DNIPRO UNIVERSITY of TECHNOLOGY 1899

Mining of Mineral Deposits
Volume 14 (2020), Issue 2, 95-102

MMD JOURNAL / MINING.IN.UA

UDC 661.842 https://doi.org/10.33271/mining14.02.095

Research into the process of storage and recycling technogenic phosphogypsum placers

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Abstract

Purpose. Study of technogenic placers storage conditions using the example of phosphogypsum dumps at PJSC "Rivneazot" by determining the rocks sorption properties, distribution and concentration of elements, as well as substantiation of recommendations for this production waste recycling.

Methods. A series of experimental, laboratory, and full-scale studies of the hydrophysical soils properties have been conducted and the degree of their pollution by phosphogypsum waste under PJSC "Rivneazot" conditions has been revealed. Coefficient of permeability was found using the PVN-OO appliance. Granulometric composition was determined by the method of N.A. Kachynskyi. Mathematical modelling of the elements distribution process within the waste storage was applied. The migration of phosphorus, fluorine, sulphur, copper, chromium, manganese, zinc, lead, cadmium, iron, nickel and cobalt along the profile of artificial soil cross section has been studied. The experimental data were approximated and statistically processed in the MathCad and Microsoft Excel software packages.

Findings. The patterns of rare earth elements distribution in technogenic placers within the mining waste storage have been determined. The authors have developed a mathematical model of the polluting agents' filtration process through the soil massif. The recommendations are presented on the environmentally safe storage and recycling of phosphogypsum waste. A technology is proposed for the comprehensive phosphogypsum wastes recycling of anti-radiation building products manufacture, which is accompanied by rare earth elements extraction.

Originality. The main factors and patterns have been revealed that regulate the distribution of rare earth elements in technogenic placers within the mining waste storage, which influence the rocks sorption properties.

Practical implications. Based on determined patterns, the study substantiates the practical possibility for recycling the technogenic placers within the phosphogypsum waste storage and identifying the zones with maximum elements concentration.

Keywords: *technogenic placers, elements distribution, mining operations, rare earth metals, phosphogypsum, waste recycling*

1. Introduction

Wastes generated during mining and recycling of minerals, pollute the environment (soil and groundwater) and require storage [1]-[3]. Nowadays, the total volume of solid waste accumulated in Ukraine is 25-28 billion tons. They are stored in dumps, the total area of which is about 180 thousand hectares and is increasing annually by 3-6 thousand hectares. Primarily, this refers to the mining and smelting complex, since the waste generated from this industry accounts for 90% of the total industrial waste volume in Ukraine [4]-[7].

The problem of reducing the volume of mineral fertilizers production waste and its disposal is very acute at the moment. Utilization and recycling of this production waste together with the alternative technologies development is an urgent scientific and applied problem, the solution of which will significantly increase the environmental safety of the country and give a significant economic effect [8]-[12]. To solve the problem, related to accumulation and disposal of waste, it is necessary to conduct research aimed at assessing the state of the industry and its prospects development, as well as to develop a series of relevant actions.

A peculiarity of the Rivne Region (Ukraine) is the location on its territory of the "chemical giant" for the mineral fertilizers production (PJSC "Rivneazot"). According to the data of the Rivne geological survey expedition in the Rivne Region, the phosphogypsum dumps of PJSC "Rivneazot" have been identified in the Rivne Region at a distance of 1.5 km to the northeast of Metkiv village, and at a distance of 1 km to the east of Rubche village. As for terrain relief to the south and west of the

Published by the Dnipro University of Technology on behalf of Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

object, there is a topographic lowering towards the Goryn River, which flows at a distance of 1.6 km to the south and 1.1 km to the west of the phosphogypsum storage [13]-[16].

Many scientists and scholars in Ukraine and abroad devoted their works to modern developments in utilization and recycling of phosphogypsum [17]-[19]. As the scientific literature analysis has revealed, global trends indicate the need to develop and substantiate complex technologies for recycling phosphogypsum waste dumps [20]-[22]. Thus, according to recent studies, a promising and cost-effective direction for comprehensive recycling of phosphogypsum is rare earth metals extraction through the technogenic deposit reserves development, a constant increase in demand and the cost for rare earth metals [23]-[29].

