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EVALUATION OF TECHNOLOGIES AND TECHNICAL MEANS FOR USING THE PHENOMENON OF NATURAL BISCHOFITE IN THE FIELD OF MINING INDUSTRY AND ECOLOGY

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Abstract: ***Goal.*** *Evaluation of technologies and technical means for the use of the phenomenon of the aqueous solution of natural bischophyte (RPB) in various branches of the national economy, in particular, the mining and mineral industry, ecology and medicine. Their use will improve the economic efficiency and environmental safety of the processes of blasting rock mass in quarries and storing waste from enrichment of ore raw materials in tailings storage facilities, freezing and freezing of ore mass during its transportation to enrichment plants.*
Research methods. *During the study, systematization, and generalization of technologies and technical means of using RPB, the analysis of research and publications, the results of industrial and experimental research at landfills using standard and new methods with the participation of authors and leading specialists in the specified fields were used.*
Scientific novelty. *The main scientific, practical and social results of the assessment of technologies and technical means for the use of the phenomenon of water RPB in various sectors of the national economy, in particular, in the mining industry, ecology and medicine, are given. The functional dependence between the freezing temperature of the mining mass (t_c, °C) and the content of the aqueous solution of natural bischofite in it (C_b, %) was established.*
Practical significance. *The technology to prevent winter slippage on quarry roads using RPB has been developed and implemented. Recommendations are given for combating the release of dust during the transportation of rock mass by rail transport, during mass explosions in quarries, on quarry highways and on tailings piles of GZK, with the use of RPB and bitumen emulsion, which allow to effectively fix dust surfaces from blowing dust. To reduce dust emission into the atmosphere during mass blasts in quarries, it is proposed to wet the surface of drilling dust with RPB with a density of 1250 - 1270 kg / m^3 and a consumption of 4.5 - 5.0 l / m^2.*
The results. *When using RPB instead of water during blasting operations in quarries, BP costs are reduced by 1.4-1.5 times and emissions of harmful gases during blasting are reduced by 20-30%. In underground mining operations, when water is replaced with RPB for moistening BP granules, the release of gases during a mass explosion in the mine is reduced by 1.3-1.4 times. To prevent freezing or freezing of rock mass to the inner surface of open wagons during transportation in the cold, preventive treatment of the inner surface of RPB railway wagons is carried out. In order to prevent ice on highways in quarries, they are also pre-treated with RPB. The technology of preventing winter slippage and dusting of quarry roads with RPB reagents with the use of watering machines was developed and implemented in the conditions of PJSC "Southern GZK" (Kryvbas, Ukraine). Recommendations for fighting dust on highways, landfills and tailings storage facilities of GZK, using RPB and bitumen emulsion, which allow to effectively fix dusty surfaces from blowing dust, using specially developed equipment, are given. In particular, the cost of processing ragweed RPB with an average overgrowth density of 5.0 kg/m^2 at the current cost of the solution of UAH 960/ton does not exceed UAH 40 per 100 m^2 (acre). One of the promising areas of further research is the use of large volumes of man-made underground cavities, formed during the leaching of bischofite, for the storage of useful liquid substances or for the disposal of waste at a depth of more than 1500 m.*
Keywords: *natural bischofite, mining industry, ecology, medicine*

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1. Introduction

The mineral bischofite ($MgCl_2$) is widely used in the national economy, medicine, cosmetology, ecology, etc. Bischofite contains sodium, calcium, potassium, bromine, etc. The purest deposits of bischofite (93-96%) in Ukraine are located in the Poltava and Chernigov regions, and in the Russian Federation in the Volgograd region, where they are located at great depth in the form of solid layers up to 30 m thick [1], [2]. In Ukraine, an aqueous solution of natural bischofite (RPB) ($MgCl_2 \cdot 6H_2O$) from the Poltava deposit is mainly used (Table 1) [3], [4].

Table 1. Physicochemical properties of a solution of natural bischofite

Name of indicators	Norm
Appearance	Aqueous colorless liquid, oily to the touch, odorless (color up to light brown with turbidity is allowed)
Density at 20 °C, kg/m^3	Not less than 1250
Total mineralization, kg/m^3	Not less than 320
Hazard class	Fourth
Solubility in water	Good. The solution has high hygroscopicity.
Toxicity	Not toxic
Aggressiveness	Not aggressive
Flammability	Not flammable
Explosiveness	Not explosive
Mass fraction,%: magnesium ions Mg+2	Not less than 7

Bischofite is used to treat arthritis, arthrosis, rheumatism, radiculitis, arrhythmia, hypertension, atherosclerosis, ischemic heart disease, neuroses, stress, gallstone disease, etc. Bischofite, as a balneological remedy, is used in the form of compresses, rubbing, local and general baths [5], [6]. Bischofite has found wide application in cosmetology, where it is used in various forms: massage gels; nasal sprays; toothpastes and mouthwashes; hair oil - magnesium bischofite; other cosmetics. The main scientific and practical results of technologies and technical means in the field of mining, ecology and medicine are most fully presented in works with the participation of the authors [7], [8].

