Ecologically safe device technologies of road covering with the use of technogenic materials

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Abstract. The influence of nepheline sludge on the soil of a roadside strip when used in the device of road coverings is studied. Chemical analysis of soil samples taken from the roadside strip of a highway constructed using a base made of nepheline sludge was performed. It is shown that the change in the content of calcium—the main element of the sludge at a distance from 5 to 100 m from the road did not exceed its value in the background sample, and the content of exchangeable aluminum in the soil of the analyzed areas was at a very low level—less than 0.5 mg/kg and practically did not affect its content in the soil at all sampling points from 0 to 150 m from the road. Based on the conducted ecotoxicity studies using single- and dicotyledonous plants, the possibility of using nepheline sludge as a component of road covering in the form of a nepheline-crushed stone mixture has been established and the absence of toxicity in the analyzed soil samples at various distances from the roadside strip has been proved.

Introduction.
In the context of increasing the number of vehicles and the increasing anthropogenic load on the environment, the problem of expanding the raw material base for road construction by maximizing the use of waste from various industries is of particular importance [1,2,3]. In Russian and foreign practice of road construction, local construction materials and soils reinforced with various binders are beginning to be widely used. The bases of road coverings made of materials reinforced with a binder are not only strong, but also economical. Currently, one of the most urgent tasks in the field of ecological safety is research on the creation of new effective composites based on non-toxic technogenic raw materials, characterized by reduced cost and meeting modern requirements for road construction materials [4,5]. The problem of industrial waste disposal is acute throughout the civilized world. Lime, metallurgical slags, waste from mining and volcanic production, and other industrial wastes are widely used in Russia and abroad instead of expensive cement [6-8]. But before using technogenic materials in the device of road coverings it is necessary to study their harmful effect on the roadside soil. According to the results of research conducted at the Research institute of water management in Russia (Yekaterinburg), it was found that the greatest pollution is exposed to a 100-meter strip along roads with high traffic intensity. The main goal of road construction and reconstruction is not only to improve the capacity of vehicles, isolate transit and cargo traffic from residential development, but also to improve the development level of the surrounding area and the possibility of improving the environment. Technical solutions for road construction and reconstruction include other measures that ensure drainage, ecological requirements, and the use of ecologically safe materials for road coverings. Therefore, the problem of ecological pollution of roadside strips is very complex and it is necessary to assess the impact of applied construction materials on the soil objects of...
One of the promising wastes in Siberia for use in the device of road coverings is nepheline sludge (NS) of JSC "RUSAL Achinsk" [9]. Earlier in the 80-90-ies of the last century, there were attempts to use nepheline sludge in the construction of roads in Siberia, but there was no large-scale use of other wastes of alumina production [10]. In recent years, the volume of nepheline sludge placed on the sludge maps of JSC “RUSAL Achinsk” exceeds 100 million tons and requires immediate solutions to the problem of using this waste.

**Results and discussion**

The conducted sanitary and epidemiological examination of nepheline sludge for radiation safety indicators showed that the specific activity of natural radionuclides contained in nepheline sludge does not exceed the hygienic standard established for industrial waste used in the manufacture of construction materials of the I" class and, accordingly, is equal to 66.9 Bq/kg with a standard of 370 Bq/kg [5]. Using x-ray phase analysis, the mineralogical composition of nepheline sludge placed on the sludge map of JSC “RUSAL Achinsk” was studied (table 1).

| Component | 2CaO·SiO₂ | Na₂O·Al₂O₃·SiO₂ | 2CaO·Al₂O₃·SiO₂ | Na₂O·Al₂O₃ | CaFe₂O₄ | CaCO₃ |
|-----------|------------|-----------------|-----------------|-------------|----------|--------|
| Content, %| 80.0-85.0  | 1.0-3.0         | 0.5-1.0         | 0.5-1.0     | 1.5-4.0  | 1.0    |

As can be seen from table 1, the main mineral composition of the nepheline sludge placed on the sludge storage in samples is dicalcium silicate - β-2CaO·SiO₂ (more than 80%).