Apatite concentrate, supplied from the Khibinsk fields, was the phosphorous raw material for the mineral fertilizers production in Ukraine. Apatite $Ca_5(PO_4)F$ does not break down in water and is not absorbed by plants. To obtain mineral fertilizer, it should be converted into a soluble form, and for this apatite must be treated with sulphuric acid. As a result, soluble phosphates are produced, and calcium and fluorine are wastes [30]-[32].

The solid products of reaction, which are mainly composed of gypsum ($CaSO_4 \cdot 2H_2O$), are called phosphogypsum. To produce 1 ton of phosphatic acid, depending on the type of raw material, from 4.3 to 5.8 tons of phosphogypsum is spent [33], [34].

In terms of dry matter, the phosphogypsum of PJSC “Rivneazot” contains 94% of $CaSO_4$, 1.8 of undercomposed apatite, 1.8 phosphorus acid, 0.22 silico-fluorhydric acid, 1.92 insoluble residue, up to 1% of iron and aluminum oxides. The moisture content of freshly produced phosphogypsum is 42%, of which 17-19% of water is included in the gypsum crystal lattice and 22-24% is free. The presence of phosphorus and silico-fluorhydric acids causes an acidic reaction of pore moisture.

2. Methods

The object of research are phosphogypsum dumps near the production site of PJSC “Rivneazot”. These are wastes of the fourth hazard class, which are mainly represented by phosphorus oxides, accumulated in the phosphogypsum dumps. The dumps (Fig. 1) occupy an area of 58 hectares and their total volume is 15.3 million tons.

Figure 1. Stockpiled mining waste (PJSC “Rivneazot”)

Water, which is washed out of phosphogypsum by atmospheric precipitation, penetrates into the soil and then into the Goryn River. Therefore, dumps are a special threat not only to adjacent territories, but also to the entire basin of adjacent rivers [35]-[38]. Thus, the search for ways to prevent pollution of soils and groundwater from the phosphogypsum dumps influence, as well as phosphogypsum recycling and utilization are important and urgent tasks.

To describe a pollution migrating from phosphogypsum dumps, it is necessary to simulate a process of polluting agents’ filtration through a soil massif [39]-[42].

For this purpose, a longitudinal section line is studied, in which an elementary soil layer with a thickness of ∂l is conditionally accepted. The change in the pollution concentration level in the soil $\partial c'$ within the seam is proportional to the pollution content c'_0, entering from phosphogypsum dumps, as well as to the seam thickness ∂l:

$$\partial c' = -\alpha c'_0 \partial l, \tag{1}$$

where:

α – absorbtion coefficient (“–” sign indicates a decrease in the pollution content downstream with the groundwater flow).

By integrating (1) within $c'_0 - c'$ and $0 - L$, as well as performing the necessary transformations:

$$\int_{c'_0}^{c'} \frac{dc'}{c'_0} = -\int_0^L \alpha dl; \tag{2}$$

$$\ln c \Big|_{c'_0}^{c'} = -\alpha L \Big|_0^L, \ \ln c' - \ln c'_0 = -\alpha L, \ \ln \frac{c'}{c'_0} = -\alpha L, \tag{3}$$

it has been found that the polluting agents content when flowing through a soil layer with a certain thickness decreases according to the law:

$$c' = c'_0 e^{-\alpha L}, \tag{4}$$

where:

L – section line length.

The main indicator of the precipitation effectiveness of the polluting agents impurities in the soil is the decontamination factor of a liquid:

$$\psi = \frac{c'_0 - c'}{c'_0} = 1 - e^{-\alpha L}, \ \xi = -\ln(1-\psi), \tag{5}$$

where:

ξ – logarithmic decontamination factor of soil.

The set of studies of the soils hydrophysical properties included determining the granulometric composition, permeability (coefficient of permeability), and density [43]-[45]. Granulometric composition was determined by the method of N.A. Kachynskyi.

To determine the density, soil was sampled in dug pits using a cylinder with a volume of 250 mm^2 in three-fold repetition. Coefficient of permeability was found using the PVN-OO appliance.

To determine the pollution content in soils and in the Goryn River, the study was conducted in two stages: at the first stage, soil and water samples are taken in the Goryn River, and at the second stage, the study results are processed.