Objective: Technologies and technical means for using the phenomenon of water RBP in various areas of the national economy, such as: mining industry, ecology, medicine, construction and agriculture. One of the most problematic areas is the technology for storing waste from ore processing, according to which the tailings of the mining and metallurgical plant are sent through a slurry pipeline to a tailings storage facility in the form of pulp with a solid-to-liquid mass ratio of 1:2. At wind speeds of 5 m/s or more, the surface of the tailings storage facility becomes an intensive source of dust emission and environmental pollution.

Goal. Evaluation of technologies and technical means for the use of the phenomenon of the aqueous solution of natural bischophyte (RPB) in various branches of the national economy, in particular, the mining and mineral industry, ecology and medicine. Their use will improve the economic efficiency and environmental safety of the processes of blasting rock mass in quarries and storing waste from enrichment of ore raw materials in tailings storage facilities, freezing and freezing of ore mass during its transportation to enrichment plants.

To achieve the stated goal, the authors solved the following tasks:

• analyze and evaluate the use of the phenomenon of water RPB in the field of mining, ecology and medicine, as well as other sectors of the national economy;

• consider the possibility of using the phenomenon of water RPB in construction, agriculture and weed control (ragweed);

• recommend technologies and means for blasting rock mass in quarries, storing waste from ore enrichment in tailings, preventing freezing and congealing of the ore mass during its transportation to the enrichment plants of Krivbass**.**

Methodology: During the study, systematization, and generalization of technologies and technical means of using RPB, the analysis of research and publications, the results of industrial and experimental research at landfills using standard and new methods with the participation of authors and leading specialists in the specified fields were used. During laboratory studies, the consolidation of dusty surfaces of tailings ponds was carried out in special ditches located in the open air. Experiments were conducted to study a soil mixture consisting of a soil mixture (clay), perennial grass seeds, mineral and organic fertilizers, film-forming materials, mulching additives (sawdust, chopped straw, water), which yielded positive results. An

industrial experiment on the consolidation of dusty surfaces was carried out directly on the southern part of the operating tailings pond of the hydrometallurgical plant (HMP) (Zhovti Vody, Ukraine). In the conditions of the tailings pond, three consolidation methods were tested on a plygon including 10 sections measuring 2.0 x 1.0 m: chemical; soil mixtures in the form of pellets; soil mixtures in the form of a specially prepared solution.

2. Discussion of research results

Bishofit is a unique natural remedy that is widely used in various branches of the national economy.

The use of RPB in construction. Bischofite is used in the production of xylalite for poured floors and tiles. Bischofite is also used for the production of glass-magnesium sheets. RPB is also used as a means of combating frostbite. It quickly melts the ice layer on the surfaces of highways, roofs of buildings and other structures.

Use of RPB in agriculture. Bishofit is used for feeding, first of all, crops with a large green biomass: corn, sugar beet, soybean, sorghum, potatoes, etc. To increase the fertility of seeds, their resistance to diseases and pests, as well as yield, pre-sowing treatment of grain crops with bischophyte is used. Garden trees and shrubs are sprayed with bischofite solution in the spring before the buds open.

Use of RPB in animal husbandry. The effectiveness of bischofite feed additives provides an increase in live weight for calves by 15-17% and young pigs by 16.5%.

The use of RPB in the fight against weeds. Ambrosia is an allergen that can lead to fatal consequences, so it is included in the list of quarantine objects. Ambrosia is very prolific. One ambrosia bush produces 30,000 to 150,000 seeds per season, the fertility of which remains for 40 years. A brief analysis of the known methods of fighting ragweed shows that they can be used in limited conditions, are not efficient enough and are not economical. A method of weed control based on the application of aqueous RPB has been developed and tested in industrial conditions [9], [10]. Treatment of leaves of ragweed RPB can be carried out at any stage of development from seedlings to flowering in dry weather. It is not advisable to process during the flowering period due to the appearance of pollen and the growth of seeds. RPB, which has the fourth class of danger and is used in medicine as a therapeutic agent, can be used to fight ragweed in the territories of cities, resorts, near roads, around fields, etc.

