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Suitability Evaluation of Ash-And-Slag Waste from Coal Power Plants as Soil Components

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Abstract

The chemical and fractional composition of ash-and-slag waste and fly ash materials of three large combined heat and power plants in Central Russia was compared in this study to assess their influence on the germination of oats as an indicator of the phytotoxic effect of these materials as soil components. It was found that these materials have an acceptable chemical composition from the viewpoint of their release into the environment, but there are factors such as fractional composition that significantly affect the growth and the development of plants when using these materials as soil components during soil reclamation.

Keywords: Ash-And-Slag waste, coal fly ash, Chemical and fractional composition

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1. Introduction

The problem of disposal and safe use power plants waste, especially coal-fuelled, is quite relevant worldwide. Globally, ash and slag waste (ASW) in general and fly ash (FA) in particular generated in large quantities from coal power plants is serious solid waste. The current world annual production of fly ash from coal combustion is about 600 million tons (in the 2000s), which is 75–80% of the total FA production. And only *ca.* 10% of this production is processed worldwide [1]. The remaining amounts are disposed of or not processed at all, which is an economical problem due to high costs and environmental risks such as leaching, which leads to significant pollution of natural waters, soils, and the atmosphere. In the US and EU, FA is not classified as a hazardous waste, since coal FA and other coal by-products do not exhibit such characteristics of hazardous waste as corrosivity, radiation hazard, flammability, and toxicity [2]. This allowed the widespread use of FA in construction industry (e.g., the production of cement, concrete, embankments, and other structural aggregates and bricks). In addition, coal FA is usually used for geotechnical (soil stabilization or road construction) and land reclamation (quarries and pits). However, there are no clear rules, specifications, or guidelines for FA use in remediation and agriculture, even in the US. For example, some US states regulate the use of ASWs, but their principles differ from state to state. Such a lack of standards or guidelines is one of the main barriers to the use of coal-fired power plants to improve soils [3, 4].

Russia has a huge reserve of coal and developed coal-consuming industry. Nevertheless, despite the world and domestic practice of using ASW as soil components, there is almost no research on the actual degree of ASW environmental impact in Russia. The situation is complicated by the fact that the chemical and physical properties of coal ASW significantly depend on both the feedstock and combustion technology. The aim of this study is to determine the chemical and fractional composition of ash and to assess their influence on the germination of the test culture of oats as an indicator of the phytotoxic effect of ASW as soil components.

2. Results and Discussion

A comparison was made of the chemical composition of ASW materials of three large combined heat and power (CHP) plants in Central Russia. A mixture of bottom ash and FA was obtained from two power plants as their technological processes do not provide for the separate removal of these wastes; from the third CHP, only FA was used. From this point on, they are designated as CHP 1, 2, and 3, respectively.

Alkaline fusion with lithium metaborate was used to determine the bulk macroelement composition, and micronutrients were determined by treatment with nitric acid and a mixture of nitric and hydrofluoric acids under pressure in Teflon autoclaves under microwave heating in a Milestone Ultraclave furnace. The solutions obtained by various decomposition methods were analyzed by inductively coupled plasma atomic emission spectrometry (ICP–AES) on an Agilent ICP-AES 720ES spectrometer. The bulk compositions are shown in Figure 1.

It was found that the investigated ASW consist mainly of Al, Ca, Si, Fe, K, Mg, Na, P, and S and do not differ significantly by its composition. In fact, we did not find a significant difference between ASW and FA. The bulk contents of trace elements, including hazardous As, Pb, Cd, and others, are within the ranges typical of soils and do not significantly exceed their natural contents.

Analysis of the mineralogical composition of the ASW material was carried out on a Rigaku Rotaflex D/MAX-RC X-ray diffractometer with a copper tube. Comparison of the obtained diffraction patterns, Figure 2, revealed a high similarity in the mineralogical composition of ASW samples. The main crystalline phases are quartz, hematite, and

