GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2022 Volume 38 Issue 4 Pages 173–189

DOI: 10.24425/gsm.2022.143629

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Analysis of the properties of coal sludge in the context of the possibility of using it in biological reclamation

Introduction

The circular economy concept, as well as legal regulations in the field of waste management, are aimed at saving natural resources and maximizing the re-use of waste (EC 2014). One of the industries that must cope with these changes is the mining industry.

In the case of underground mines, water from the drainage of mining excavations is pumped to surface settling tanks in which the sedimentation of solid particles takes place. As a result, underground water is purified and may be re-used as process water or discharged into surface watercourses. However, solids settled in the tank constitute waste with the catalog

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(Decision EC 2014) code "19 13 06" – sludges from groundwater remediation other than those assigned code "19 13 05". When this waste comes from a hard-coal mine, it is called "coal sludge" (CS) or "coal slurry".

Settling tanks need to be cleaned from time to time. The resulting CS contains mainly fragmented gangue and particles of hard coal. According to tests performed on coal sludges deposited in several surface settling tanks (Lutyński and Szpyrka 2012), the mean values of moisture, ash content and calories in coal sludges were 22.7%, 42.5% and 16.4 MJ/kg, respectively. SiO_2 (47.5%), C (23.2%) and Al_2O_3 (6.7%) prevailed in the chemical composition. The other ingredients – CaO (0.06%), MgO (0.77%), K_2O (1.87%), Na_2O (0.65%) and P_2O_5 (0.04%) – were present in much smaller amounts.

One of the ways of re-using CS is energy recovery. Unfortunately, this waste must be dehydrated on filter presses due to its high moisture content. Research was conducted on the mixing of coal sludges with water-binding additives, such as CaO, and other materials, such as pulverized lignite or sewage sludge. The mixtures prepared in order to produce fuel are subjected to either pressure agglomeration or non-pressure agglomeration (Fraś et al. 2013; Feliks 2017; Klojzy-Kaczmarczyk et al. 2019). CS is characterized by a relatively low filtration coefficient in the range of 10^{-5} to 10^{-10} m/s. This parameter can be further reduced by mechanical concentration or by mixing with other wastes, such as fly ash from coal combustion (Klojzy-Kaczmarczyk and Mazurek 2017; Adamczyk and Pomykała 2022). Therefore, CSs are used to build settling tanks (in which they are deposited) or other hydrotechnical facilities or separation barriers. CS can also be used for the manufacture of light artificial aggregates. The process consists in the granulation of CS mixed with municipal sewage sludge and other mineral waste and then sintering the granules at a temperature of 900–1,150°C (Góralczyk and Baic 2009). Coal sludges are used as a material for the preparation of waste-water suspensions used for the backfilling of underground mining excavations (Pomykała and Kępys 2021).

Reclamation processes are another feasible application of CS. The reclamation of land degraded by industry, as well as landfills, has been one of the main ways of using wastes from hard-coal mines for many years. This primarily applies to wastes from deposit-exposing works and from processing; the typical grain size distribution is from 2 to 300 mm (Fraś and Przytaś 2013; Chugh and Behum 2014; Klojzy-Kaczmarczyk et al. 2016). Therefore, they are used in the technical phase of reclamation for landscaping. There are far fewer experiments described on the re-use of fine-grained wastes, such as CS, in reclamation processes. Due to this grain composition profile, CS and other fine-grained wastes are most often used to thicken wastes featuring larger grain sizes. However, the content of fine grains in CS can be beneficial when making a reclamation cover and can significantly facilitate and accelerate the rooting process in plants. In addition, due to the content of micro- and macro-nutrients in CS, it is proposed to use this type of waste as a component of plant growth substrates to adjust physical structure, pH, and nutrient availability in soils (Kugiel and Piekło 2012; Firpo et al. 2021). The authors of these publications described the use of CS in mixtures with sewage sludges, iron slags and rice husk ash.

One of the basic requirements for the re-use of waste for reclamation is the lack of an adverse effect on the aquatic and ground environments as well as on vegetation which will grow on a substrate made of wastes or a mixture of wastes with virgin soil. It is also important to determine the properties of CS resulting from the lithology of rocks surrounding coal beds, the chemical composition of mine waters and physicochemical processes occurring in mine-water settling tanks. The CS deposited in a settling tank is exposed to rainwater, which can lead to a change in the content of soluble chemical compounds contained in it. In addition, sulphur found in coal wastes in the form of sulphides, mainly pyrite, as a result of weathering passes into the form of sulphates, which increases the risk of the penetration of sulfuric ions to the soil and water environment, which causes acidification. One of the ways to avoid this phenomenon while using CS for reclamation is to mix CS with fly ashes from coal combustion. These ashes stabilize the reclamation layer, prevent the weathering of sulphides and improve physico-chemical properties of CS in terms of suitability for biological reclamation (Strzyszcz and Łukasik 2008). In addition, the authors have found that vegetation appeared, as a result of natural succession, after about two years in the place of application of CS alone and after just a few months where a mixture of CS with fly ash had been applied. This illustrates the beneficial effect of the presence of CS in the substrate on the growth of vegetation, also in the case of the presence of waste alone in the substrate.