Use of RPB in medicine. Bishofit is one of the most harmless medicines that nature gives us. It is used for the treatment of arthritis, arthrosis, rheumatism, radiculitis, arrhythmia, hypertension, atherosclerosis, ischemic disease, neurosis, stress, cholelithiasis, etc. Bishofit, as a balneological remedy, is used in the form of compresses, rubbing, local and general baths [11], [12]. Bischofite has found wide application in cosmetology, where it is used in different forms: massage gels; nasal sprays; toothpastes and mouthwashes; hair oil - magnesium bischofit; other cosmetic products.

This work is a continuation of the research, the main scientific and practical results of which were obtained in the course of the research projects: "Research and development of dust suppression methods during transportation, warehousing, storage of minerals and waste from ore mining and processing at uranium industry facilities" ("Dust suppression") State registration number 0102U003095; "Research and development of technology and recipes for hardening mixtures from GMZ-2 tailings for filling surface storage maps, State registration number 0108U008936, scientific supervisor of the topic V.I. Lyashenko and are most fully presented in works with the participation of the authors [13], [14].

The study and generalization of studies in which the issue of using water RPB in the mining industry, ecology, and medicine is considered show that there is currently no systematic approach to their generalization.

Using RPB in blasting operations. It is known that most blasted holes in quarries are flooded, so they are loaded with loose explosives (EE), such as grammonite 79/21, in polyethylene sleeves. But water constricts the sleeve. Therefore, plugs of explosives are formed at the point of constriction. Water dissolves ammonium nitrate, which leads to a decrease in the amount of explosives and a violation of its oxygen balance and an increase in the gas content of the explosives. The authors proposed replacing the water supplied to eliminate the plug with RPB with a density of more than 1250 kg/m^3, which does not dissolve ammonium nitrate and has a cost an order of magnitude lower than grammonite 79/21 [15], [16]. This allows reducing the consumption of explosives by 1.4 - 1.5 times and reducing emissions of harmful gases by 20 - 30%.

When pneumatically charging boreholes in underground conditions. To prevent premature explosion from static electricity discharge, the regulatory document provides for moistening of grammanite 79/21 with water at a rate of 3 - 5%. Industrial studies have been conducted on replacing water with bischofite, which

made it possible to reduce gas emissions during a mass explosion in a mine by 1.3 - 1.4 times. In addition, an aqueous solution of bischofite completely eliminates the accumulation of electrostatic electricity during friction of explosive granules on the surface of the charging hose, due to its high conductivity [17], [18].

Using RPB in transporting rock mass. When transporting iron and manganese ores in the winter, at negative air temperatures, freezing to the inner surface of railway cars and their freezing occurs. The main reason for the freezing of the rock mass is their humidity. Therefore, mechanical or preventive methods of cleaning wagons are used to remove it, which leads to long periods of downtime of railway wagons and significant costs compared to RPC (Table 2).

Table 2. Characteristics of methods and means for restoring the flowability of frozen cargo

Name methods and means	Minimum freezing temperature, °C	Average consumption, kg/t	Cost, UAH/t
Mechanical crushing of cargo	any	-	15,0 – 20,0
Thermal treatment of cargo	any	-	7,0 – 12,0
Dehydration of cargo with quicklime	minus 30	60 – 65	8,0 – 14,0
Defrosting of cargo in greenhouses	any	-	1,5 – 9,0
Aqueous solution of calcium chloride	minus 25	0,2 – 0,4	0,7 – 0,8
Preventive treatment with niogrin	minus 35	0,5 – 0,6	0,6 – 0,8
Preventive treatment with severin	minus 55	0,5 – 0,6	0,8 – 1,0
Mechanical crushing of cargo	minus 15	0,8 – 1,0	0,5 – 0,6
Thermal treatment of cargo	minus 30	0,2 – 0,4	0,15 – 0,2

As can be seen from Table 2, the most cost-effective method is the preventive treatment of the inner surface of railway cars with RPB, which has been used at mining enterprises for over 25 years. In addition, compared to crude oil or petroleum products, bischofite is safe. Cars treated with petroleum products often catch fire during repairs [19].

Every year, to prevent freezing of ores, 3.0 - 5.0 thousand tons of bischofite are delivered to mining enterprises, depending on climatic conditions. RPB is delivered in railway tanks, which are more often used to transport petroleum products. As a rule, a layer of oil accumulates in such tanks. RPB cleans the tanks and acquires the smell of petroleum products, which eliminates its theft.

