Eco-protective Technologies in Transport Construction

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Abstract. As the environmental situation continues to deteriorate as a result of anthropogenic activities, research is needed to develop new multifunctional eco-protective technologies that will help clean up already polluted soil and water bodies, dispose of waste and provide preventive protection for areas that have not yet been polluted. Industrial and construction waste was investigated for heavy metal ions in soil and wastewater using the ionometric method. The ability of wastes such as phosphogypsum, heavy concrete and foamed concrete to absorb cadmium, lead and copper ions from aqueous solutions and different types of soils was tested. It has been experimentally established that the absorption mechanism is not an ionic exchange, but only a one-way process of sorption on the surface of substances. Based on the discovered properties of waste, ecoprotective technologies have been proposed that can be used in transport construction for the preventive protection of soils and runoff from roads and railways. Also, these technologies can be applied to already built and operating traffic arteries. In the course of the study, nine types of eco-shields were experimentally tested.

Keywords: Ecoprotective technologies · Geosystem pollution · Heavy metal ions · Mineral wastes · Road construction

1 Introduction

The problem of the accumulation of industrial and construction waste has been a source of concern for people for many years, and many works by domestic and foreign scientists have been devoted to it [1–3].

Developing industry and an ever-expanding transport network cause the problem of pollution of the hydrosphere and lithosphere by heavy metals [4–6], whose detrimental effects on the body have been proved by medical research [7, 8]. The issue of treatment of wastewater and soils from heavy metal ions (HMI) has been actively raised in recent decades by scientists from various countries [9–11].

In recent years, the problems of waste recycling and environmental cleanup have been approached in an integrated manner, developing ways to solve them simultaneously [12–16].

This study aims to address several environmental issues through the development of new eco-protective technologies:

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– treatment of wastewater and soils of traffic arteries from HMI;
– recycling of industrial and construction waste;
– preventive protection of land and water resources during transport construction.

The primary challenge is to prove that some waste can sorb heavy metals entering the soil and water near roads and railways. The next task is to develop ecoprotective technologies with their use.

2 Methods

Experiments were carried out in the laboratory and field conditions, the method of ionometry was used. The concentration of heavy metal ions was measured using ion-selective electrodes of an Expert-001-1 liquid analyser.

Phosphogypsum was chosen as an industrial waste for the study, and the construction waste was a waste of heavy concrete and foamed concrete. All of the substances presented are classified as Hazard Class 4, i.e. they are not harmful to the environment if used rationally.

Cadmium, lead and copper were chosen as pollutants for the experiments as some of the main pollutants from transport.

Soil samples were loam, sandy loam, and peat sampled in the Leningrad Region.

3 Results

Phosphogypsum has a very fine fraction of 0.114–0.315 mm, so for the first experiment to select the concentration of the initial HMI solution (using cadmium ions as an example) construction waste scrap was also crushed to this fraction.

As a result of this study (Table 1), the average concentration of HMI in solution was selected for further experiments.

For waste with a variation in fraction, a study of the sorption capacity dependence on the fraction was carried out (Table 2), which showed that for concrete and foam concrete a fraction of 0.315–0.630 mm can be used as the most frequently used for sorbents in industrial filters.

The next step was to investigate the dependence of the sorption capacity of the waste on the interaction time with the HMI solution (Table 3). The experiment showed that fifteen minutes of interaction is sufficient, as in the case of phosphogypsum the final concentration changes only slightly.

Further, under the chosen conditions of the study (concentration of the HMI solution $10^{-4} - 4$ mol/L, a fraction of construction waste 0.315–0.630 mm, time of interaction of waste with the HMI solution 15 min) the sorption capacity of waste for lead and copper ions, polluting roadside areas along with cadmium was determined (Table 4).

Table 1. Dependence of the static sorption capacity of waste on the initial concentration of the HMI solution

Initial concentration of Cd(NO$_3$)$_2$3)2 solution		Phosphogypsum		Heavy concrete		Foam concrete	
mol/L	mg/l	Final concentration, mg/l	Capacity, mg/g	Final concentration, mg/l	Capacity, mg/g	Final concentration, mg/l	Capacity, mg/g
10^{-6}	0.042	0.011	0.003	0.000	0.004	0.000	0.004
10^{-5}	1.620	1.367	0.025	0.000	0.162	0.000	0.162
10^{-4}	12.786	2.195	1.059	0.000	1.279	0.000	1.279
10^{-3}	162.817	57.102	10.570	93.704	6.911	0.000	16.282
10^{-2}	1537.309	663.379	87.393	1341.988	19.532	1003.109	53.420