Many mines have problems with storing their wastes. Storage is the least favorable form of disposing of them. Hard-coal mines are changing their approaches to their wastes in accordance with the circular economy philosophy. They are also reducing the nuisance on the environment by, among other strategies, reducing the number of mine-water settlers which occupy significant areas of land; additionally, there is often no possibility for building new settling sites or for increasing the height of those that already exist. For this reason, the periods of storing CSs in settling tanks are increasingly shortened, which makes it necessary to dispose of fresh waste.

The analyses of selected properties of coal sludges were aimed at assessing their properties from the point of view of their re-use for the reclamation of degraded areas, particularly for the formation of surface reclamation layers or for the improvement of native soils before the planting of vegetation. In view of the above, the article presents the results of chemical and phytotoxic tests of CSs stored in settling tanks over different periods. Determining the effect of CSs on the growth of plants makes it possible to assess the feasibility of using this type of waste in reclamation as well as contributing to re-using them in more ways.

1. Materials and research methodology

The subject of the research was waste in the form of coal sludges (CSs) from the treatment of hard-coal mine waters. CS samples were taken from surface settling tanks. One sample (CS1) was collected from waste stored in a settling tank over several years and the other sample (CS2) was collected from fresh waste (stored over several days). In order to determine the feasibility of re-using CS in reclamation as an ingredient of substrates for growing plants, the first step of the study examined their physico-chemical properties and the second step examined their phytotoxicity.

The following properties were tested in the first step:

- Grain composition by means of the sieve analysis.
- Ignition loss in accordance with EN 15169 (Characterization of waste – Determination of loss on ignition in waste, sludge and sediments).
- The content of ingredients potentially harmful to soil by means of digestion in a microwave oven using a mixture of HNO_3/HCl. The resulting solution was analyzed after dilution by the inductively coupled plasma spectrometry/atomic emission spectroscopy (ICP-AES) and the inductively coupled plasma mass spectrometry (ICP-MS) methods.
- Leachability according to the EN 12457-2 standard. Distilled water with a liquid-to-solid ratio (L/S) of 10 was used as the leaching solution. The suspension was agitated in a plastic flask for twenty-four hours, then the mixture was filtered through a 0.45 μm membrane filter. The resulting leachate was analyzed for pH and trace elements using the ICP-AES and the ICP-MS methods. The amount of chlorides was analyzed using the Volhard titration method.

The following properties were tested in the second step:

- The toxicity to garden cress (*Lepidium sativum*) using a standard phytotest. In order to assess the phytotoxicity of the waste, a water extract from the waste was prepared according to the standard procedure (PN-EN 12457-4:2006), then a number of dilutions of the water extract with distilled water were made with concentrations of 100, 50, 25, 12.5 and 6.25%. The control liquid was pure water (0%). Ten garden cress seeds were placed in each of the eighteen petri dishes, then 5 ml triplets of each of the test solutions were added to the dishes (3 × 6). The seeds were incubated at 25°C for 72 hours. After the three days of the test, germinated seeds were counted and the lengths of their roots and shoots were measured. The results were analyzed statistically using the Statistica application.

2. Results and discussion

According to the grain size distribution test (Figure 1), the samples contained mainly sand fractions: CS1 – 96.1%, CS2 – 94.2%. The CS2 sample was finer: the characteristic diameter d50 values were 0.16 mm for CS2 and 0.25 mm for CS1. There were no grains larger than 1 mm in the samples. There was a significant difference in the ignition loss of CS1 – 24.3%, CS2 – as much as 46.1%. This was due to the difference in the content of small grains of coal.

The permissible contents of various substances in soils (at a 0–0.25 m depth range), broken up into soil groups (based on land uses) and soil sub-groups (based on soil properties, set for Group II) are defined in the Regulation of the Minister of Environment of 01/09/2016

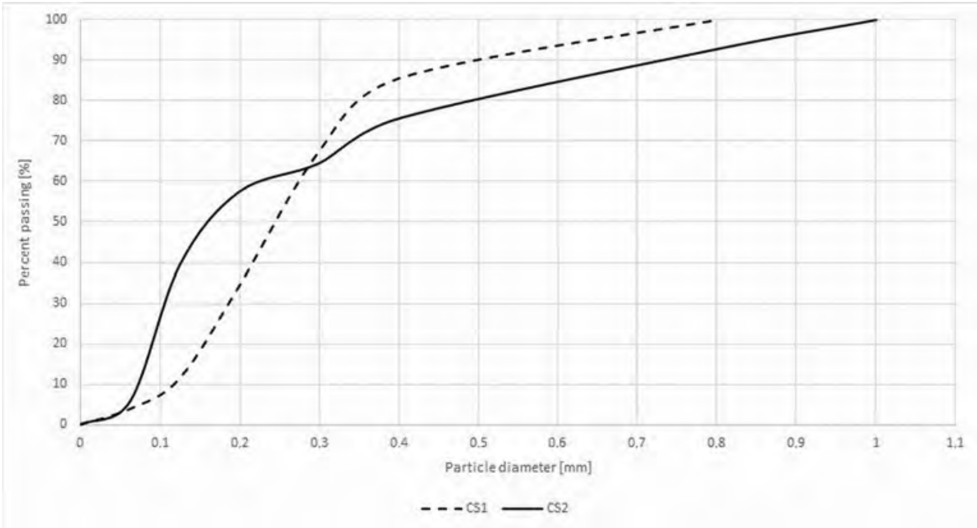

Fig. 1. Grain size distribution curves for CS1 and CS2

Rys. 1. Krzywe składu ziarnowego dla CS1 i CS2

on evaluation of ground surface pollution (Ordinance ME 2016). The contents of hazardous substances in the samples and their limit values are shown in Table 1.

