

Influence of the Addition of Solidifying Materials on the Heavy Metals Immobilization in Sewage Sludge

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1. Introduction

Sewage sludge constitutes an inseparable product of wastewater treatment. Its treatment and disposal should complement the processes undergoing in each Wastewater Treatment Plant. Until now a significant majority of wastewater treatment plants faced have problems of sludge formation and further on, organization of a system of its removal and disposal. By-products generated in each of the plants constitute troublesome waste, which in most cases is deposited at the municipal landfill sites. Wastewater sludge contains considerable amounts of mineral and organic substances which makes it an attractive material to be used for natural purposes, among others as a natural fertilizer. Its fertilizing and soil-forming values are determined mainly by the fact that next to the organic substance it contains nitrogen and phosphorus, as well as nutritive heavy metals, the so-called microelements. However, this method of wastewater sludge management is limited by the content of hazardous heavy metals and pathogenic organisms. In connection with the above some reclamation processes of waste disposal sites are recommended. Those processes are based on lime application enabling to obtain a hygenized product which at the same time is adequately stabilized and dehydrated [1].

Sewage sludge applicability for natural purposes comprises the following processes:

- soil and plants fertilization,
- production of compost and fertilizing preparation,
- soil-less grounds reclamation,
- biological stabilization of dusting surfaces,
- soil-drainage fertilization [2].

Sludges to be used for natural purposes should comply with the relevant standards and regulations permissible concentrations of heavy metals and pathogenic organisms and also methods of its introduction to the ground [3].

Our knowledge about the total of heavy metals concentrations in sewage sludge still does not reflect their potential threat for the environment. As the most mobile, thus, easily penetrating the soil solution and therefore easily absorbed by plants, are considered those forms of heavy metals which are soluble in water – the so called exchangeable metals and metals chemically bound to carbonates. However, metals bound to iron and manganese oxides and to organic substances are also available for plants but their release into the soil is much slower [4-5].

An annual dose as well as the permissible charge of heavy metals should be compliant with the Decree of the Minister of the Environment of August 1st 2002, concerning municipal sewage sludge [2]. Migration of heavy metals from soil into the food chain depends on many factors, such as susceptibility of various plants to pollutants absorbed from soil and varied degrees of their accumulation in edible parts of those plants. A similar mechanism of entering and intake of various toxic substances can be observed in animal organisms. Transformations and kinetic changes undergoing with the participation of heavy metals inside the living organisms may assume different forms depending on the matrix of the analyzed material [6,7].

Solidification is the method of sewage sludge management which deserves particular attention. Waste with various levels of hydration may be solidified both by means of removing liquids from them and by adding specific substances which change its chemical and physical properties.

- change of consistence from liquid or semi-liquid into solid, as a result of the application of physical processes,
- chemical fixation with stabilization consisting in the transformation of components contained in the sludge into the form insoluble or slow-soluble form in water [8].

Heavy metal compounds present in water, containing simple ions, oxides, hydroxides or sulphates, interact creating different types of bonds and solidification in the process of stabilizing material hydration reaction. Metal ions of the mixed sludges penetrating the pores either get adsorbed on the walls of the pores or get bound into complexes with the stabilizing mass components [9].

In the present work some aspects of heavy metals speciation before and after the sewage sludge solidification process. The carried-out research aimed at determining the percentage content of heavy metals in the mobile- ion-exchanging fraction and individual fractions. An attempt at evaluating the im-

pect of solidification and the time of its duration on the participation of metals in individual fractions was made. The obtained results will enable us to determine the degree of heavy metals from sludges mobility.

2. Materials and methods

Research on the sewage sludge solidification process performed with the use of ash dusts from “Bełchatów” Power Plant was carried out for sewage sludge samples from from the “Bielawin” Wastewater Treatment Plant in Chem. In the solidification process the following doses of ash dusts were applied: 0.2; 0.6; 1.0 kg dust/kg d.m. The analysed material was dried for 48 hours in the temperature of 105°C and then ground in a ball-grinder.

The total heavy metals concentrations in sludges and dust were determined after mineralization in a CEM-2100 microwave oven. Concentrations of heavy metals were determined with the use of inductively coupled plasma atomic emission spectrometry with the use of ICP JY 238 ULTRACE instrument.

In order to quantify five forms of heavy metals sequential extraction was carried out basing on the scheme presented in Table 1.