Table 2. Dependence of the sorption capacity of construction waste on the fraction

Waste	Fraction size, mm			
	0.114–0.315	**0.315–0.630**	**0.630–1.250**	**>1.250**
Heavy concrete	1.279	1.277	1.271	1.212
Foam concrete	1.279	1.276	1.269	1.204

Table 3. Dependence of the sorption capacity of waste on the interaction time with the HMI solution

Interaction time, h	Phosphogypsum		Heavy concrete		Foam concrete	
	Final concentration, mg/l	Capacity, mg/g	Final concentration, mg/l	Capacity, mg/g	Final concentration, mg/l	Capacity, mg/g
0.25	2.195	1.059	0.000	1.279	0.000	1.279
2	2.170	1.062	0.000	1.279	0.000	1.279
6	2.573	1.021	0.000	1.279	0.000	1.279
24	2.322	1.046	0.000	1.279	0.000	1.279

Table 4. Sorption capacity of waste for different HMIs

HMI	Capacity, mg/g		
	Phosphogypsum	Heavy concrete	Foam concrete
Cadmium	1.06	1.28	1.28
Copper	1.28	1.34	1.34
Lead	1.51	1.52	1.52

In order to prove that HMI cleaning is a sorption process and not an ion exchange process, an experiment was carried out to investigate the leachability of the HMI from the reacted waste using heavy concrete as an example.

First, the concentration of cadmium ions in the $Cd(NO_3)_2$ solution was determined using ion-selective electrodes, then concrete was added to this solution and the concentration of cadmium and calcium ions was measured after the selected interaction time. Next, we determined the concentration of calcium ions in the $CaCl_2$ solution and added the dried heavy concrete that had previously reacted with the cadmium solution to this solution, and then measured the concentration of cadmium and calcium ions again. Experimental results confirming interaction with HMI through sorption are shown in Figs. 1 and 2.

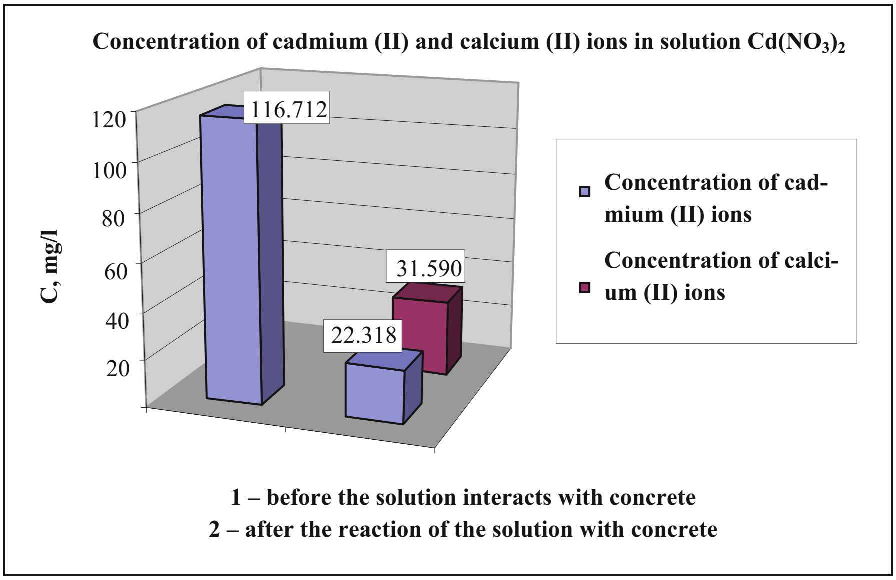

Fig. 1. Absorption of cadmium ions from solution by heavy concrete.