To take soil samples, the experimental site is divided into five section lines, projected at the lowest terrain points. The first three section lines are projected to the west of the storage towards the village of Rubche, 1 km long; the fourth section line is to the south of the object with a length of 1.5 km; the fifth section line is to the east of the object towards the forest, 0.9 km long. Total number of wells is 22 pcs.

The sampling wells were drilled with a hand-held drill (geological drill, diameter 50 mm) to a depth of 6 m. Soil samples were taken every meter, beginning with the surface with a three-fold repetition of each sample. The distances between the wells in the first three section lines are 50, 250, 300, 400 m, respectively. Along all three section lines, there is a lowering of the territory towards the Goryn River. The distances between the wells in the fourth section line are 50, 250, 300, 400 and 500 m, respectively. The fifteenth and sixteenth wells are located on a hill, then there is a lowering towards the river.

The water in the section line was sampled at three points near the surface, at a depth of 1.5 m and at the bottom. To prevent errors, a three-fold water sampling is performed at each depth. For sampling, polyethylene bottles with a capacity of 1 litre are used with the corresponding labelling of each sample.

The full-scale measurement data have been processed together with specialists in the laboratory of the State Administration of Ecology and Natural Resources in the Rivne Region. The total content of the salts dry residue in the test samples has been determined.

3. Results and discussion

As a result of experimental laboratory and full-scale studies to identify the phosphogypsum dumps influence on the pollution of soils, groundwater and the Goryn River water, the sorption properties of soils have been determined.

The migration of phosphorus, fluorine, sulphur, copper, chromium, manganese, zinc, lead, cadmium, iron, nickel and cobalt along the profile of artificial soil cross section has been studied. The research results have confirmed the increased accumulation in soils of the metals mobile form.

The changes have occurred in the groundwater chemical composition. Straight within the dump site boundaries, the nitrate content mainly exceeds the maximum permissible concentration (MPC) (45 mg/dm^3) and ranges from 30 to 90 mg/dm^3. The manganese content in groundwater within the boundaries of the studied area in all samples exceeds the MPC (0.1 mg/dm^3). An area with a manganese content in groundwater of 50-300 mg/dm^3 and an iron content in groundwater in the range of 2000-1000 mg/kg (MPC – 0.3 mg/dm^3) has been identified straight near the dumps. Petroleum products have been revealed in groundwater and amount to 4.3 mg/dm^3, which exceeds the MPC (0.3 mg/dm^3). The content of lead, zinc, copper, cadmium, nickel, cobalt, nitrites in groundwater everywhere exceeds the MPC. The chemical analysis results of water samples taken from the site show that water has a salinity level of 8.3 mg/dm^3. The total chromium content exceeds the MPC (1 mg/dm^3) and is 3-6 mg/dm^3.

Assessment of distribution of the chromium with various oxidation degrees in the upper metre-deep soil layer of the waste storage area has shown that the average chromium (III) content over the area is 51.3 mg/kg, which exceeds the maximum permissible concentration. This evidences the technogenic pollution and the accumulation by soils of this form of chromium. At the same time, the mobile chromium (III) content in the soil averages 4.7 mg/kg (about 3%), which does not exceed the MPC. The chromium distribution in the soil massif is shown in Figures 2 and 3.

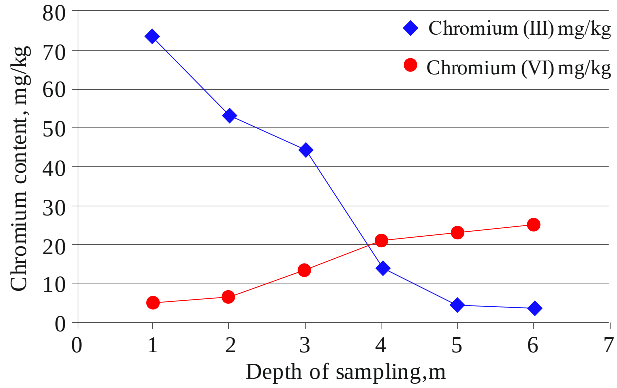

Figure 2. The chromium content in the experimental soil samples taken at a distance of 50 m from the source of pollution