Table 1. Scheme of analytic procedures in sequential extraction [10]

Tabela 1. Schemat postępowania analitycznego w ekstrakcji sekwencyjnej [10]

Fraction	Type of extraction agent	Temperature °C	Duration and conditions of extraction
I. Exchangeable metals	1M MgCl ₂ , pH=7	22	shaking 1 h
II. Metals bounded with carbonates	1M CH ₃ COONa acidified CH ₃ COOH, pH=5	22	shaking 5 h
III. Metals bounded with iron and manganese oxides	0,04M NH ₂ OH • HCl in 25% (v/v) CH ₃ COOH	95	shaking 5 h
IV. Metals bounded with organic substance	0,02M HNO ₃ + 30% H ₂ O ₂ at pH=2	85	shaking 2 h
	H ₂ O ₂ , pH=2		shaking 3 h
	3,2M CH ₃ COONH ₄ in 20% HNO ₃ (v/v)	22	shaking 0,5 h
V. Metals residue	HF + HNO ₃	mineralization	

After each of the stages the solid phase was separated from the liquid phase by means of centrifugation of a sample on the MPW-350 centrifuge (time of centrifugation – 30 min, rotation speed – 4000 rot./min). The supernatant was decanted from above the sludge. Next, the sludge was rinsed with a small amount of distilled water, which was added to the formerly extracted solution. In the so prepared samples the content of heavy metals was determined.

Organic carbon contained in the eluate was determined with the use of the total and organic carbon analyzer SHIMADZU TOC – 5050A.

3. Discussion

Total heavy metals concentrations for sewage sludge and ash dusts are presented in Table 2.

Table 2. Chemical composition of sewage sludge from the “Bieławin” Wastewater Treatment Plant in Chełm and of ash dusts from the “Bełchatów” power plant

Tabela 2. Skład chemiczny osadów ściekowych z oczyszczalni ścieków „Bieławin” w Chełmie oraz pyłów dymnicowych z Elektrowni „Bełchatów”

Component	Sewage sludge			Ash dusts
	IV 2003	X 2003	IV 2004	
Lead	21.20	20.123	18.43	30.69
Cadmium	1.64	2.52	2.40	0.97
Nickel	27.20	25.62	30.35	22.77
Zinc	284.00	293.20	272.45	79.20
Copper	40.40	44.02	41.63	23.20
Chromium	78.20	68.14	74.52	136.00

Based on my own test results and on the results documented by other authors [11, 12], it can be stated that the determination of the total content of particular metals is insufficient for proper assessment of their toxicity, assimilability, accumulation and migration, as these properties depend on the chemical and physical forms in which they occur.

One of the techniques applied in the extraction of particular phases and the forms in which they occur was the procedure of sequential extraction. It consists of multiple extraction of the analyzed samples with varied leaching potential reagents. Taking into account my own research and the researches carried out by other authors [13, 14, 15, 16, 17] particular attention should be paid to the problem of re-adsorption.

For the purpose of potential risk assessment that may be the result of the introduction of the mixture of sludge and dusts into the environment speciation analysis was carried out directly after and 28 days after the solidification process. The results of those analyses are presented in Tables 3 and 4.

Table 3. Speciation analysis of heavy metals content in sewage sludge and in the mixture of sludge and dusts

Tabela 3. Analiza specyjacyjna metali ciężkich w osadach ściekowych i mieszance osadowo pyłowej

Fraction	Content of particular heavy metals [%]						Dose of dust [kg/kg d.m.]
	Pb	Cd	Ni	Zn	Cu	Cr	
I	3.66	12.00	10.72	5.43	0.91	1.67	sewage sludge
II	5.14	11.28	10.61	19.70	0.82	1.58	
III	21.60	22.61	36.64	51.21	0.87	20.52	
IV	26.53	16.09	22.13	7.20	85.98	52.10	
V	43.07	38.02	19.90	16.46	11.42	24.13	
I	3.01	13.12	13.60	8.12	4.79	9.98	0.2
II	2.69	12.83	23.88	23.15	3.97	8.93	
III	24.23	23.65	15.56	52.00	2.35	31.73	
IV	25.78	14.94	16.48	4.05	80.23	37.34	
V	44.29	35.46	30.48	12.68	8.66	12.02	
I	2.52	13.68	10.32	4.32	8.63	5.27	0.6
II	2.40	13.87	10.99	22.68	3.97	3.62	
III	25.20	26.22	32.44	53.33	1.91	30.78	
IV	24.31	12.31	15.63	3.40	74.67	35.44	
V	45.57	33.92	30.62	16.27	10.82	24.89	
I	1.44	14.69	8.63	8.22	10.55	2.02	1.0
II	3.45	14.47	8.61	22.68	3.01	2.37	
III	30.09	29.64	23.00	53.33	2.19	32.62	
IV	18.08	10.49	14.13	2.55	21.09	31.55	
V	46.94	30.71	45.63	13.22	23.16	31.44	