As can be seen, these sludges may not be used in residential, built-up, recreational and sports areas (Group I) and in most agricultural areas (Sub-groups II-1 and II-2). However, they can be used in agricultural areas with medium-density mineral soils with the 0.02 mm grain size fraction content ranging from 20–35% and with a pH_{KCl} value higher than 5.5, as well as in high-density mineral soils with the 0.02 mm grain size fraction content larger than 35% and with the pH_{KCl} value higher than 5.5. Also, these sludges may be used in mineral-organic and organic soils with an organic carbon content larger than 6%, regardless of the pH_{KCl} value. They may also be used in forest areas (Group III) and in industrial or transport areas (Group IV), regardless of the grain composition and soil reaction. The main reason for the restriction is the presence of barium and chromium in quantities exceeding the limits set for Groups I and II of soils. The contents of the individual substances in silts can vary. They are influenced by the amount and chemical composition of mineral substances present in hard-coal deposits (coal quality) and by the chemistry of mine waters. Furthermore, physicochemical processes (such as leaching or weathering) take place during the storage of sludge, which changes their chemical composition.

The average global concentration of barium in hard coal is 50 mg/kg. In Poland, it is about 165 mg/kg (up to 196 mg/kg) but can be much higher (even more than 1,000 mg/kg). Similarly high values were also found in Brazil and Bulgaria (Huidi et al. 2022). In addition, the high concentrations of barium found in the samples are also associated with the occurrence of barium ions in the waters of Polish hard-coal mines. The concentrations of

Table 1. Contents of soil-threatening substances in the samples

Tabela 1. Zawartość substancji w CS stwarzających ryzyko dla ochrony powierzchni ziemi

Substance	Upper limit (mg/kg) according to [1]						Actual content (mg/kg)	
	Group I	Sub-*gr. II-1	Sub-gr. II-2	Sub-gr. II-3	Group III	Group IV	CS1	CS2
Arsenic (As)	25	10	20	50	50	100	11.71	9.31
Barium (Ba)	400	200	400	600	1,000	1,500	573.17	487.00
Chromium (Cr)	200	150	300	500	500	1,000	347.08	227.26
Tin (Sn)	20	10	20	40	100	350	1.34	1.20
Zinc (Zn)	500	300	500	1,000	1,000	2,000	194.07	241.32
Cadmium (Cd)	2	2	3	5	10	15	0.24	0.31
Cobalt (Co)	50	20	30	50	100	200	16.74	5.15
Copper (Cu)	200	100	150	300	300	600	52.18	31.32
Molybdenum (Mo)	50	10	25	50	100	250	1.83	5.23
Nickel (Ni)	150	100	150	300	300	500	54.51	41.64
Lead (Pb)	200	100	250	500	500	600	79.44	152.47
Mercury (Hg)	5	2	4	5	10	30	0.05	0.04

* Subgroups.

the individual ions in mine waters varies depending on the mine and the depth from which these waters are extracted. The authors of the study (Gombert et al. 2019), who analyzed forty-four water samples, report that barium concentrations in mine waters in Poland range from 0.12 to 7.7 mg/l. However, the authors of the study (Chałupnik et al. 2020) report that the concentration of barium in waters rich in this element can be as large as 2 g/l.

The contents of chromium in carbon deposits also affects the presence of this element in the tested samples. The average content of chromium in Polish coals is 23 mg/kg, compared to 11 mg/kg worldwide (Ptak 1997). The concentration of chromium in waters of Polish hard-coal mines ranges from 0.6 to 155 µg/l (18.9 µg/l on average) (Gombert et al. 2019).

Other studies of coal sludge presented in literature (Baic 2013) also mention above-limit metal concentrations in soils. This is the case with barium (333.2–1,123.4 mg/kg of dry weight), zinc (405.9–604.2 mg/kg d.w.), cobalt (20.3–184.0 mg/kg d.w.) and nickel (178.9––156.0 mg/kg d.w.). According to the authors, these excess concentrations are not only due to their presence in the exploited deposits but also to anthropogenic pollution (their presence in the land surrounding the area of the examined deposits).