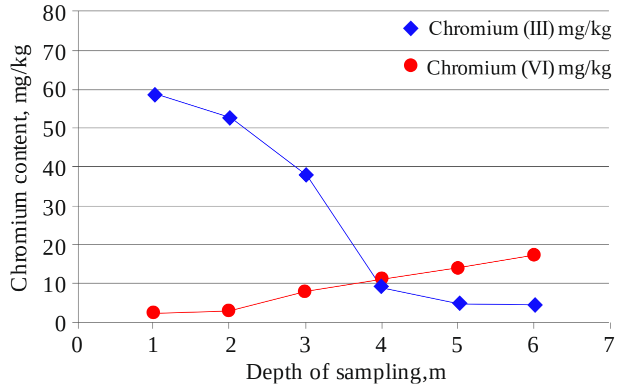

Figure 3. The chromium content in the experimental soil samples taken at a distance of 1000 m from the source of pollution

Loess-like loams, which represent the soil of the object from 1.5 to 6.0 m, are largely polluted with trivalent chromium.

The rocks of the studied area is a geochemical barrier to chromium flow and can form a source of recontamination. To solve this problem, a quantitative assessment is necessary of the strongly bonded and migratory-capable compounds of chromium (III) and chromium (VI), which should be conducted according to the results of determining the mobile and total chromium contents with various degrees of oxidation. Such a statement of the problem is connected with various MPC values for total and mobile chromium (VI) and allows to assess the differences in the sorption properties of rocks and the migratory forms of metals. This ultimately determines the direction of pollution processes.

It can be asserted that chromium (III) is firmly held by the rock. The content of mobile chromium (III) in the rocks depends on soil saturation with water. At the same time, it is necessary to take into account not only the groundwater level, but also the wastewater leaking from the source of their accumulation.

The results on the chromium (VI) sorption and desorption indicate that the rocks do not obstruct the migration of chromium (VI). And its exceeding content in the rock is observed only in the zone of complete water saturation due to the pore space filling.

Groundwater is polluted predominantly by chromium (VI), the concentration of chromium (VI) is 0.02-850 mg/dm^3 and in 95% of samples it exceeds the MPC. While chromium (III) is absent in 20% of samples, but in 30% of samples it exceeds the MPC.

The chromium (III) content in the rocks depends on the distance to the source of pollution and on the type of rock. The maximum values corresponding to the total chromium (III) content in the rock reach 350 mg/kg, the average values – 150 mg/kg. Moreover, the volume of chromium (III) in mobile form is small – an average of 2-5% of the total content.

The mobile phosphorus content in the soil ranges from 280 to 3100 mg/kg, which significantly exceeds the MPC. At the level of groundwater occurrence, the phosphorus content is by 2-3 times higher than that above the groundwater level occurrence. This indicates that soil pollution occurs due to permeability of water from the source of pollution.

The same trend is observed with the iron content in the experimental samples (2500-10700 mg/kg).

The phosphorus content in the section line above the studied object is by 5.5 times less than in the section line on the phosphogypsum dumps territory. Drainage water samples from the phosphogypsum dumps territory, taken before and after dumps indicate that the phosphorus content increases by 10 times. By analysing soil samples taken from the phosphogypsum dumps, it can be asserted about the tendency to accumulate the mobile phosphorus in the soil. Thus, in samples taken at a distance of 500 m to the west in 2015, the mobile phosphorus content in the soil is 332 mg/kg, and in 2018 – 780 mg/kg.

The content of the most toxic components such as lead, cadmium is constantly exceeding the MPC, cadmium is in the range of 2-10 times, and lead is in the range of 5-10.

When analysing the content of nickel, lead, sulphur, manganese, cobalt and zinc in the experimental samples, the distribution pattern is observed:

– the content of these microelements in the samples taken at a depth of 3-6 m is by 2-3 times higher than the content of these microelements taken above the groundwater level occurrence;

– if to consider a longitudinal section line of the well, then there is an accumulation of nickel, lead, sulphur, manganese, cobalt and zinc depending on the depth. And at a depth of 6 m, there is a decrease in the these microelements concentration.

These microelements content depends on the distance of the section line to the object of pollution.

Figure 4 shows the manganese distribution depending on the depth of sampling.

