Ecological foundations for use of mining and metallurgical industry slags in fields of Western Siberia

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Abstract. The mining and metallurgical industry annually accumulates millions of tons of solid waste, which is stored in technological dumps in the immediate vicinity of enterprises. Under the influence of rain and wind, waste can cause environmental degradation in the region. Therefore, at present, we are actively looking for the possibility of their secondary use or efficient disposal. Metallurgical slag in its chemical composition is considered a universal fertilizer for agriculture. The content of calcium and magnesium in it can reach 65%, which is enough for effective liming of acidic soils, the area of which in Russia reaches 65 million hectares, and in the South of the Tyumen region – 3.4 million hectares. Slag does not have hygroscopicity and caking, which makes it possible to make it effectively in the fields. The high content of phosphorus makes it an attractive phosphate fertilizer for farmers, the cost of which is 5 times lower than phosphate flour or simple superphosphate. Scientifically based introduction of slag in the fields of Siberia can significantly reduce the amount of waste from mining and metallurgical industry without deterioration of the ecological state of the territory. A thorough chemical analysis of each batch for heavy metal content is required before solid industrial waste is used. Slag that does not meet environmental requirements must be disposed of in another way.

1. Introduction. Mining and metallurgical industries are characterized by a large number of technological wastes, which, possessing a certain economic value, are usually stored in dumps [1]. In the smelting of iron and steel, it accounts for up to 80% of slags, consisting of waste ore, fluxes, fuel ash and oxidation products of related impurities. Up to 0.7 tons of slag is formed for smelting 1 ton of pig iron. Currently, more than 400 million tons of wastes from the metallurgical industry are concentrated in slag dumps of Russia. The area under them is 2.5 thousand hectares [2]. Usually the dumps are in close proximity to the steel mills and take up valuable land. Being in the open air, dumps are washed annually by precipitation, thereby negatively influence ecosystems of the rivers and reservoirs [3]. In recent decades, hydro-ecologists have repeatedly drawn attention to the fact that in regions with developed mining and metallurgical industries, the chemical composition of sediments and floodplain soils has changed significantly. Also dumps are often exposed to swelling with the wind, because the composition of the waste has rather high content of dust particles with low density. Air flows carry small fractions of slag and can worsen the ecological situation of the entire region. The absence of systematic utilization of mining and metallurgical industry waste forms a high environmental burden on environmental objects [4]. This does not comply with the principles of
sustainable development and requires compliance with environmental requirements when placing non-
recycled residues.

Metallurgical slag has valuable properties from an agronomic point of view. Their use in the fields
has become one of the directions of slag utilization. At the same time, environmental and economic
problems for the metallurgical and mining industries are solved: waste is sold, not placed in dumps
around enterprises. For agriculture, this can also be beneficial, since the cost of slag waste is much
lower than the currently used fertilizers and improvers.

2. Materials and methods. Agroecological substantiation of slag waste use in the fields of Western
Siberia was carried out on the basis of the analysis of long-term studies of the state agrarian University
of Northern Trans-Ural and annual reports of agrochemical services. Data on the chemical
composition of metallurgical slag were obtained from open sources published in peer-reviewed
journals.

3. Results and discussion. Western Siberia is considered to be potentially favorable for agriculture.
The development of new agricultural technologies, the creation of varieties and hybrids of crops that
can grow in adverse soil and climatic conditions, make it possible to obtain crops even in the taiga
zone. However, there is a problem of low fertility of Siberian soils, as they were mainly formed in the
humid zone and under forests. Therefore, the main areas of agricultural land in Western Siberia are
characterized by high acidity and low nutrient reserves. In Russia, the area of acid soils is 65 million
hectares, and in the Tyumen region, 57% of agricultural land belongs to the needy in liming soils.
Podzolic and gray forest soils are the most acidic in the Tyumen region. Their total area is 3435
thousand hectares (Fig.1).