Another important problem that can arise when re-using waste for reclamation is its impact on the aquatic environment through the dissolution and leaching of substances

Table 2. Leachability of chemicals pollutants from the sludges

Tabela 2. Wymywalność zanieczyszczeń chemicznych z mułów

Indicator or substance type	Actual contents (mg/dm^3)		Upper limits acc. to [2] (mg/dm^3)	Substance type	Actual contents (mg/dm^3)		Upper limits acc. to [2] (mg/dm^3)
	CS11	CS2			CS1	CS2	
Sodium	7.98	6.67	6.5–9.0	Mercury	< 0.0002	< 0.00020	0.03
Potassium	21	3,535	800	Cadmium	0.0001	< 0.00003	0.2
Calcium	8.87	70.49	80	Selenium	< 0.02	< 0.02	1
Magnesium	43.4	215	N/a	Antimony	0.0004	0.00822	0.3
Barium	13.89	210	N/a	Aluminum	0.067	0.00200	3
Manganese	0.024	0.029	N/a	Chromium	0.007	0.00810	0.5
Zinc	0.01	0.003	N/a	Molybdenum	0.001	0.00940	1
Copper	< 0.002	< 0.002	2.0	Titanium	0.033	< 0.005	1
Nickel	0.0006	0.01660	0.5	Arsenic	< 0.0003	0.01500	0.1
Cobalt	0.0041	0.00240	0.5	Chlorides	19.4	5,456.0	1,000
Lead	0.0005	0.00044	1.0	Sulphates	178.9	1,039.0	500
Ołów	0.0003	0.01070	0.5	Sulphides	< 0.05	0.06	0.2

N/a – Not applicable.

contained in the waste. The results of the tests of leachability of the tested sludges are presented in Table 2.

The leachability results were compared with the upper limits of substances that are particularly harmful to the aquatic environment when introduced into soils and/or surface waters (Ordinance MMEIN 2019). The pH value of the water extracts complies with the limits. In the case of biological reclamation, the pH value has a significant impact on the growth, development and yield of plants. The most advantageous level is in the range from slightly acidic to neutral (Boroń et al. 2009). The pH values in the samples are close to neutral. Despite the presence of heavy metals in the samples, their leachability does not pose a threat to the aquatic environment. This is because the metals are chemically bounded and, therefore, sparingly soluble (Baic 2013). The leachability of chlorides and sulphates from the CS1 sample was at a safe level while in the CS2 sample, the limits were exceeded. Undoubtedly, it was the difference between the time spent in the settling tanks (and the leaching by rainwater) that contributed to the significant differences in the amounts of dissolved chlorides and sulphates between samples CS1 and CS2. Chlorine is an element that determines the proper course of photosynthesis and phosphorylysis processes, but it belongs to micronutrients. The adverse effect of Cl- on plants is mainly associated with the disturbance of water and the ionic management of plants (salt stress). The tolerance of plants to the chloride content in the substrate is very diverse. Some cultivated plants, such as tobacco, tomatoes, beets and spinach, do not show signs of toxic effects even at 900–3,500 mg of Cl per dm^3 (Kabata-Pendias 1999). In turn, sulphur is a biogenic element, necessary for the life of plants, drawn exclusively from the soil in the form of dissolved sulphates. Therefore, the studied coal sludges can contribute to the reduction of the sulphur deficit in soil.

The results of the toxicity tests carried out by adding the water extracts from the CS1 and CS2 samples to the seeds of garden cress (*Lepidium sativum*) did not show any adverse effect of the extracts on the germination and early growth of the plant. No inhibition of seed germination was found for any of the tested concentrations of the water extracts from the two samples.

The water extract from the CS1 sample showed no toxic effects at any of the tested concentrations. When comparing the mean values of the shoot and root gains, a slight decrease in the growth of the former was observed for the 6.25% and 50% concentrations compared to the control liquid (0%) (Figure 2). However, after the ANOVA test, it was not found to be a statistically significant decrease. The range of the shoot and root growth values for plants growing on the water extract from the CS1 sample is shown in Figure 4.

The results of the toxicity test showed no statistically significant differences between the length of the roots in the plants exposed to sample CS1 vs. the control plants (Figures 3 and 4). Significant differences only occurred between plants treated with the 6.25% solution and plants treated with the higher concentrations.

The effect of the CS2 sample on the early plant growth was beneficial for most of the tested plants. Significant differences were found in the growth of the shoots compared to the control plant for concentrations ranging from 12.5% to 100% (Figures 5 and 7).

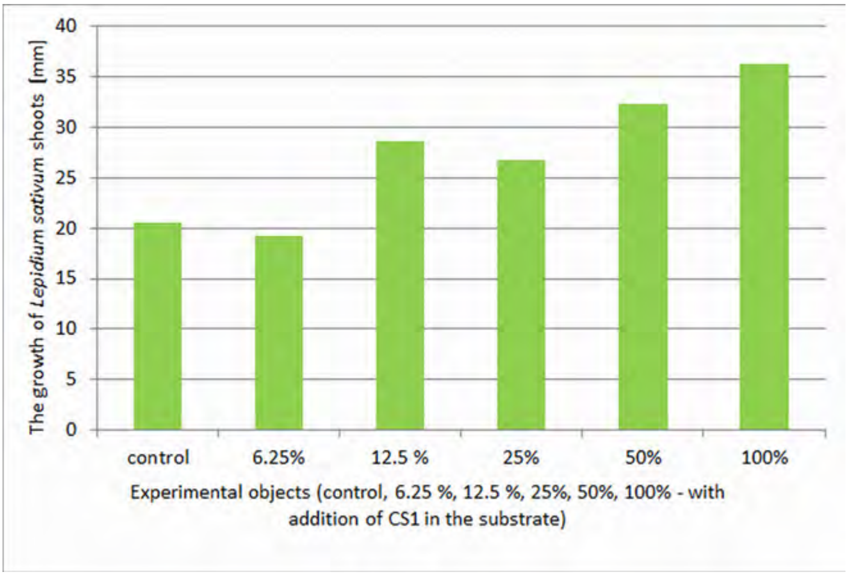

Fig. 2. The growth of *Lepidium sativum* shoots depending on the concentration of the water extract – the test of phytotoxicity of sample CS1