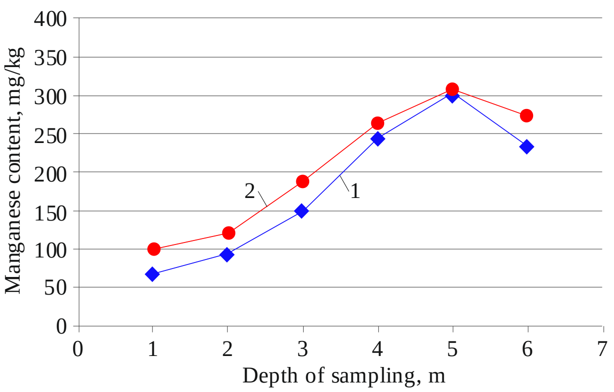

Figure 4. The manganese content in the soil at a distance of: (1) 50 m from the source of pollution; (2) 1000 m from the source of pollution

The results on sorption and desorption of nickel, lead, sulphur, manganese, cobalt and zinc indicate that the rocks do not obstruct migration of these microelements. And their exceeding content in the rock is observed only in the zone of complete saturation with water due to the pore space filling. Due to an increase in the depth of sampling, the soil porosity and the coefficient of permeability decrease. Consequently, the pore space is reduced – this leads to a decrease in the content of corresponding microelements in the soil.

The experimental studies data evidence that phosphogypsum dumps cause the soil and groundwater pollution, which is spread by groundwater. This is confirmed by the salt content in the soil – a smaller value of the mass fraction of salts dry residue near the soil surface and a larger value below the level of groundwater occurrence. That is, pollution is caused by filtration of water from the dumps territory. It can be asserted that chromium (III) is firmly held by the rock. The content of mobile chromium (III) in the rocks depends on saturation of soil with water. The results on the chromium (VI) sorption and desorption evidence that the rocks do not obstruct the migration of chromium (VI). And its exceeding content in the rock is observed only in the zone of complete water saturation due to the pore space filling. Groundwater is polluted predominantly by chromium (VI).

The full-scale measurement and modeling data on the salts dry residue in the soil depending on the section line length are presented in Figure 5.

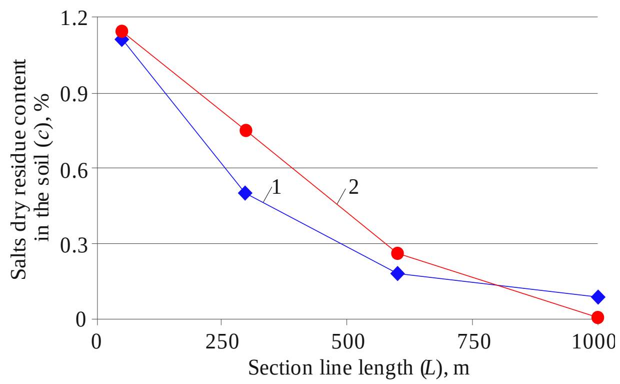

Figure 5. The salts dry residue content in the soil at a depth of 4 m depending on the distance to the phosphogypsum dumps: 1 – modeling data; 2 – full-scale measurement data

This model shows that the polluting agents concentration in the soil, which is determined mathematically, and the concentration, determined by full-scale measurements, varies exponentially, and their values are slightly different. The average relative difference between the experimental data and the mathematically obtained data does not exceed 7%, which is explained by the soil massif heterogeneity and the sorption properties of soils.

The model of physico-mathematical description of the polluting agents flow from the phosphogypsum dumps takes into account the parameters of the substance density and the parameters of the convective-diffusion transfer of polluting agents, given the indicator of the impurities precipitation effectiveness. In this case, the logarithmic decontamination factor of soil has a direct proportional dependence on the coefficient of soil permeability and the distance to the source of pollution.

To protect the soil from pollution, which is transferred by the filtration flow from phosphogypsum dumps, it is proposed to set an intercepting drainage, under the action of which the salt composition of soil will also be changed. Dependence of the polluting agents' concentration in the soil over time at different distances of the drainage setting is shown in Figure 6.