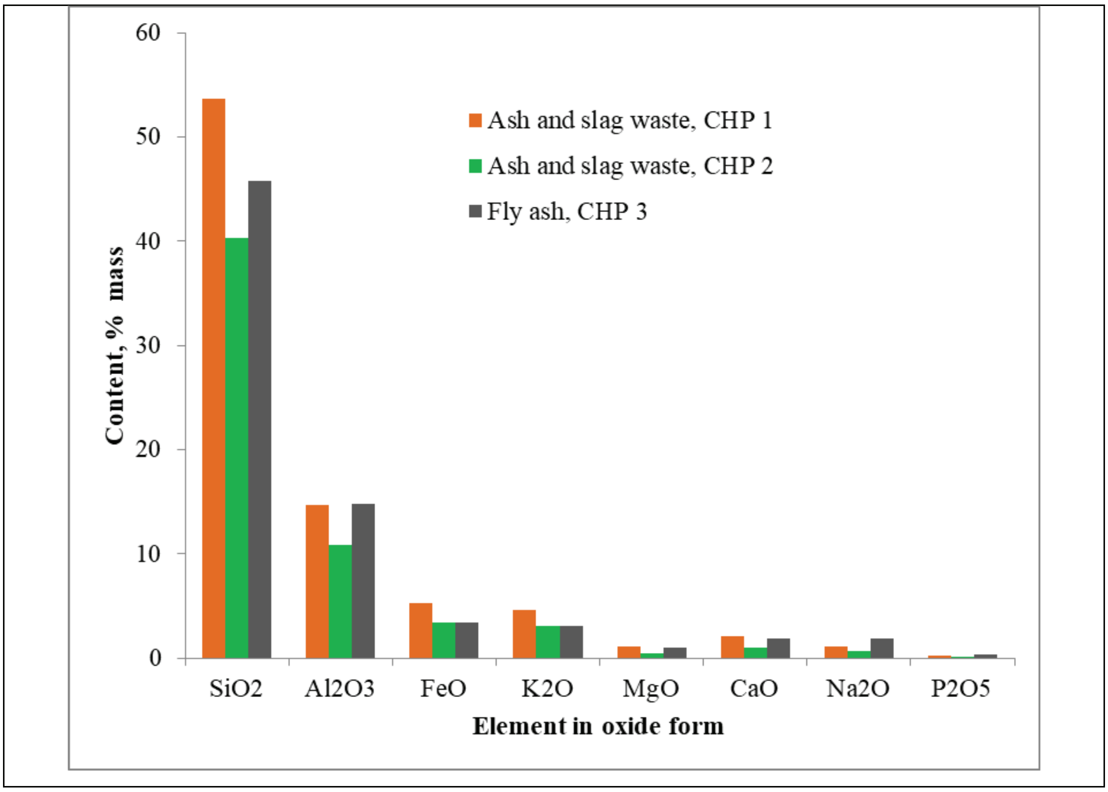

Figure 1: The content of macronutrients in samples of ash and slag materials.

pinakiolite. In FA of CHP 3, a high content of aluminum borate is noted. Calcite is determined in the composition of the ash of CHP 2.