Rys. 2. Wzrost pędów *Lepidium sativum* w zależności od stężenia ekstraktu wodnego – test fitotoksyczności próbki CS1

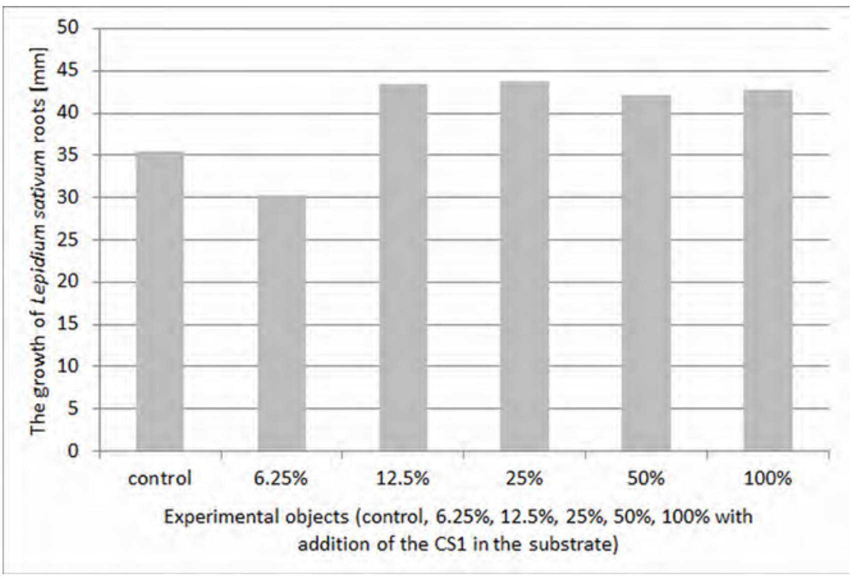

Fig. 3. The plant root growth depending on the concentration of the water extract – sample CS1, the test of phytotoxicity to *Lepidium sativum*

Rys. 3. Wzrost korzeni roślin w zależności od stężenia ekstraktu wodnego – próbka CS1, test fitotoksyczności wobec *Lepidium sativum*

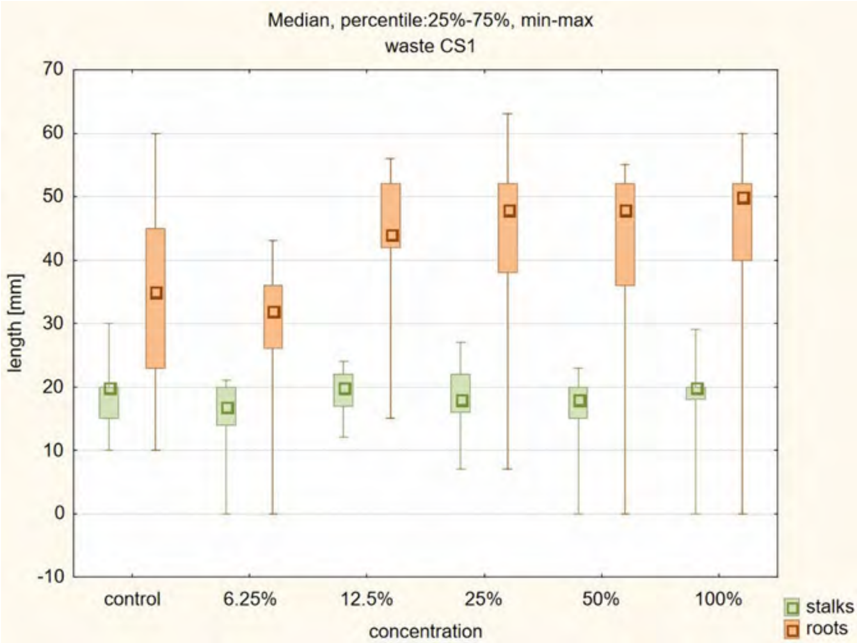

Fig. 4. The ranges of shoot and root growth values for the individual concentrations of the water extracts – sample CS1, the test of phytotoxicityto *Lepidium sativum*

Rys. 4. Przedziały wartości wzrostu pędów i korzeni dla poszczególnych stężeń ekstraktów wodnych – próba CS1, test fitotoksyczności wobec *Lepidium sativum*

Similarly, the assessment of the elongation of the plant roots showed no toxic effect. The 50% concentration had a beneficial effect on the growth of the roots compared to the control plant (the difference in the root length in both trials is statistically significant). The 100% concentration of the water extract from the CS2 inhibited the root growth when compared to the 50% concentration, but the result was comparable to that for the control plant and for the plants treated with concentrations ranging from 6.25% to 25% (Figure 6). The range of the shoot and root growth gains is shown in Figure 7.