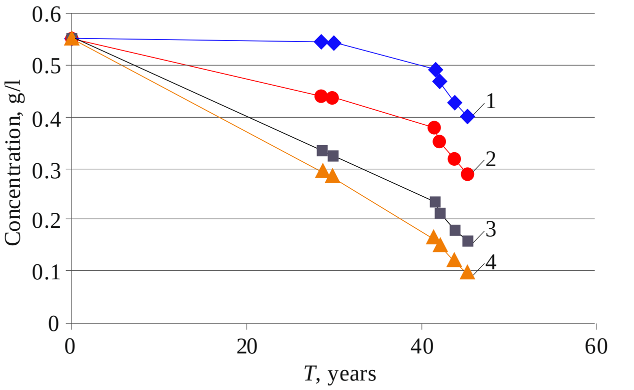

Figure 6. Change in the polluting agents' concentration in the soil over time at a distance from the drainage: 1 – 20 m; 2 – 30 m; 3 – 40 m; 4 – 45 m

To prevent the phosphogypsum dumps detrimental effect on the environment, engineering methods and substantiated technological parameters are proposed to intercept and withdraw the polluted water.

Based on the performed studies, the recommendations have been developed for the environmentally safe storage and recycling of technogenic placers within phosphogypsum dumps, which include three stages:

– engineering scheme for intercepting polluted water from the phosphogypsum dumps territory;

– covering phosphogypsum dumps with a protective polyethylene film, as well as subsequent covering with a fertile soil layer and planting of vegetation;

– a phosphogypsum processing into building materials for non-residential premises (brick, panel blocks) with the accompanying extraction of rare earth elements, as well as the creation of X-ray protective structures from composite X-ray protective materials with high X-ray protective properties.

Based on experimental studies data, a design and technological scheme has been developed for intercepting polluted waters from the phosphogypsum dumps territory. It has been revealed that not only the phosphogypsum dumps of PJSC "Rivneazot", but also the adjacent area is the source of pollution. As a result of spreading phosphogypsum by wind erosion and groundwater, the soil pollution content in a radius of 1 km around the dumps has exceeded the maximum permissible standards. The nitrate content in the soil exceeds the MPC (45 mg/dm^3) and ranges from 30 to 90 mg/dm^3. The manganese content in groundwater within the boundaries of the studied area in all samples exceeds the MPC (0.1 mg/dm^3). An area with a manganese content of 50-300 mg/dm^3 in groundwater has been identified straight on the territory of the municipal solid waste site. The iron content in groundwater straight within the boundaries of the waste site is in the range of 2000-1000 mg/kg (MPC – 0.3 mg/dm^3). The content of lead, zinc, copper, cadmium, nickel, cobalt, nitrites in groundwater everywhere exceeds the MPC. The chemical analysis results of water samples taken from the site show that water has a salinity level of 8.3 mg/dm^3. The total chromium content exceeds the MPC (1 mg/dm^3) and is 3-6 mg/dm^3.

To prevent the spreading pollution, a utility system has been developed to intercept high-mineralized water from the phosphogypsum dumps territory (Fig. 7).

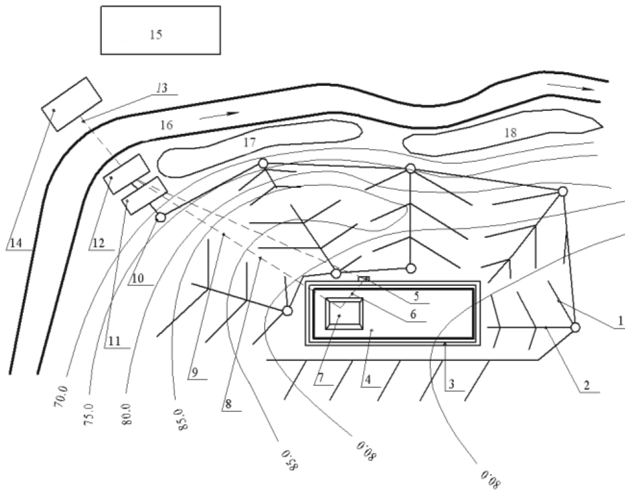

Figure 7. The proposed utility system to prevent pollution within the boundaries of influence of the phosphogypsum dumps: 1 – drains; 2 – collecting receiver; 3 – intercepting channels; 4 – phosphogypsum dumps; 5 – pumping station; 6, 13 – pressure pipeline; 7 – water-collecting pool; 8, 9 – gravity pipeline; 10 – drainage well; 11 – collecting basin; 12 – pumping station; 14 – treatment facilities; 15 – PJSC "Rivneazot"; 16 – Goryn River; 17 – Metkiv village; 18 – Rubche village