Table 4. Speciation analysis of heavy metals content in sewage sludge and in the mixture of wastewater sludge and dusts after 28 days of solidification**Tabela 4.** Analiza specjacyjna metali ciężkich w osadach ściekowych i mieszance osadowo pyłowej po 28 dniach solidyfikacji

Fraction	Content of particular heavy metals [%]						Dose of dust [kg/kg d.m.]
	Pb	Cd	Ni	Zn	Cu	Cr	
I	7.58	15.98	14.72	2.15	2.08	1.42	sewage sludge
II	5.03	14.07	14.37	6.07	1.19	1.47	
III	23.52	15.62	30.72	27.68	1.06	19.77	
IV	23.23	5.29	18.07	4.40	45.60	41.97	
V	40.64	49.04	22.12	59.70	50.07	35.37	
I	1.46	4.59	18.09	11.08	5.81	13.03	0.2
II	1.95	4.27	17.04	15.23	4.90	12.27	
III	18.98	22.22	14.12	50.31	1.93	11.53	
IV	18.32	4.10	8.14	1.82	10.74	17.92	
V	59.29	64.82	42.61	21.56	76.62	45.25	
I	1.27	5.04	13.73	11.15	10.10	8.46	0.6
II	1.56	5.57	5.87	13.53	4.84	6.66	
III	22.42	24.41	30.77	51.60	2.17	19.14	
IV	15.55	3.80	6.11	1.21	10.05	15.24	
V	59.20	61.18	43.52	22.51	72.84	50.50	
I	0.51	6.13	12.24	11.29	12.11	5.15	1.0
II	2.29	5.61	3.94	12.92	5.68	5.93	
III	23.97	29.08	21.52	51.12	1.87	13.99	
IV	14.00	2.52	5.55	0.68	6.63	12.28	
V	59.23	56.66	56.75	23.99	73.71	62.65	

Fraction IV is the second largest fraction. In the case of lead this fraction is bound mainly to protein complexes of the metalothionein character and constitutes on average 26,53% of sewage sludge. The fraction gets reduced by approximately 8,5% at the highest dose of ash dusts. It can be justified by denaturation and/or hydrolysis of the proteins forming complex systems, which makes lead more available accessible and further on causes an increase of the percentage share of lead in fraction V with the increasing dose of dust. This last fraction is the largest of all the fractions and constitutes more than 40% of lead contained in sewage sludge. The addition of dusts to sludges results in the increased percentage of this metal in the remaining fraction by approximately 4%, and then after 28 days of solidification the percentage of this fraction reaches approximately 60% forming, most probably as a result of lime application, slow-soluble compounds with phosphorus, e.g. $Pb_5Cl(PO_4)_3$ [18].

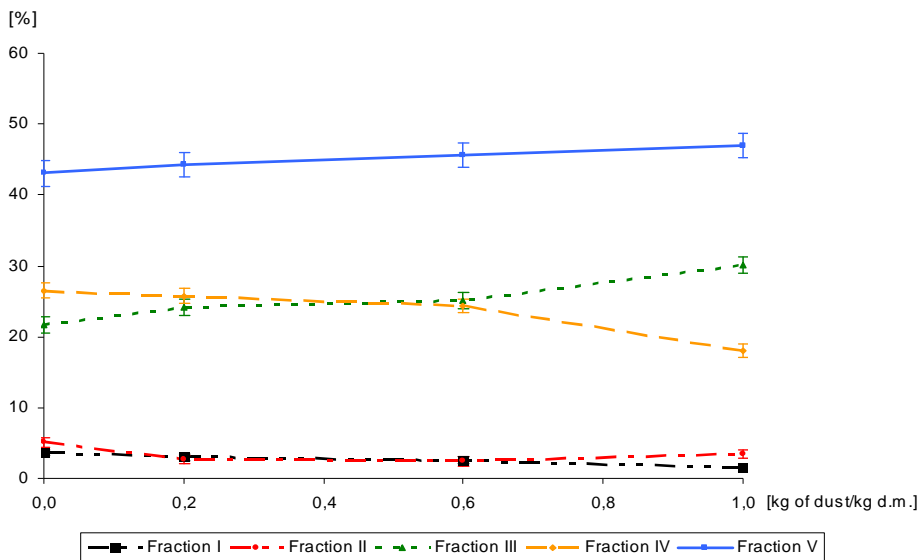


Fig. 1. Characteristics of the percentage share of particular fractions directly after mixing for Pb depending on the dose of dusts for sludge-dust mixtures in sewage sludge samples from Chełm