It was also found to contain sodium and calcium aluminosilicates (Na₂O×Al₂O₃×SiO₂, 2CaO×Al₂O₃×SiO₂), iron compounds in the form of ferrites and oxides (CaFe₂O₄, Fe₂O₃), calcite (CaCO₃) and sodium aluminate (Na₂O×Al₂O₃). Up to 5% of the nepheline sludge contains: calcium magnesium silicates CaO×MgO×SiO₂, calcium hydrogranates 3CaO×Al₂O₃×SiO₂×6H₂O, calcium aluminates CaO×Al₂O₃ [9]. The presence of dicalcium silicate and calcium hydrosilicates in the nepheline sludge confirms the conducted differential thermal analysis.

The study of the granulometric composition of nepheline sludge sample showed a relatively small fraction content of more than 2 mm, which makes it easy to use it in road technologies almost without preliminary preparation. The granulometric composition of nepheline sludge of JSC “RUSAL Achinsk” is shown in table 2.

| Fraction size, mm | Less 0.01- | 0.05- | 0.1 | 0.25- | 0.5 | 1.0 | 2.0 | More |
|-------------------|------------|-------|-----|-------|-----|-----|-----|------|
| The contents of the fraction, % | 1.2 | 5.7 | 8.1 | 20 | 26 | 26.6 | 11.1 | 1.3 |

The use of nepheline sludge in road coverings is currently carried out in the form of a nepheline-crushed stone mixture, which is prepared at the production area, then it is laid in the base of the road and rolled with rollers [12]. To simulate the process of forming the base of road coverings, experimental samples were prepared in the form of cubes of a nepheline-crushed stone mixture. When making the control composition of the road mixture, crushed stone from the Masul mine was taken as a large aggregate of the mixture, which meets the regulatory requirements. For forming, the molding process forming with pressing of a nepheline-crushed stone mixture at a pressure of 15 MPa was used. The method provided for holding samples of pressed road mixture for 28 days, after which water extracts from fresh nepheline sludge of current production and its mixture with crushed stone were studied. The analysis showed that in the water extract from fresh nepheline sludge, when crushed
stone is added to it, the content of potassium (in 1.6 times) and the content of aluminum (in 3 times) is significantly reduced during the formation of road mixtures. Thus, the model studies have shown that various industrial wastes, such as nepheline sludge and overburden from the Masul limestone mine, can be effectively used as cheap raw materials for obtaining construction material for the construction of road coverings. However, the use of nepheline sludge as a component of road coverings can become effective only in the absence of their negative impact on the soil layer of the roadside strip adjacent, which was considered necessary to study in the course of pilot field studies on the existing road constructed with the use of nepheline sludge.

Analysis of changes in the water extract pH of the roadside soil showed that the pH of the soil selected near the highway in the city of Sosnovoborsk, built using a crushed stone base reinforced with nepheline sludge of JSC “RUSAL Achinsk”, has a highly alkaline reaction of the medium (figure 1).

![Figure 1. Changing the water extract pH of the roadside soil:](image)

1 - road built without the NS (city of Zheleznogorsk);
2 - road with the NS (city of Sosnovoborsk); 3 - road with the NS (village of Zeledeevo)

A characteristic feature of the land from the surveyed territory in the area of Sosnovoborsk is the alkaline reaction of the soil. The water extract pH from various samples taken at a distance of 5, 10, 50, 100 m from the road ranges from 8.2 to 8.8 pH (figure 1), which confirms the increased alkalinity of the soil of this site, even at a great distance from the road. At the same time, the pH value for the background sample taken at a distance of 100 m from the road also had an alkaline reaction of soil water extraction from this area (8.5 pH). The use of nepheline sludge in the reconstruction of the highway at the area near Sosnovoborsk did not affect the pH change, since even in the background sample, the pH value had an alkaline reaction, which is due to soil contamination by nearby industrial facilities.

For comparison, samples were taken on the highway in the village of Zeledeevo, which was also built using a base made of nepheline sludge, but has a longer (15 years) service life and no anthropogenic impact of large industrial facilities. As seen in Fig.1 the water extraction pH of soil samples taken from the roadside of this highway had a smooth character of decreasing to a neutral value almost at a distance of 10-50 m, which confirmed the absence of harmful effects of nepheline sludge on the territory adjacent to the highway.