According to this scheme, it is proposed to set a drainage system around the dumps for intercepting and withdrawing the polluted groundwater to the treatment facilities of PJSC "Rivneazot", located at a distance of 5 km from the territory of the studied object. The intercepting channels are designed around the object perimeter in order to intercept polluted water that comes from the phosphogypsum dumps territory and is accumulated in dumps as a result of atmospheric precipitation in the form of rain and snow. Then, high-mineralized solution is fed from intercepting channels to the holding pond with volume of 406000 m^3, located at the top of dumps. The holding pond arrangement at the top of the dumps is reasoned by the prevention of high-mineralized solution penetration to the soil and the further spread of pollution through groundwater into the Goryn River.

The pumping station provides for operation in two modes: main and emergency. The main mode provides for the water supply to the holding pond, the emergency mode provides for emergency operation of the holding pond, that is, the polluted water is supplied from intercepting channels directly to the treatment facilities of PJSC "Rivneazot". A collector-drainage system is designed around the dumps, that intercepts and withdraws polluted groundwater to the treatment facilities of PJSC "Rivneazot", located at a distance of 5 km from the territory of the studied object. Groundwater is intercepted by drains, from where it is transferred by a collecting receiver to a collecting basin. When the maximum water level in the basin is reached, a pumping station pumps water from the basin to the treatment facilities of PJSC "Rivneazot". The pumping station functions in the automatic mode in accordance with the outcoming signals of the water level sensors in the basin.

In order to prevent penetration of the high-mineralized water into the soil in case of heavy precipitation, a gravity pipeline is provided to transfer high-mineralized water to treatment facilities. At the second stage, it is recommended to cover the phosphogypsum dumps with a protective polyethylene film, and subsequent covering with a fertile soil layer and planting of vegetation. This will prevent from wind erosion and pollution of adjacent territories. The service life of screens with soil covering is up to 100 years. Small bushes with planting the grass is the vegetation recommended for planting in a soil meter layer. The third stage is designed for a more extended periods of time – a phosphogypsum processing into building materials with the simultaneous phosphogypsum disinfection from harmful elements and extraction of rare earth metals, which can be met in the composition of phosphogypsum – up to 1%.

4. Conclusions

The result of multi-year storage of waste from the mineral fertilizers production at PJSC "Rivneazot" is the formation of technogenic phosphogypsum dumps, which amount to 15.2 million tons and require a constant increase in the territories allocated for its storage.

Toxic waste is stored in dumps, and this leads to pollution of soils, surface and underground waters, negatively affects the population health. The main factor that causes soil pollution on the phosphogypsum dumps territory is the filtration of polluted water. This is evidenced by soil pollution, which is by 5-10 times higher at the level of groundwater occurrence than that on the surface. And this index is growing over time.

The microelements distribution in the soil at a depth of groundwater occurrence in the direction of the filtration flow, has a tendency to decline along the length of the flow. But for some microelements such as nitrates, manganese, fluorine, sulphur, phosphorus – there is a constant change towards reducing the microelements content along the length of the flow.

Based on the performed studies, the recommendations have been developed for the environmentally safe storage and recycling of technogenic placers within the boundaries of phosphogypsum dumps, which include three stages:

– engineering scheme for intercepting polluted water from the phosphogypsum dumps territory;

– covering phosphogypsum dumps with a protective polyethylene film, as well as subsequent covering with a fertile soil layer and planting of vegetation;

– a phosphogypsum processing into building materials for non-residential premises (brick, panel blocks) with the accompanying extraction of rare earth elements, as well as the creation of X-ray protective structures from composite X-ray protective materials with high X-ray protective properties.

In such a way, the complex of studied measures will be a solution to the problem of coordinating relations between production, on the one hand, and nature, on the other. It will also reduce the excessive technogenic load on natural objects, protect the soil, ground and surface water from pollution, and will provide an economic effect by introducing the waste recycling technologies.

Acknowledgements

This work would not have been possible without the support and assistance provided by P.P. Bortnik, Director of PJSC "Rafalovsky Quarry" in performing experiments.