Rys. 1. Charakterystyka udziałów poszczególnych frakcji bezpośrednio po zmieszaniu dla Pb w zależności od dawki pyłów dla mieszanek osadowo-pyłowych z wykorzystaniem osadów z Chełma

In the case of **cadmium** the highest percentage share was determined in two fractions: fraction III and fraction V with a relatively high share in fraction IV bound to organic matter, mainly to proteins constituting “protection” for living organisms against toxic properties of this metal. It was observed that when ash dusts were added the fraction bound to organic matter got reduced (Fig. 2) in favor of fraction III and V respectively bound to Fe/Mn oxides and to the residue soluble in the mixture of HF and HNO₃.

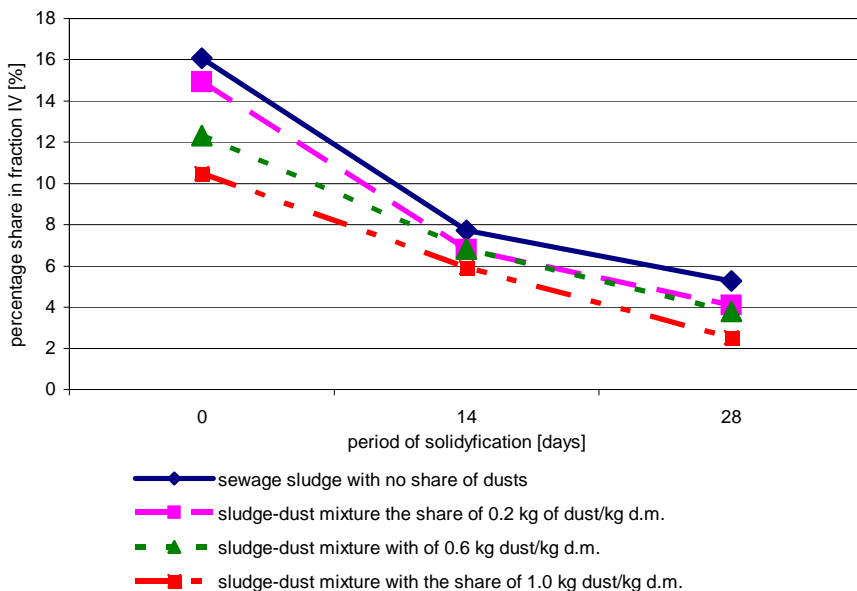


Fig. 2. Dependence of the percentage share of cadmium in fraction IV on the dose of ash dusts and time of solidification for sewage sludge from Chełm and its mixtures

Rys. 2. Zależność udziału kadmu we frakcji IV od dawki pyłów dymnicowych i czasu zestalania dla osadów z Chełma i ich mieszanek

Together with the increased dose of dusts a slight, a few percent increase of the percentage share in fraction I with the correlation coefficient $R^2_1 = 0,945$ was observed. It can be justified by the fact that cadmium occurs in ash dust in the form adsorbed on the surface of dust particles and as a result it can be relatively easily released. After 28 days of solidification we observed that the percentage share of cadmium in fraction I was reduced to approximately 5-6%. In fraction II bound to carbonates we observed a slight increase of the share of this metal when dusts are applied which can be justified by the fact that it is absorbed on the surface of dust particles. In the case of fraction III bound to Fe/Mn oxides a few percent increase was observed when dusts were applied. A relatively high percentage in fraction III does not limit the possibility of mixtures application as this fraction is not mobile and stable in environmental conditions. Fraction V, similarly to fractions I, II and III, increased the percentage share proportionally to the dose of dusts applied. It has to be stressed here that at the highest applied dose of dusts reduction of this fraction was observed to-

gether with an increase of the share in fraction III bound to Fe/Mn oxides. It implies that occlusion in oxides is the most competitive one.

Nickel seems to be the easiest metal to be immobilized. Even in sludge itself its percentage share in the bio-available fractions I and II oscillates around the level of approximately 10%, in more than 35% it is bound to the oxides fraction and in more than 22% to the organic fraction.