Comparing the growth shoot increments in the plants treated with the same concentrations of the two samples (CS1 and CS2), it was found that, starting from the 12.5% concentration, these increments were higher for the plants exposed to the CS2 sample. This observation is confirmed by the results of the ANOVA analysis. This effect was not observed for the roots. Their lengths in the plants treated with the same concentrations of CS1 and CS2 did not show significant differences. The results of the ANOVA analysis are shown in Figure 8.

The phytotoxicity analysis shows that none of the tested wastes had phytotoxic properties. In addition, sample CS2 stimulated the growth of shoots more than the CS1 sample, despite the high concentration of sulphates and chlorides in the former. This effect can be

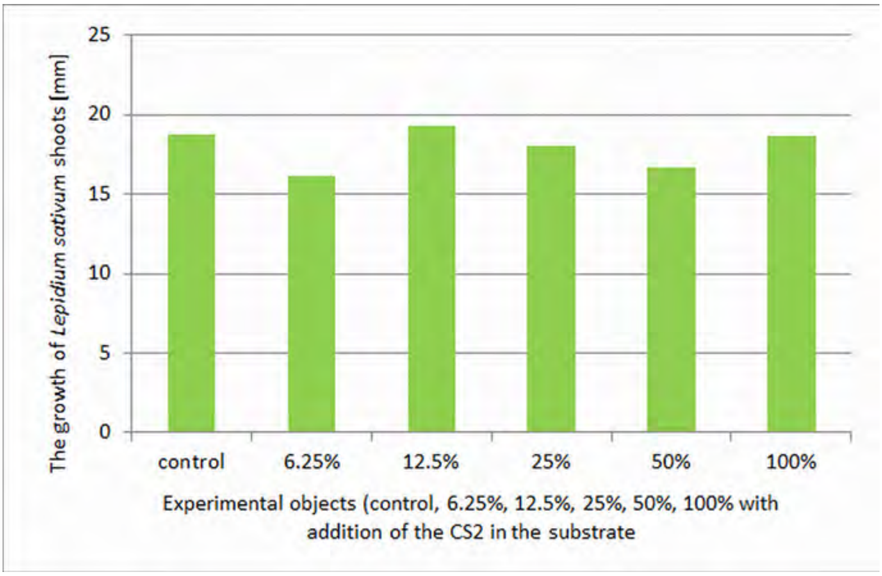

Fig. 5. The shoot growth depending on the concentration of the water extract – sample CS2, the test of phytotoxicity to *Lepidium sativum*

Rys. 5. Wzrost pędów w zależności od stężenia ekstraktu wodnego – próba CS2, test fitotoksyczności wobec *Lepidium sativum*

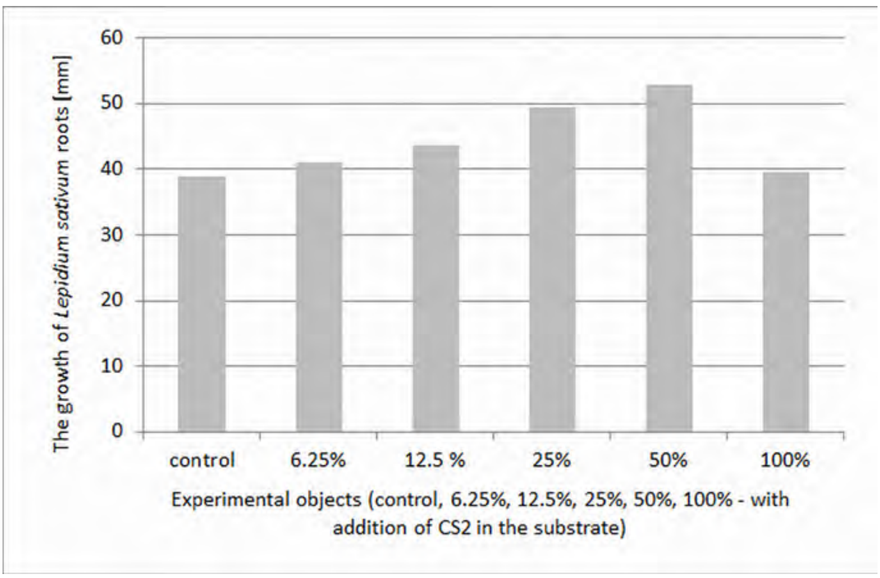

Fig. 6. The root growth depending on the concentration of the water extract – sample CS2, the test of phytotoxicity to *Lepidium sativum*

Rys. 6. Wzrost korzeni w zależności od stężenia ekstraktu wodnego – próbka CS2, test fitotoksyczności wobec *Lepidium sativum*