The nature of changes in the soil pH taken from the roadside strip near the city of Zheleznogorsk, which has a crushed stone base of the road surface made without the use of nepheline sludge showed that within the range of 10 to 50 m, the soil also had a highly alkaline reaction of the medium from 8.3 to 9.4 pH (figure 1). The increased pH values at a distance from the roadside strip are primarily due to the high traffic intensity on this highway, similar to the section near the city of Sosnovoborsk. At the
same time, a decrease in the soil pH of the water extraction to neutral (7.4 pH) was noted when analyzing the soil of this area, selected at a distance of only 100 m from the road. The pH value for the background sample at this area was 7.3 units.

Given that the main mineral compound in nepheline sludge is dicalcium silicate (up to 85%), it was considered appropriate to study the calcium content in the roadside soil. Changes in the calcium content in the soil on the analyzed sections of the road with a base constructed with and without nepheline sludge had a similar character at the distance of the road from 5 to 100 m (figure 2).

At the same time, at a distance of 5 and 10 m from the highway, the calcium content was the highest (from 5.12 to 6.79 mmol/100g). At a distance of 50 m, a decrease in the calcium content was observed to a value of 2.9 mmol /100g, which was even lower than the value in the background sample. Tests of soil samples taken at a distance from the roadside proved that the content of exchangeable aluminum in the soil of the analyzed areas was at a very low level (less than 0.5 mg /kg), while the use of nepheline sludge in the device of the base in road coverings practically did not affect its content in the soil at all sampling points from 0 to 100 m from the road.

Additional ecotoxicological studies were conducted to confirm the absence of toxic effects from nepheline sludge. Using the method of phytotesting, the absence of toxic properties from water extracts from a mixture of nepheline sludge with crushed stone (in the ratio of % mass fraction 30:70) and hydrated nepheline sludge was determined. The results of studies obtained on distilled water served as a control. Soft spring wheat (Triticum vulgare L.) sort of Novosibirsk 29 and watercress (Lepidium sativum L.) sort of Donskoy were used as test organisms. Ecotoxicological studies of samples by phytotesting using single- and dicotyledonous plants have established that the nepheline-crushed stone mixture is low-toxic in terms of reducing seed germination and inhibiting root growth of test plants, and the hydrated nepheline sludge stored on the slurry map is practically non – toxic. Using microbial strains, it was found that there was no toxic effect of water extracts from a mixture of nepheline sludge with crushed stone and hydrated nepheline sludge on single-celled green algae Chlorella vulgaris and soil infusoria of the genus Colpoda. It is also noted that fresh nepheline sludge of current production has toxicity, but during its storage in the sludge field, it is hydrated and it does not have a toxic effect on test plants and microorganisms.

**Conclusion**

The studies performed to assess the impact of nepheline sludge of JSC “RUSAL Achinsk” were confirmed in practice in the process of experimental field work on various sections of roads.
constructed using this sludge. The change in the content of roadside soil of calcium, as the main element present in the sludge, had a similar character at the distance of the road from 5 to 100 m on all analyzed sections of the road with a base built with nepheline sludge and without sludge. Tests of soil samples taken near the roadside strip proved that the content of exchangeable aluminum in the soil of the analyzed areas was at a very low level (less than 0.5 mg/kg) and did not affect the presence of sludge in the road mixtures. The conducted studies of the soil selected at various distances from the roadside strip proved the absence of toxicity in the analyzed soil samples. Based on ecotoxicity studies using single-and dicotyledonous plants and single-celled algae Chlorella vulgaris and soil infusoria of the genus Colpoda, the possibility of using nepheline sludge as a component of road covering in the form of a nepheline-crushed stone mixture has been established. At the same time, it should be considered that in tight conditions, when rolling the covering base, the nepheline sludge is rapidly hydrated and it passes into a monolithic state similar to concrete [2,5,6].

The widespread use of non-toxic technogenic materials of alumina production in road construction technologies allows us to solve the problem of resource saving of natural building materials and reduce the impact on the environment of industrial waste in places where they are located.

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