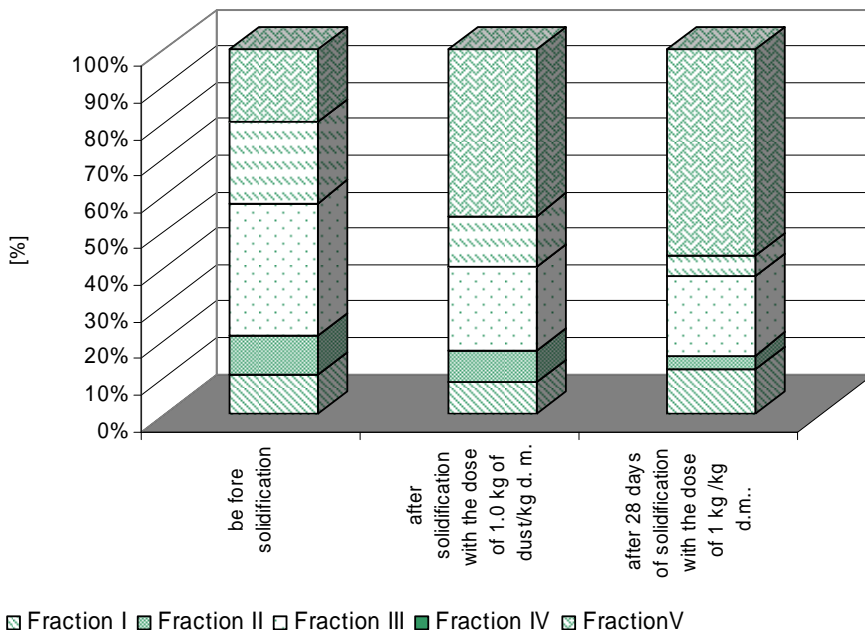


Fig. 3. Percentage share of nickel for particular fractions in wastewater sludge before and after process of solidification with the dose of dust in the amount of 1 kg dust/kg dry mass

Rys. 3. Procentowy udział niklu dla poszczególnych frakcji w osadach ściekowych przed i po procesie solidyfikacji dawką 1 kg pyłu/kg s.m.

When ash dusts are added fraction V increases by more than 25%. However, the fastest changes are observed in the percentage share in fraction IV – the organic fraction – where nickel is most probably bound in the form of simple bio-complexes. Similar changes are observed in the function of the time of solidification.

Fraction III occurs on the level of 36% and its percentage share after ash dusts are added is reduced to the level of 23%, after 28 days of solidification, where in fact the balance is already established, the share of nickel in the

oxides fraction drops down to 21% at the maximum dose of dust. Low correlation coefficients for fraction III $r_{III} = 0,08$, with the determination coefficient $R^2_{III} = 0,007$ indicate that the volume of Fe/Mn oxides-bound fraction III does not depend on the dose of dusts.

Nickel's behavior indicates that it occurs in sludge in the form of simple ions or labile complexes with humic or fulvic acids. Ease with which this metal gets immobilized indicates at the fact that even considerable content of nickel in sewage sludge cannot constitute a serious problem when it comes to its use for natural purposes.

Zinc is a metal, whose percentage share in particular fractions oscillates around the level of 5% in fraction I and approximately 20% in fraction II, and these are the two forms which are the most available ones. With the increase of the dose of dusts and the resulting increase of pH factor of the mixtures we observe its increased percentage in fractions I and II. In alkaline environment intensified mobility of zinc is observed in the process of complex anion or oxo-anion e.g. tinites formation. In the case of zinc particular attention should be paid to its increase in the percentage share in fraction V, in which a 10% growth at the maximum dose of 1 kg dust/kg d.m. after 28 days of solidification was observed. This phenomenon is beneficial and indicates that zinc immobilization time is a rather significant parameter. Fraction III bound to iron and manganese oxides constitutes approximately 27% of shares in sewage sludge. This fraction increases its share proportionally to the dose of dusts reaching over 50% of zinc content at the highest applied dose. As a result of adding dusts to sewage sludge the percentage share of zinc decreases in fraction IV bound to organic matter. For sludge with no dusts added the percentage reaches the level of approximately 4% while in the sludge with the maximum dose of dusts it drops down to 0.6% (Fig. 4).

The lowest bio-available fraction V occurs on the level of 60% before solidification. Dusts added in the maximum dose to the sludge-dust mixture result in the reduction of this fraction to about 13%. This type of zinc's behavior can be justified by the fact that this metal occurs in all the elements of the environment as a result of which active places which could cause its sorption or deactivation get in fact saturated.