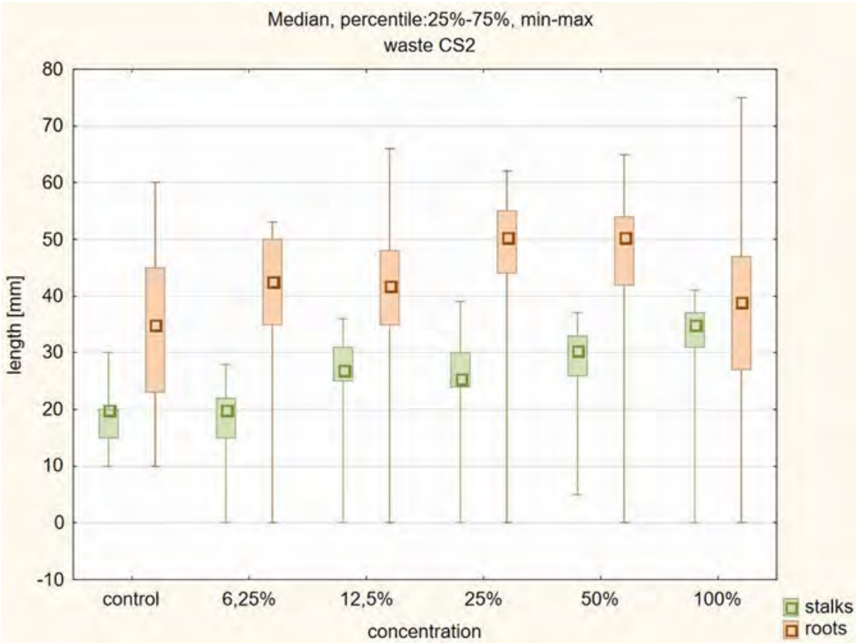

Fig. 7. The range of the shoot and root growth gains for the individual concentrations of the water extracts – sample CS2, the test of phytotoxicity to *Lepidium sativum*

Rys. 7. Zakres przyrostów pędów i korzeni dla poszczególnych stężeń ekstraktów wodnych – próba CS2, test fitotoksyczności wobec *Lepidium sativum*

explained by the higher concentrations of macro-nutrients (calcium, potassium and magnesium) in CS2 and in its water extract. These elements are the basic ingredients of mineral fertilizers. Also, the water extracts from CS2 had higher concentrations of copper and molybdenum – the micro-nutrients which are also contained in mineral fertilizers.

Conclusion

The purpose of using the tested wastes in reclamation works is to form substrates favoring the growth of desirable vegetation by providing necessary nutrients, by structuring soils or by adjusting the pH values. Such wastes introduced to the environment should not contain any substances that could adversely affect the condition of the soil and water environments or living organisms occurring in the habitats involved. It is therefore important to determine the contents of substances which can present such a risk and to assess the toxicity of wastes to living organisms.

The tests of the chemical composition of the wastes have shown increased concentrations of barium and chromium in both sludge samples, which means that they may not be used

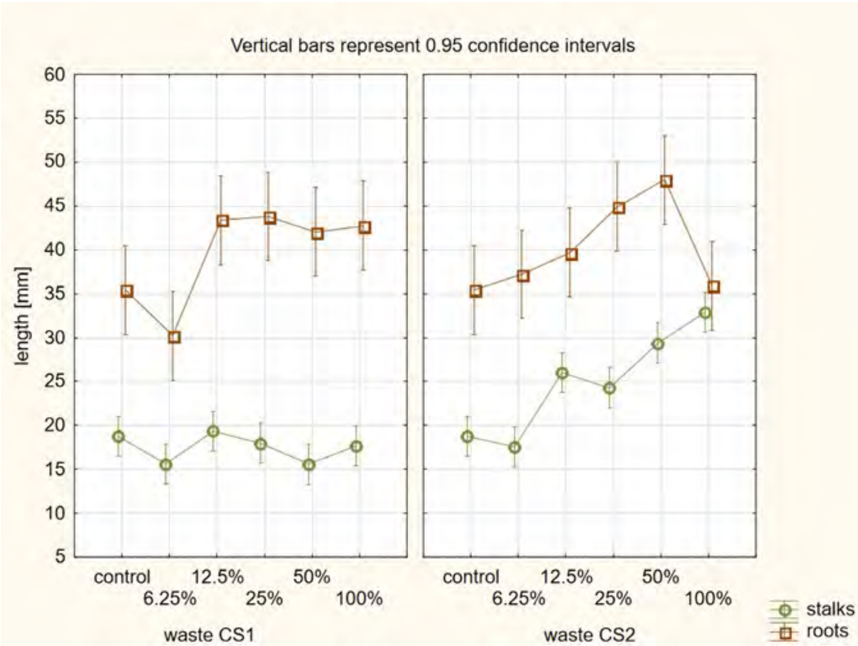

Fig. 8. The variability of the shoot and root lengths for the individual concentrations of the water extracts – samples CS1 and CS2, the tests of phytotoxicity to *Lepidium sativum*

Rys. 8. Zmienność długości pędów i korzeni dla poszczególnych stężeń ekstraktów wodnych – próbki CS1 i CS2, testy fitotoksyczności wobec *Lepidium sativum*

in residential, built-up, recreational or sports areas and in most agricultural areas. However, they can be used in forest, industrial and transportation areas.

The tests of leachability of the sludges have shown that, despite the high concentrations of metals, only small amounts of them pass into the solution. The pH is close to neutral. In this respect, therefore, they do not pose a threat to the environment. The CS2 waste was stored in its settling tank for a shorter time and has been leached to a lesser extent by rainwater than the CS1 waste, thus there are higher concentrations of chloride and sulphate ions in the former. They exceed the limits set for waste water discharged into watercourses or into the ground. The tests of phytotoxicity to *Lepidium Sativum* did not show a toxic effect at any concentration of water extracts from the CS1 and CS2 samples. It was also found that CS2 stimulated the shoot growth at water-extract concentrations starting from 12.5% and the root growth at the 50% concentration, which could be due to the higher concentrations of calcium, potassium and magnesium ions, i.e. fertilizer ingredients needed by plants to grow.