A large-scale experiment was carried out in the field to test the cleaning of soils with waste. The waste was mixed with soil samples in a 1:16 ratio by weight, placed on a

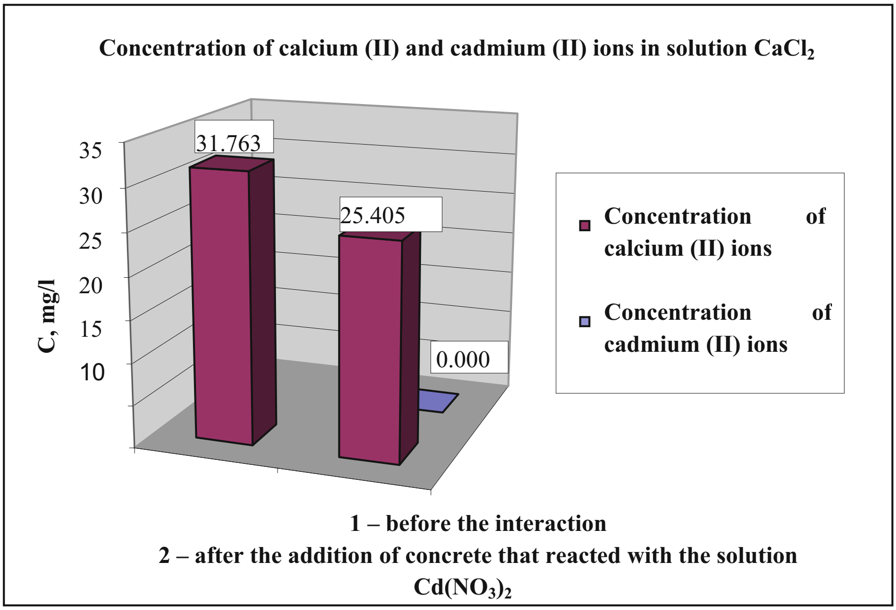

Fig. 2. No leaching of cadmium ions from absorbed heavy concrete.

cloth over a grid and a lead solution with an initial concentration of 235.875 mg/l was passed through. The contact time in this case was minimal. The filtrate collected at the bottom of the tray was tested for the presence of lead ions. Next, an aqueous extract of dried soil samples mixed with waste was analysed for lead ions leaching from them. The results of the experiments are presented in Table 5. The data in Table 5 show that the leaching of lead ions is extremely insignificant compared to the initial concentration of lead in the solution, which was 235, 875 mg/l.

The experiment showed that soils are natural filters in their own right, but the purification capacity of waste is still much higher. In addition, by using the waste as a sorbent, we recycle it and obtain a positive ecological effect, while the removal of soil for this purpose prevents resource conservation and creates a negative ecological effect.

Table 5. Efficiency of waste treatment of different types of soil

Soil sample	Final concentration of lead ions in the filtrate, mg/l	Concentration of lead ions in the water extract, mg/L	Cleaning effect, %
Loam	43.441	0.014	81.58
Loam with phosphogypsum	0.760	0.043	99.68
Loam with concrete	0.012	0.017	99.99

(*continued*)

Table 5. (*continued*)

Soil sample	Final concentration of lead ions in the filtrate, mg/l	Concentration of lead ions in the water extract, mg/L	Cleaning effect, %
Loam with foam concrete	0.075	0.016	99.97
Loam	155.674	0.031	34.00
Loam with phosphogypsum	0.413	0.165	99.82
Sandy clay with concrete	0.060	0.015	99.97
Sandy loam with foam concrete	0.438	0.002	99.81
Peat	152.375	3.517	35.40
Peat with phosphogypsum	10.216	0.891	95.67
Peat with concrete	0.584	0.802	99.75
Peat with foam concrete	10.821	0.002	95.41

4 Discussion

The found static capacity of the waste with respect to heavy metal ions suggests that it can be used as a sorbent where soils and water runoff are contaminated with heavy metals, whether this is industrial production or areas along transport highways.

Based on experiments carried out in the laboratory, it can be concluded that heavy metal removal is more effective at higher concentrations because the static capacity of the waste increases. This means that some industrial and construction waste can be used as sorbents in highly polluted areas.

The revealed dependence of the capacity on the fraction of substances showed that the heavy metal purification capacity decreases slowly with increasing particle size of the individual material. We can conclude that surface sorption mechanisms are involved in the process. The more the material is fractured, the more free surface area it has to interact with the pollutant.

A short contact time is sufficient for effective HMI water treatment, making the waste material suitable for use both in industrial filters and as backfill in roadside areas.

As phosphogypsum, heavy concrete and foamed concrete are calcium sulphate-containing and silicate-containing substances, there was a possibility that HMI simply replaced calcium ions during the reaction, i.e. the interaction followed an ion exchange mechanism. In this case, the HMIs would just as likely be leached out of the waste that absorbed them into the environment when the reaction flows backwards.