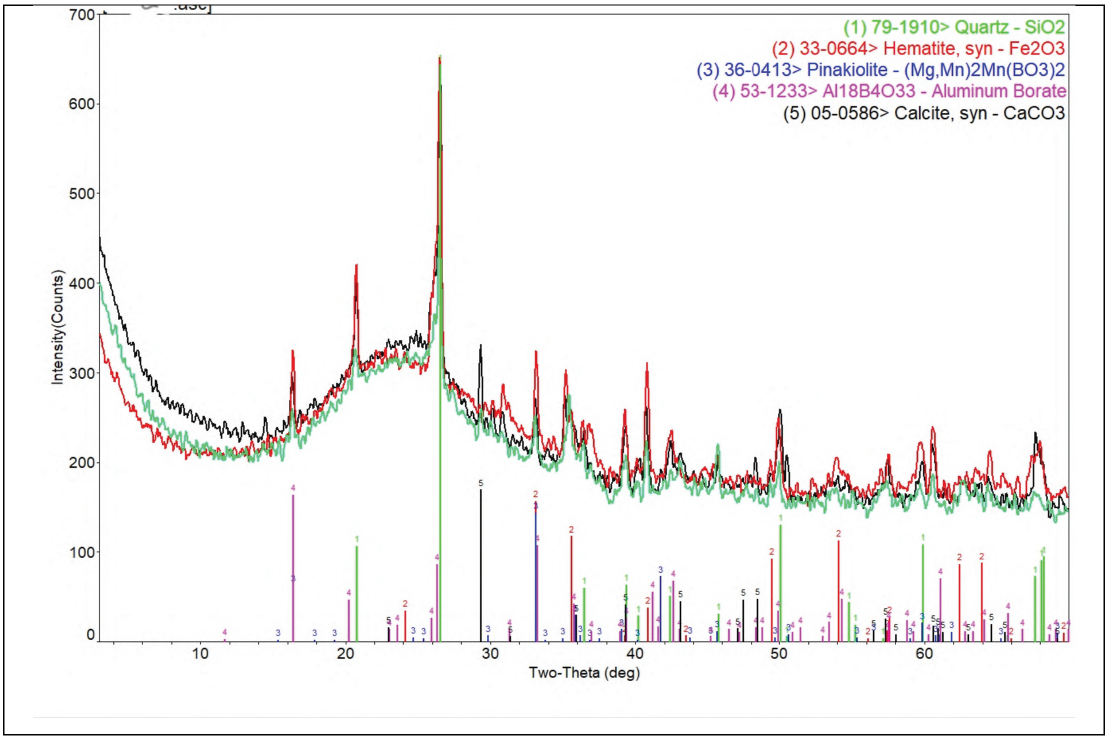

Figure 2: Diffraction patterns of ASW samples from three studied power plants

The fractional composition of the samples was determined by dry scattering using a Retsch AS200 control scattering machine and Retsch control sieves. For sieving, 1 kg of an ASW sample was used, which was taken by the quartering method to obtain a representative sample. The follolwing fractions were isolated and then analyzed: less than 0.05 mm; 0.05–0.1 mm; 0.1–0.25 mm; 0.25–0.5 mm; 0.5–1 mm; 1-2 mm; 2–5 mm; more than 5 mm.

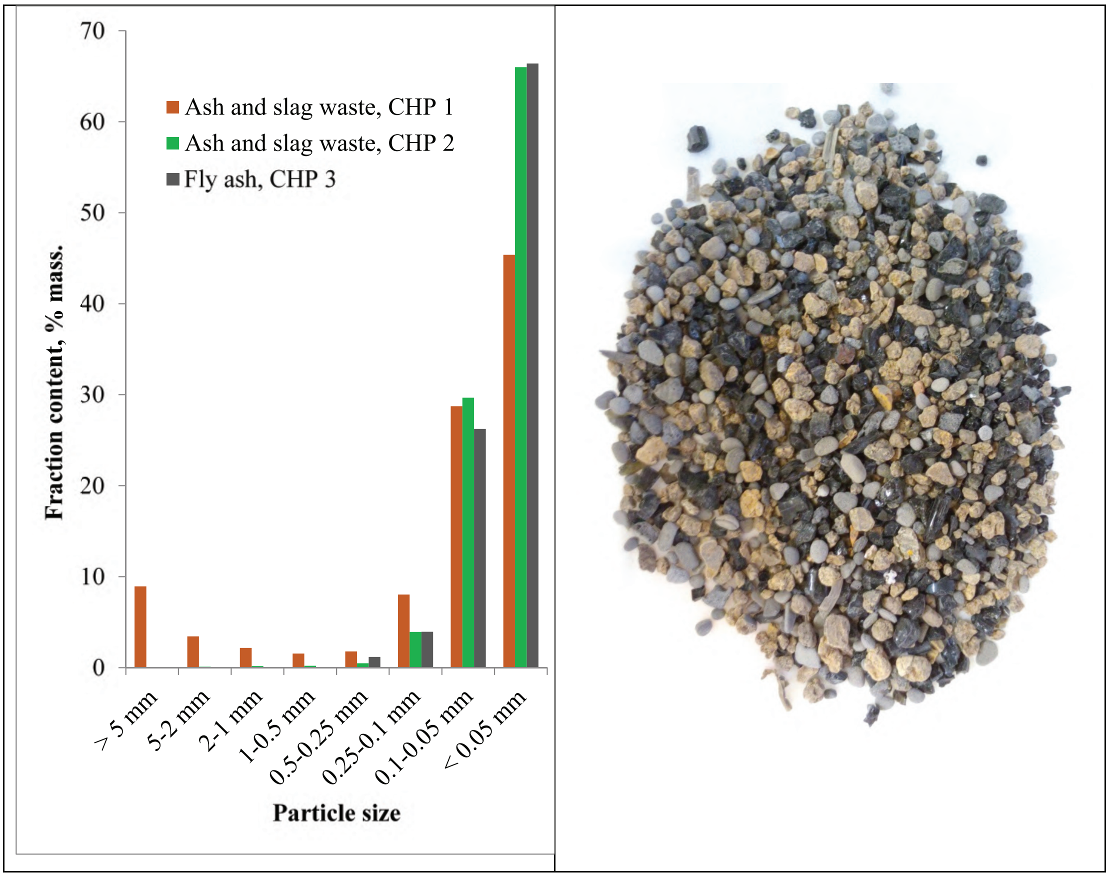

Figure 3: The fractional composition of the samples (left) and the fraction of 2–5 mm of the ash and slag sample of CHP 1 (right).

ASW samples showed a similar fractional composition; however, the ASW from CHP 1 contained significant amounts of large particles. The 2–5 mm fraction of the sample of the ash-and-slag plant of CHP 1 is shown in Figure 3 on the right. This is a heterogeneous mixture of various particles, apparently differing in their phase composition.

Evaluation of the phytotoxic effect of ASW was based on determining the energy and ability of grain germination (oats were selected as a test culture) according to the method described in GOST 10968-88 Russian State Standard. Four replicates experiments were made for each ASW sample; calcined quartz sand and a paper filter were used as controls. The substrates were moistened with distilled water. Figure 4 shows photographs of two Petri dishes with samples of ASW and fly ash.