Taking into account the foregoing results, it can be concluded that the tested coal sludges may be used for reclamation work for the formation of plant coverage. Due to the risk of excessive penetration of sulphates and chlorides into the soil and water environments, it is necessary to apply correct amounts of the wastes. This is especially true for coal sludges which have never been stored in mine-water settling tanks. Since the properties of sludges can vary, depending on the characteristics of coal deposits, analyses similar to the ones described in this article should be carried out to determine the suitability of waste from sources other than those discussed. Due to the increased chloride content in the CS2 sample, the authors also recommend carrying out laboratory experiments on plant species selected for introduction into areas to be reclaimed or the use of species more tolerant to the chloride content in the substrate.

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Analysis of the properties of coal sludge in the context of the possibility of using it in biological reclamation

Keywords

waste management, phytotoxicity, biotests, coal sludge, reclamation

Abstract

The mining industry, including hard-coal mining, has a significant and multifaceted impact on all components of the environment. One of the factors is the production of various types of waste which, due to their physico-chemical and ecotoxic properties, do not always pose a threat to the environment and can be used in various ways. Such treatment of waste perfectly fits into the concept of the circular economy through the protection of natural resources and the maximum re-use of waste. One of the wastes generated by hard-coal mines is coal sludge from the purification of underground water in surface settling tanks. The article presents the results of research on the physico-chemical and phytotoxic properties of carbon sludges from two settling tanks with regard to assessing the possibility of their re-use in the reclamation of degraded areas. These sludges contain mainly sand fractions. An analysis of their chemical composition revealed the presence of heavy metals. Leachability studies have shown that despite the high concentrations of metals, a small quantity of these metals passes into the solution. In this respect, therefore, they do not pose a threat to the environment. However, a threat may result from the presence of chlorides and sulphates, the amounts of which are influenced by, among other factors, the time of waste storage in the settling tank. Phytotoxicity tests performed on garden cress (*Lepidium sativum*) did not show a toxic effect at any concentration of the water extract. In addition, for one of the sludges, water extracts with concentrations starting from 12.5 and 50% stimulated the growth of the plant's shoots and roots, respectively. The results show that the tested coal sludges may be used in appropriate doses for reclamation work, for example, when establishing a plant cover.

Analiza właściwości mułów węglowych pod kątem możliwości ich wykorzystania w rekultywacji biologicznej

Słowa kluczowe

muły węglowe, gospodarka odpadami, fitotoksyczność, biotesty, rekultyacja

Streszczenie

Przemysł wydobywczy, w tym górnictwo węgla kamiennego, oddziałuje istotnie i wielokierunkowo na wszystkie składowe środowiska. Jednym z problemów jest wytwarzanie rożnego rodzaju odpadów, które ze względu na swoje właściwości fizykochemiczne oraz ekotoksyczne nie zawsze stanowią zagrożenie dla środowiska i mogą być w różny sposób wykorzystane, np. w budownictwie, drogownictwie, przemyśle energetycznym, górnictwie, a także zagospodarowane przyrodniczo

i w rolnictwie. Takie postępowanie z odpadami doskonale wpisuje się w koncepcję gospodarki obiegu zamkniętego, poprzez ochronę surowców naturalnych oraz maksymalne wykorzystanie powstających odpadów. Jednym z odpadów górnictwa węgla kamiennego są muły węglowe pochodzące z oczyszczania wód dołowych w powierzchniowych osadnikach.

W artykule przedstawiono wyniki badań właściwości fizykochemicznych oraz fitotoksycznych mułów węglowych pochodzących z dwóch osadników, pod kątem oceny możliwości ich wykorzystania w rekultywacji terenów zdegradowanych. Muły zawierają głównie frakcję piaskową. Analiza składu chemicznego wskazała obecność w odpadach metali ciężkich. Ze względu na ochronę gleb, wysokie zawartości baru i chromu ograniczają możliwość wykorzystania tego odpadu do terenów przemysłowych i komunikacyjnych. Badania wymywalności wykazały, że pomimo wysokich stężeń metali, do roztworu przechodzi ich niewielka ilość. Pod tym względem nie stanowią więc zagrożenia dla środowiska. Z kolei zagrożenie może wynikać z obecności chlorków oraz siarczanów, a na ich ilość wpływa m.in. czas składowania odpadu w osadniku. Wykonane testy fitotoksyczności względem *Lepidium Sativum* nie wykazały efektu toksycznego przy żadnym stężeniu wyciągu wodnego. Ponadto, w przypadku jednego z badanych odpadów, stwierdzono działanie stymulujące wzrost pędów oraz korzeni, przy stężeniach wyciągu wodnego od 12,5 do 50%. Uzyskane wyniki wskazują, że badane muły węglowe mogą być stosowane w odpowiedniej dawce do prac rekultywacyjnych, np. przy tworzeniu okrywy roślinnej.