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Дослідження процесу зберігання та переробки техногенних розсипів фосфогіпсу

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Мета. Вивчення умов зберіганні техногенних розсипів на прикладі відвалів фосфогіпсу ПрАТ “Рівнеазот” з визначенням сорбційних властивостей порід, розподілу, концентрації елементів та обгрунтування рекомендацій з переробки відходів даного виробництва.

Методика. Проведено серію експериментальних, лабораторних і натурних досліджень водно-фізичних властивостей ґрунтів та виявлення ступеню їх забруднення відвалами фосфогіпсу в умовах ПрАТ “Рівнеазот”.Коефіцієнт фільтрації визначався приладом ПВН-ОО. Гранулометричний склад визначався за методом Н.А. Качинського. Застосовано математичне моделювання процесу розподілу елементів у межах складування відходів. Досліджено міграцію фосфору, фтору, сірки, міді, хрому, марганцю, цинку, свинцю, кадмію, заліза, нікелю і кобальту вздовж профілю штучного ґрунтового перерізу. Апроксимація та статистична обробка дослідних даних проводилась у програмних пакетах MathCad та Microsoft Excel.

Результати. Встановлено закономірності розподілу рідкоземельних елементів у техногенних розсипах в межах зберігання відходів гірничого виробництва. Авторами розроблена математична модель процесу фільтрування забруднюючих речовин через ґрунтовий масив та надані рекомендації з екологічно безпечного зберігання й переробки відходів фосфогіпсу. Запропоновано технологію комплексної переробки відходів фосфогіпсу з виготовлення протирадіаційних будівельних виробів і супутнім вилученням рідкоземельних елементів.

Наукова новизна. Виявлено основні фактори та закономірності, що регулюють розподіл рідкоземельних елементів у техногенних розсипах в межах зберігання відходів гірничого виробництва, які впливають на сорбційні властивості порід.

Практична значимість. Дослідженням доведена практична можливість переробки техногенних розсипів у межах зберігання відходів фосфогіпсу та знаходження зон максимальної концентрації елементів на основі встановлених закономірностей.

Ключові слова: *техногенні розсипи, розподіл елементів, гірниче виробництво, рідкоземельні метали, збереження фосфогіпсу, переробка відходів*

Исследование процесса хранения и переработки техногенных россыпей фосфогипса

З. Маланчук, В. Мошинский, В. Цимбалюк, Л. Маланчук, Р. Жомырук, А. Васыльчук

Цель. Изучение условий хранении техногенных россыпей на примере отвалов фосфогипса ЧАО “Ровноазот” с определением сорбционных свойств пород, распределения, концентрации элементов и обоснование рекомендаций по переработке отходов данного производства.

Методика. Проведена серия экспериментальных, лабораторных и натурных исследований водно-физических свойств почв и выявление степени их загрязнения отвалами фосфогипса в условиях ЧАО “Ровноазот”. Коэффициент фильтрации определялся прибором ПВН-ОО. Гранулометрический состав определялся по методу Н.А. Качинского. Применено математическое моделирование процесса распределения элементов в границах складирования отходов. Исследована миграция фосфора, фтора, серы, меди, хрома, марганца, цинка, свинца, кадмия, железа, никеля и кобальта вдоль профиля искусственного почвенного сечения. Аппроксимация и статистическая обработка опытных данных проводилась в программных пакетах MathCad и Microsoft Excel.

Результаты. Установлены закономерности распределения элементов на техногенных россыпях в пределах хранения отходов горного производства. Авторами разработана математическая модель процесса фильтрации загрязняющих веществ через грунтовый массив и даны рекомендации относительно экологически безопасного хранения и переработки отходов фосфогипса. Предложена технология комплексной переработки отходов фосфогипса по изготовлению противорадиационных строительных изделий и попутным извлечением редкоземельных элементов.

Научная новизна. Определены основные факторы и закономерности, регулирующие распределение редкоземельных элементов в техногенных россыпях в пределах хранения отходов горного производства, которые влияют на сорбционные свойства пород.

Практическая значимость. Исследованием доказана возможность переработки техногенных россыпей в пределах хранения отходов фосфогипса и нахождения зон максимальной концентрации элементов на основе установленных закономерностей.

Ключевые слова: *техногенные россыпи, распределение элементов, горное производство, редкоземельные металлы, фосфогипс, переработка отходов*

Article info

Received: 11 September 2019
Accepted: 27 April 2020
Available online: 4 May 2020