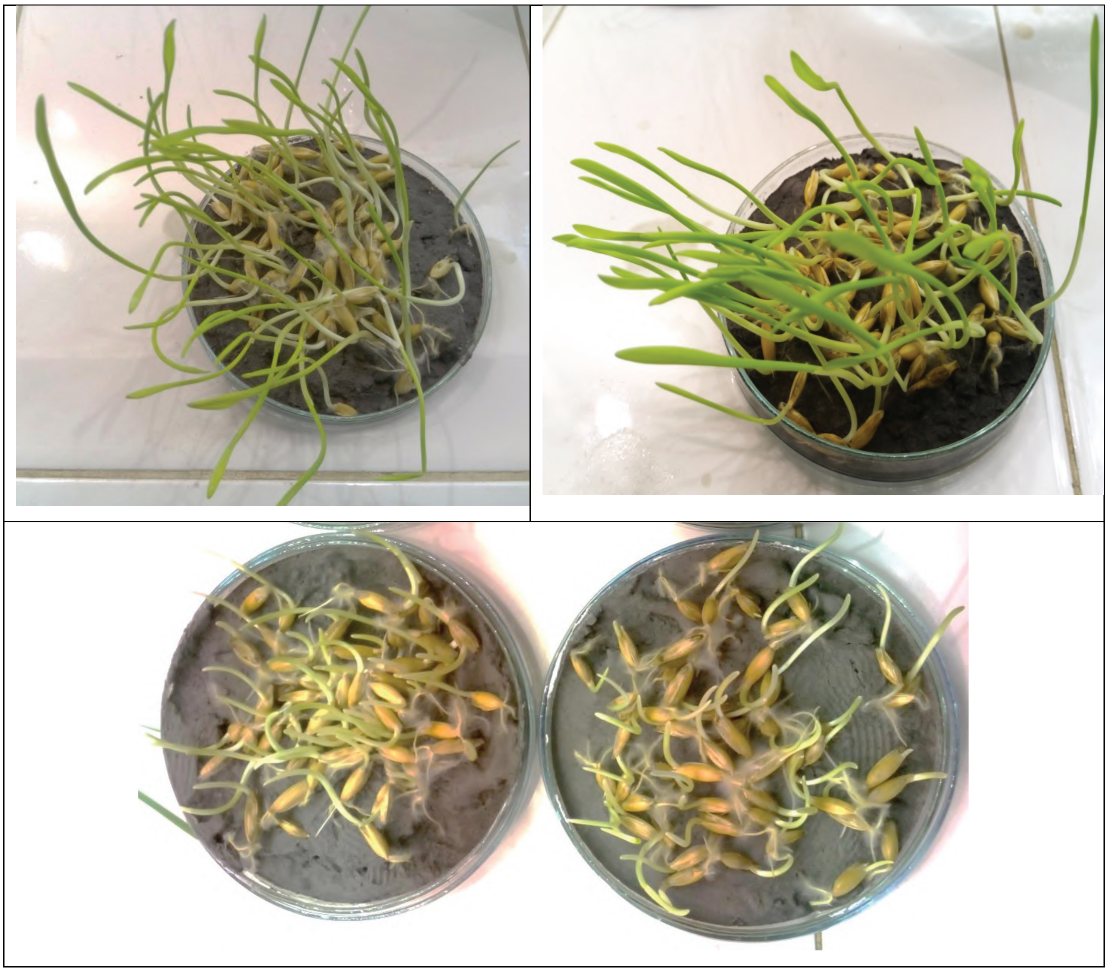

Figure 4: Type of oat seeds on day 7 of germination experiments for the ash and slag sample of Power Plant 1 (top) and fly ash of Power Plant 3 (bottom).

A comparison of the growth of plants on the day 7 of germination shows that ASW and FA have a completely different effects despite the similarity of the macrocomponent composition, the absence of significant amounts of hazardous elements in the samples, and the presence of large amounts of nutrients such as potassium and phosphorus. Calculation of the length of the roots and coleoptiles showed that in the case of fly ash, these parameters are 3.5-fold lower than in the case of ASW of CHP 1; 2.5-fold lower in the case of the ASW sample of CHP 2; and twofold lower than in quartz sand. Apparently, the inhibition occurs due to insufficient aeration in an overly densified substrate, consisting of the finest particles, in the case of fly ash.

3. Conclusions

Thus, the studied samples of the ASW material have an acceptable chemical composition from the viewpoint of their release into the environment. However, there are also factors such as fractional composition, and possibly other factors that significantly affect the growth and the development of plants when using ASW as soil components during reclamation or construction works, which requires continued work in this direction.

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