Numerous agrochemical studies have shown that on acidic soils the efficiency of mineral fertilizers
is reduced by 30-40%, so the shortage of the crop can be from 16 to 18 million tons of conditional
grain. By 2020, the shortage of products can reach 20 million tons, if you do not take any action.

![Figure 1. The area of the main soils in the agricultural zone of the Tyumen region, thousand hectares](image)

Liming eliminates harmful to the crop plants soil acidity and enriches it with calcium; it has a
positive effect on agro-physical and physico-chemical properties of soils [5]. The main materials for
the neutralization of acidity in soils are ground limestone and dolomite. In Western Siberia and in the
Tyumen region in particular, there is an acute shortage of calcareous fertilizers. We can use slag to
cover it, which is produced in large quantities by the metallurgical industry. For liming of acidic soils, it is necessary to apply slags which contain not less than 45% of calcium and magnesium. The composition of open-hearth and Converter slag after removal of iron residues contains up to 50% calcium oxide and 12% magnesium (Fig. 1). From an agronomic point of view, blast-furnace slags are not inferior to limestone flour by the sum of calcium and magnesium oxide, they are quite sufficient for effective neutralization of acidity in Siberian soils.

Liming is usually carried out once every 5-10 years because meliorate dissolves very slowly, thereby not having a negative effect on plants. During this time, large fractions of slag have time to decompose. Therefore, the presence of large fractions in calcareous fertilizers is allowed, which reduces their cost. Lime and dolomite flour in agriculture come in the form of fine powder, which is quite difficult to make in the field, because it requires special machines. Industrial fine slag is recommended to granulate or use large fractions of sizes from 3 to 10 mm. Porous fine granular slag favorably differs from slag and lime flour by the fact that this material does not dust, is not subjected to caking, can be introduced into the soil both in winter and in summer conditions. In addition, the cost of 1 ton of granular slag is much lower than the cost of 1 ton of lime flour.

The value of slag from the agronomic point of view is that in addition to calcium and magnesium, it contains phosphorus [6]. Numerous studies conducted in both Russia and foreign countries have shown that the waste of mining and metallurgical industries is similar in efficiency to a simple superphosphate or phosphorite flour. Phosphate slag, being a waste of production, has a significantly smaller cost, 3-8 times, compared to the superphosphate. Unlike conventional phosphate fertilizers, slag is not hygroscopic and is not baked, so it is easy to store and transport to the fields.

The compositions of the final slag of metallurgical production differ from each other [7]. Therefore, it is necessary to provide for a systematic analysis of the chemical composition of each batch. This will make it possible for agronomists to accurately calculate the elements entering the soil and balance the nutrition system for each culture. Figure 2 shows the average chemical composition of the elements required for efficient field use.

In appearance, the phosphate slag is a heavy almost black powder. Phosphoric acid is in the form of tetracalcium phosphate or silicone carnallite, which are insoluble in water, but rapidly decompose into a weak acid solution, forming a three-substituted calcium phosphate. The phosphorus content in these slags varies in the range of 14 to 20%. In addition to phosphorus, phosphate slag includes silicon, calcium, magnesium, iron, aluminum, manganese and some trace elements. To apply such slag is recommended for forest gray and podzolic soils, as they initially have acidic reactions and are able to quickly transform the phosphorus into plant-available compounds. Its application on Chernozem soils is not recommended due to the long period of transition of phosphorus to plant-accessible compounds. Since phosphate slag is insoluble in water, it is necessary to bring deep plowing in large doses, spreading it over the surface or shallow incorporation into the soil has no effect. The rate of absorption of phosphorus from slag will be influenced by grinding. Therefore, it is better to grind individual batches that are supposed to be applied as phosphoric fertilizers to particle sizes no more than 0.2 mm.