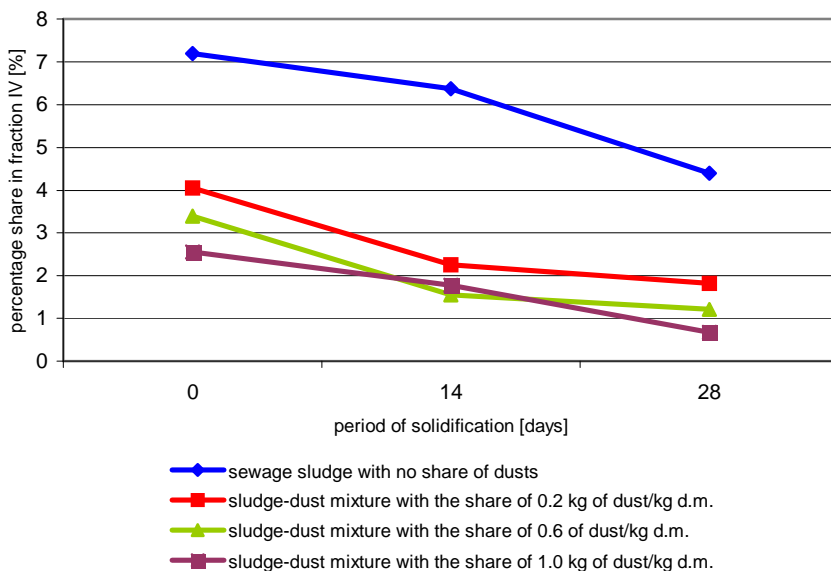


Fig. 4. Dependence of average percentage share of zinc in fraction IV on the dose of dusts and solidification time for sewage sludge samples from Chełm and its mixtures.

Rys. 4. Zależność średnich udziałów cynku we frakcji IV od dawki pyłów i czasu zestalania dla osadów z Chełma i ich mieszanek

In the case of **copper**, the situation is slightly different than in the case of cadmium, as we are dealing with an element which in more than 80% is bound to the organic fraction. Copper in fraction IV is not bound in a homogeneous way and it occurs in the form of protein complexes – susceptible to pH changes – and also complexes with porphyrine rings – less susceptible to the pH balance alterations - which can release copper ions based on the ionic exchange process. Copper may be replaced with ions of similar diameters e.g. Mg^{2+} . A similar exchange may take place in the case of Fe^{2+} and Ca^{2+} ions. Rather large residues of the organic fraction even after a longer period of solidification prove that a considerable part of copper occurs in the form of porphyrine complexes (6-10% after 28 days of solidification).

Prolonged solidification time and an increased dose of dusts cause the growth of the percentage share in fraction V at a significant participation of fraction IV (Fig. 5), which proves intensive correlation with the dose of dusts $R^2_{IV} = 0,97$. With time copper contained in the sludge-dust mixture transforms into slow-soluble ions bound to fraction V (approximately 23% at the dose of

dust 1 kg dust/kg DSM). Slow speed of these transformations confirms that what we observe is rather an ion exchange process.

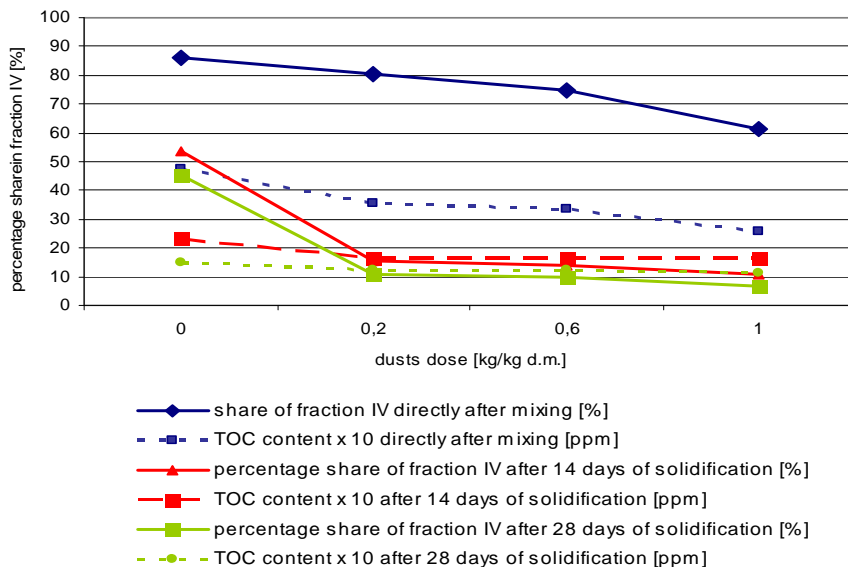


Fig. 5. Changes in the percentage share of fraction IV and TOC for copper depending on the dose of dusts for sewage sludge and its mixtures formed with the sludge from Chełm with regard to the time of solidification.

