarowego OciTop Control. *Acta Agrophysica*, 19, 2, 379-390.

Prost, K., Borchard, N., Siemens, J., Kautz, T., Sequaris, J.-M., Moeller, A., Amelung,W. (2013). Biochar affected by composting with farmyard manure. *Journal of Environmental Quality*, 42, 164-172.

Richard, T.L. (1992). Municipal solid waste composting. Physical and biological processing. *Biomass & Bioenergy*, 3 (3-4), 195-211.

Richard, T.L., Hamelers, H.V.M., Veeken, A., Silva, T. (2002). Moisture relationship in composting process. *Compost Science & Utilization*, 10 (4), 286-302.

Roy, W.R., Krapac, I.G., Chou, S.F.J., Griffin, R.A. (1991). Batch-type procedures for estimating soil adsorption of chemicals, Illinois State Geological Survey, Champaign, Illinois 61820, USA.

Sidełko, R. (2009). Wpływ czasu przetrzymywania wsadu w bioreaktorze na stabilizację kompostu. *Rocznik Ochrona Środowiska*, 11, 393-402.

Sidełko, R., Siebielska, I., Szymański, K., Skubała, A., Kołacz, N. (2014). Ocena stabilności kompostu w czasie rzeczywistym. *Inżynieria i Ochrona Środowiska*, 17(2), 221-230.

Siebielska, I., Janowska, B. (2011). Porównanie zawartości wybranych metali ciężkich w próbkach kompostów. *Rocznik Ochrona Środowiska*, 13, 815-830.

Sobik-Szołtysek, J. (2006). Sorpcja kationów cynku na materiałach mineralno-węglowych. Materiały V Konferencji Naukowo-Technicznej „Węgiel aktywny w ochronie środowiska i przemyśle", Wyd. Politechniki Częstochowskiej, 412-420.

Weber, J., Karczewska, A., Drozd, J., Licznar, M., Licznar, S., Jamroz, E., Kocowicz, A. (2007). Agricultural and ecological aspects of sandy soil fertility as affected by the application of composts produced from municipal solid wastes. *Soil Biology and Biochemistry*, 39, 6, 1294-1302.

Williamson, J.C., Akinola, M., Nason, M.A., Tandy, S., Healey, J.R., Jones, D.L. (2009). Contaminated land clean-up using composted wastes and impacts of VOCs on land. *Waste Management*, 29, 1772-1778.

Abstract

EU directives on the landfill of waste oblige member states to gradually reduce the deposit of biodegradable waste in landfills. In particular, the entire mass of green waste should be transformed into compost, representing a valuable material. Scientific publications contain numerous reports concerning co-composting of green waste with other types of waste materials, including mineral ones. Appropriate choice of input materials may have a positive effect on the properties of the final product. In particular, improving the sorption capacity of compost in terms of the possibility of using it to improve the properties of the soil seems to be a very important issue.

The aim of the study was to determine the effect of the addition of waste coal sludge on changes in the sorption capacity of the obtained composts.

The potential of using different substrates in the composting process is determined primarily by their proper moisture content, optimal C/N ratio and proper structure, forming an environment with good oxygenation. After theoretical analysis and practical testing, several substrate combinations were selected for the study. The process was conducted using only basic materials (grass, organic fraction of municipal waste, structure-forming materials), and coal sludge in the amount of 10 and 25% by weight.

Since composting is a biological process, the course and conditions of the process need to be optimized and controlled. The research was conducted in two series: series 1, at room temperature of bioreactors, and series 2, with additional thermal insulation of bioreactors. The sorption capacity of the obtained composts was determined with reference to methylene blue and zinc sorption from aqueous solutions (the batch method) at a constant liquid-solid contact ratio of 1:20.

The most favorable process parameters and satisfactory quality of the obtained compost were observed in mixtures with a lower proportion of coal sludge composted in bioreactors with additional insulation (series 2). In all composts produced with the addition of coal sludge, higher values of the specific surface area (S_t) with reference to methylene blue were obtained compared to samples without added sludge. These composts also showed a high capability to remove zinc ions (above 92.9%), regardless of the type and proportion of individual substrates.

The obtained results confirmed the beneficial effect of 10% of coal sludge addition on the efficiency of the composting process, improvement of the sorption properties of composts, and the quality of the obtained final products.

Keywords:
composting, coal sludge, sorption capacity

Wpływ dodatku odpadów węglowych na przebieg procesu kompostowania i pojemność sorpcyjną kompostów

Streszczenie

Dyrektywy Unii Europejskiej w sprawie składowania odpadów zobowiązują państwa członkowskie do stopniowego ograniczenia deponowania odpadów biodegradowalnych na składowiskach. Zwłaszcza cała masa odpadów zielonych powinna ulegać przetworzeniu na cenny materiał – kompost. W publikacjach naukowych pojawiają się liczne doniesienia dotyczące współkompostowania odpadów zielonych z innymi materiałami odpadowymi, w tym mineralnymi. Odpowiedni dobór materiałów wsadowych może korzystnie wpływać na właściwości uzyskiwanego produktu. Zwłaszcza podwyższenie pojemności sorpcyjnej kompostu w aspekcie możliwości wykorzystania go do poprawy właściwości podłoża glebowego wydaje się być zagadnieniem bardzo istotnym.

Celem podjętych badań było określenie wpływu dodatku odpadowych mułów węglowych na zmiany pojemności sorpcyjnej wytworzonych kompostów.

O możliwości wykorzystania w procesie kompostowania różnych substratów decyduje przede wszystkim ich odpowiednia wilgotność, optymalny stosunek C/N oraz właściwa struktura, tworząca środowisko o dobrym natlenieniu. Po analizie teoretycznej i próbach praktycznych do badań wybrano kilka kombinacji substratów. Proces prowadzono z wykorzystaniem wyłącznie materiałów podstawowych (trawa, organiczna frakcja odpadów komunalnych – OFOK, materiały strukturotwórcze), jak i z dodatkiem mułów węglowych w ilości 10 i 25% wag. Z uwagi na to, że kompostowanie jest procesem biologicznym przebieg i warunki prowadzenia procesu wymagają optymalizacji i kontroli. Badania prowadzono w dwóch seriach: seria I – pokojowa temperatura otoczenia bioreaktorów, seria II – dodatkowa izolacja termiczna bioreaktorów. Pojemność sorpcyjną uzyskanych kompostów określono w odniesieniu do błękitu metylenowego oraz sorpcji cynku z roztworów wodnych (metoda batch) w stałej proporcji kontaktu ciecz - ciało stałe, wynoszącej 1:20.

Najkorzystniejsze parametry procesowe oraz satysfakcjonującą jakość uzyskanego kompostu zaobserwowano w mieszankach z mniejszym udziałem mułów węglowych, kompostowanych w bioreaktorach z dodatkowym ociepleniem (seria II). We wszystkich kompostach wytworzonych z dodatkiem mułów węglowych uzyskano wyższe wartości powierzchni właściwej (S_t) w odniesieniu do błękitu metylenowego w porównaniu do próbek bez dodatku mułu. Również właśnie te komposty wykazały dużą zdolność do usuwania jonów cynku (powyżej 92,9%), niezależnie od rodzaju i udziału poszczególnych substratów. Uzyskane rezultaty badań potwierdziły korzystny wpływ 10% dodatku odpadowego mułu węglowego zarówno na przebieg procesu kompostowania, poprawę właściwości sorpcyjnych kompostów, jak i jakość uzyskanych produktów końcowych.

Słowa kluczowe:
kompostowanie, muły węglowe, pojemność sorpcyjna