Figure 2. The chemical composition of the slag in metallurgical industry (average data), %

- CaO 53%
- SiO2 15%
- Al2O3 2%
- MgO 12%
- MnO 4%
- Fe3O4 14%
- Others 1%
Metallurgical slags are not recommended to be used simultaneously with ammonia fertilizers, because there are gaseous nitrogen losses due to the presence of free calcium oxide. Also, they cannot be mixed with potash fertilizers, because there is the formation of fast-hardening magnesia cement.

In addition to the basic batteries, slag has a number of important trace elements. It is not so important for soils of the Chernozem range, in which there is always enough of them. However, on sandy soils, metallurgical slag can significantly improve the availability of arable land trace elements. Also, the deficiency of trace elements is present in drained peatlands, since they almost completely consist of plant residues [8]. Previously, the problem of trace elements in the sands and peatlands was solved quite simply: phosphorite flour and superphosphates, being crushed apatite or phosphorite, initially contained trace elements in themselves. Currently, synthetic fertilizers are used in agriculture, in which there are no trace elements. Therefore, in recent years, the fields began to show signs of micronutrient starvation.

Introduction of metallurgical slag allows solving three problems of soil fertility, which are considered to be the most important in Siberia: the fight against acidity; increasing the availability of phosphorus arable land; creating a deficient balance of trace elements. To obtain the maximum effect, the slag must be scented, not scattered over the surface and, moreover, not applied to the snow, as recommended by individual researchers. Since the nutrients contained in the slag are insoluble in water, they will lie unclaimed on the soil surface or can be washed off from the field in the nearest water bodies. For the same reason, it is useless to use metallurgical slag in fields with perennial grasses. Plowing is better to conduct in a steam box, in combination with organic fertilizers or other improvers.

In recent decades, humankind has faced another problem—the creation of artificial soil rehabilitation. Active extraction of natural hydrocarbons has led to the fact that the vegetation layer has been destroyed [9]. Reclamation by regular sowing of perennial grasses is impossible because there is no fertile soil layer. Therefore, during restoration works, peat-sand mixture is usually used [10, 11]. However, as practice shows, it is far from perfect. This mixture is very often characterized by high acidity and nutrient imbalance. When creating artificial soil-mix, you can use the waste from the mining and metallurgical industry, because they have a favorable chemical composition. Most interesting in this case is phosphate slag, which provides plants with phosphorus, potassium and trace elements for a very long period, and it will support the acid-base characteristics of soils within the optimum. When using slag as an ingredient of artificial soil mixture, granulation is no longer required, which will favorably affect the cost of production.

The only condition for the usage of wastes of mining and metallurgical industry in agriculture is the lack or low content of heavy metals that can cause serious damage not only to plants, but also to humans [14, 15]. Therefore, every batch of slag leaving industrial waste dumps must be thoroughly inspected and, if there is a threat of heavy metal contamination, it must be disposed of in some other way.

**Conclusion.**
Currently the mining and metallurgical industry in Russia uses old technologies, in which a huge amount of waste is generated, accumulating around the plants. The presence of slag in the open air and its high concentration on a small area leads to disruption of the ecological balance of the region. Therefore, one of the ways of recycling slag is its use in agriculture. Carefully tested raw materials for the absence of heavy metals and other harmful substances, can be used as a liming material to neutralize acidity of soils of Siberia. The content of calcium and magnesium on average can reach 65% by weight, which is comparable to calcareous fertilizers. Thus, the slag does not possess the disadvantages inherent to improvers – high hygroscopicity and caking. Having a high content of phosphates, iron and steel slag can be fully used instead of phosphate or ordinary superphosphate. The price of 1 ton of slag in this case will be 5 times less. The presence of trace elements allows us to assert that the slag is treated as a complex fertilizer, which can be effective on sandy soils and peat...
bogs. Favorable granulometric and chemical composition makes slag a potentially promising ingredient in the creation of artificial soils for the reclamation of man-made disturbed areas.

The use of mining and metallurgical waste in agriculture should be carried out only with a scientifically based recycling system in the fields so as not to cause deterioration of fertility and violation of the ecological situation of the territory.

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