Rys. 5. Zmiany udziałów frakcji IV i TOC dla miedzi w zależności od dawki pyłów dla osadów i ich mieszanek wytworzonych na bazie osadów z Chełma z uwzględnieniem czasu zestalania.

In the case of **chromium** we have observed a similar behavior in fractions I and II. The percentage in fraction I oscillates around the level of 1.6% for sewage sludge itself up to 5-9% for sludge-dust mixtures while at the highest dose of dust after 28 days of solidification it reaches the level of 2%. Increased share of chromium in these fractions may be the result of Cr^{3+} presence on the surface of dust particles. However, the growth is not a significant one and does not limit the safety of the mixtures applied.

Fraction IV (fig. 6), constituting over 52%, is the fraction the volume of which decreases both with the application of dusts and with the time of solidification. The fact that initially fraction mineralization undergoes very fast and then gradually slows down proves that there exist many forms of organic chromium.

Fraction V shows a reverse tendency when compared to fraction IV which when the dusts are applied increases its share from 24% up to more than 60% after 8 days of solidification at the maximum dose of dusts.

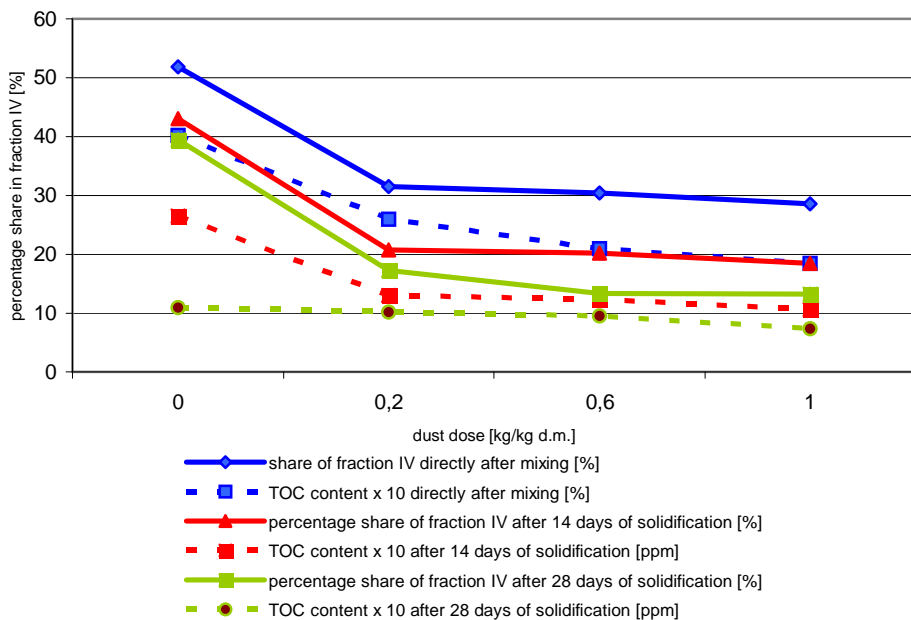


Fig. 6. Changes in the percentage share of fraction IV and TOC for chromium depending on the dose of dusts for sewage sludge and its mixtures formed with the sludge from Chełm with respect to the time of solidification.

Rys. 6. Zmiany zależności frakcji IV i TOC dla chromu w zależności od dawki pyłów dla osadów i ich mieszanek wytworzonych na bazie osadów z Chełma z uwzględnieniem czasu zestalania

4. Conclusions

Analyses carried out on raw sewage sludge and on sludge solidified with ash dusts prove that:

1. Ash dusts-hygenised sewage sludge from the “Bielawin” Wastewater Treatment Plant does not pose any chemical threat and may be used for any natural purposes in any possible way.
2. Together with the alkaline reaction increases the concentration of copper and zinc in the ion-exchange fraction.

3. Tests of the fractionated leaching show that bio-available fractions get reduced for each of the analyzed metals. Zinc constitutes an exception but it is widely available in the environment while in the case of nickel and chromium the share of the bio-available fractions does not exclude the possibility of their use for natural purposes.
4. Low content of heavy metals in the sludge-dust mixtures creates a possibility for multiple soil fertilization without the threat of introduction of excess heavy metals.
5. The component applied for solidification is an ecologically arduous waste material and its application instead of burnt lime has a strong economic justification.
6. The applied technology of sludge solidification with ash dusts is a simple and easy method and the obtained product is not arduous when its odor is concerned.