The experiment showed that the heavy concrete absorbs cadmium ions from the solution and releases calcium ions into the solution during the primary interaction, but the reverse reaction does not occur, and the heavy concrete saturated with cadmium ions does not release them into the solution with the calcium ions.

In a soil cleaning study, all wastes absorbed HMI without being leached out of the aqueous extracts. These results exclude the interaction of the waste with the HMI through ion exchange and suggest that absorption takes place on the surface of the substances through a sorption mechanism, by binding and neutralising the hazardous substances, which means that there is no fear of the HMI being released back into the environment over time.

The results obtained can be applied to create new eco-protective technologies, including in transport construction.

Waste can be used as a sorbent for HMI in drainage channels along railways and roads, both under construction and existing ones.

For ease of loading into and removal from the trays at the end of the use period, and also to avoid being washed away by runoff, the fine fraction waste should be wrapped in geotextile (Fig. 3, a). The coarse fraction waste can be loaded directly into the drainage trough (Fig. 3, b).

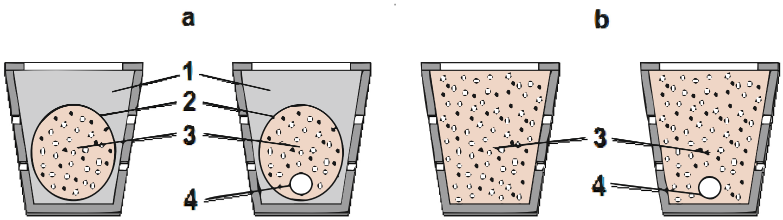

Fig. 3. Disposal of sorbent waste in a drainage flume (1 - backfill (for example, crushed stone); 2 - geotextile; 3 - sorbent from waste; 4 - perforated tube)

A further use of waste is the creation of an eco-shield during the construction of railways and motorways. When building a slope, topsoil is placed on top of the slope to protect it from water erosion (Fig. 4, left). It is suggested that the waste be mixed with this soil before backfilling begins. Such a screen will protect the soil and runoff of roadside areas from HMI (Fig. 4, right).

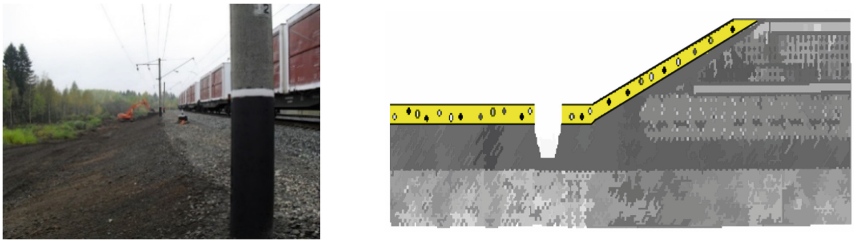

Fig. 4. Placement of an eco-shield on the slope of a motorway

These eco-protective technologies can be combined to provide greater efficiency and longer sorbent lifetime (Fig. 5).

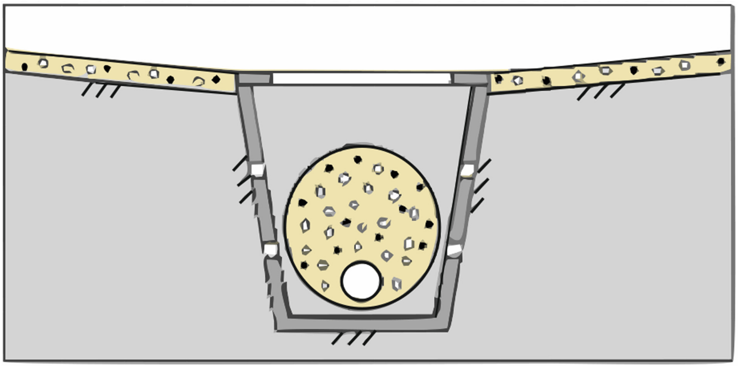

Fig. 5. United ecoprotective technologies

5 Conclusion

In the light of all of the above, it can be concluded that research into the discovery of the beneficial ecoprotective properties of industrial and construction waste is justified and should be continued. Accumulated stockpiles of various substances occupy a huge space taken out of nature's use and threaten soil, water and air pollution, but they also have great potential for resource conservation and are not used only because of ignorance of their potential. They are also very inexpensive compared to traditionally used materials.

The use of eco-friendly technologies based on industrial and construction waste in transport construction achieves multiple positive environmental effects.

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