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Wpływ dodatku materiałów zestalających na immobilizację metali ciężkich w osadach ściekowych

Streszczenie

Metodą utylizacji osadów ściekowych zasługującą na szczególną uwagę jest solidyfikacja. Odpady o różnym uwodnieniu mogą być zestalane zarówno poprzez usuwanie z nich cieczy jak również przez dodanie do nich specjalnych substancji powodujących zmianę właściwości fizycznych i chemicznych. Obniżenie kosztów solidyfikacji stało się możliwe przy zastosowaniu pyłów dymnicowych zawierających w swoim składzie duże ilości tlenu wapnia.

W pracy przedstawiono wyniki badań dotyczące określenia wpływu solidyfikacji osadów ściekowych na immobilizację metali ciężkich.

Badania solidyfikacji osadów ściekowych za pomocą pyłów dymnicowych z Elektrowni „Bełchatów” wykonano dla próbek osadów ściekowych pochodzących z oczyszczalni ścieków „Bieławin” z Chełma, stosując dawki 0,2; 0,6; 1,0 kg pyłu/kg s.m.o.

Całkowite stężenia metali ciężkich w osadach ściekowych i pyłach oznaczono po mineralizacji w mineralizatorze mikrofalowym CEM-2100. Stężenia metali ciężkich oznaczono przy zastosowaniu aparatu ICP JY 238 ULTRACE.

W celu ilościowej analizy pięciu form występowania metali ciężkich przeprowadzono sekwencyjną ekstrakcję w oparciu o schemat przedstawiony w tabeli 1.

Na podstawie badań własnych oraz badań przedstawionych przez innych autorów [11, 12], można stwierdzić, że oznaczanie całkowitej zawartości konkretnych metali jest niewystarczające do właściwej oceny ich toksyczności, możliwości asymilacji, akumulacji oraz migracji, ponieważ te własności zależą od chemicznych i fizycznych form, w których występują.

Jedną z technik stosowanych w ekstrakcji poszczególnych faz i form, w których one występują jest procedura ekstrakcji sekwencyjnej. Polega ona na wielokrotnej ekstrakcji analizowanych próbek różnymi reagentami. Biorąc pod uwagę badania własne oraz badania innych autorów [13, 14, 15, 16, 17] szczególną uwagę należy zwrócić na problem ponownej adsorpcji.

W celu oceny potencjalnego ryzyka, które może być wynikiem wprowadzenia mieszanki osadu i pyłów do środowiska przeprowadzono analizę specjacyjną bezpośrednio po oraz po 28 dniach procesu solidyfikacji. Wyniki analiz przedstawiono w tabelach 3 i 4.

W celu określenia poziomu immobilizacji metali ciężkich przeprowadzono frakcjonowanie osadów, przed i po procesie solidyfikacji stosując procedurę ekstrakcji sekwencyjnej. Składa się ona z wielokrotnej ekstrakcji poddanych analizie próbek odczynnikami o zróżnicowanym potencjale ługowania.

Z przeprowadzonych analiz surowych osadów ściekowych i solidyfikowanych pyłami dymnicowymi wynika, że:

1. Osady ściekowe zhigienizowane pyłami dymnicowymi pochodzące z oczyszczalni ścieków „Bieławin” nie stwarzają zagrożenia chemicznego i mogą być wykorzystywane w każdym sposobie przyrodniczego wykorzystania.
2. Wraz ze wzrostem pH wzrasta stężenie miedzi i cynku we frakcji jonowymiennej.
3. Testy frakcjonowanego wymywania pokazują, że dla każdego z analizowanych metali zmniejszeniu ulegają frakcje biodostępne. Wyjątek stanowi cynk, ale jest on pierwiastkiem powszechnie dostępnym w środowisku, natomiast w przypadku niklu i chromu wielkości frakcji biodostępnych nie przekreśla ich przyrodniczego wykorzystania.
4. Niskie zawartości metali ciężkich w mieszkankach osadowo-pyłowych stwarzają możliwość wielokrotnego naważenia gleby bez obawy wprowadzenia nadmiaru metali ciężkich.
5. Zastosowany komponent do solidyfikacji stanowi materiał odpadowy uciążliwy ekologicznie, a zastosowanie go zamiast wapna palonego ma mocne uzasadnienie ekonomiczne.
6. Zastosowana technologia solidyfikacji osadów pyłami dymnicowymi jest prosta i łatwa w realizacji, a otrzymany produkt nie jest uciążliwy zapachowo.