One of the active sources of environmental pollution by ore enrichment products are tailings dumps. During the equipment of tailings dumps, dehydrated areas of large area are formed on their surfaces. In summer periods, the surface heats up to 60 °C and the dry layer reaches a thickness of 30-50 cm. Dry tailings are loose sandy material, between the particles of which (except for insignificant forces of surface tension, molecular, chemical bonds and silicification) there are no stable bonds, for example, dust. At a wind speed of 5 m / s or more, the surface of the tailings dump becomes an intensive source of dust emission,

The traditional method of combating dust on dry beaches of tailings dumps is based on fixing dusty surfaces by creating films or anti-erosion crusts. Humidification is the most commonly used method of combating dust. Humidification of the highest 2500 m tailings dump in the world Los Pelambres in Chile is shown in Fig. 1 [20].

Fig. 1. Mauro tailings dam at the Los Pelambres copper-molybdenum mine in Chile (photo)

A wet beach does not produce dust either, but moisture sometimes evaporates and such a beach requires additional water supply, which is very expensive. In addition, reclamation of such tailings will be difficult due to the low strength of their surfaces. Fixing agents are applied to the surface of the tailings. In bulk tailings, light fractions (silt and clay) are concentrated in the upper layer of the beaches. The upper layer (10–20 mm) contains up to 90% of the particles of these fractions. The filtration coefficient of the upper layer is on average 0.02–0.03 m/day. Due to low filtration, penetration of fixing solutions deep into the tailings does not occur and an insoluble crust does not form. After drying, a thin film is formed on the surface of the fixing agent, which is easily destroyed and washed away with water. Most of the fixing solution goes through cracks or collects in the formed depressions. The anti-erosion film is a sliding plane with reduced strength characteristics - the angle of internal friction and adhesion, which contributes to the destruction of dams. Enrichment tailings with various fillers and additives are subject to natural leaching, the products of which disrupt the ecosystems of the environment (Table 3).

Table 3. Strength of anchoring the surface of the tailing dump

Massif fixation technology	**Strength, MPa**		
	min	**max**	**average**
Claying	0,05	2,2	1,1
Cementation	0,22	6,6	1,7
Silicatization	0,10	10,0	3,2
Bituminization	0,10	2,0	1,2
Combined with PVA additive	0,10	3,3	1,4
Herbal fixation	herbal fixation		
Carbonatization	0,30	1,50	0,80
Chemical fixation	0,30	0,46	0,67

Technologies with fixation of leaching tailings with secondary mineralization products have been used for 40 years in the development of the Bykogorskoye uranium deposit (North Caucasus) by underground mine leaching with a 3% sulfuric acid solution. As a result of the colmatation processes, the leaching tailings acquired a strength of 0.5–1.0 MPa [21].

Selection of effective methods of fixing dusty surfaces. Chemical fixation of the dusty surface consisted of treating the surface of the tailings storage facility with chemicals (see Fig. 2,a). Water-soluble polymers exhibit stabilizing properties when contained in soils in the amount of 10-2…10-1 mass %. The solid to liquid (S:L) ratio in the initial pulp varied from 1 to 5. The content of fixing agents (polymers) in relation to water was 0.5% polyacrylamide and 2% hypane and lignosulfonate. An aqueous solution of fixing agents was prepared immediately before their application. Application to the dusty surface of the tailings storage facility was carried out by spraying with a watering can. The solution consumption was 5-6 liters per 1 m^2 of surface, adjusted taking into account small areas to be fixed.

Biological fixation of the dusty surface. Fixing of dusty surfaces with soil mixtures in the form of pellets consisted of laying a spherical fixing material on the dusty surface, while the pellets were made of clay, straw (reed), sawdust, binding additives (GIPAN, lignosulfonates) and water in the following ratios of ingredients, mass %; clay - 68-75; crushed straw, reed or sawdust - 3-8; lignosulfonates or GIPAN - 0.3-1; plant seeds, water - the rest (see Fig. 2, b). Pellets were prepared in advance in the laboratory conditions of the State Enterprise "UkrNIPIIpromtekhnologii". Consumption of 8-10 kg of pellets per 1 m^2. Straw or reed was cut into pieces up to 2 cm long, sawdust, sifted through a sieve with a hole diameter of 10 mm, was cut into pieces up to 2 cm long, and sawdust, sifted through a sieve with a hole diameter of 10 mm, was cut into pieces up to 2 cm long. 1 cm. Straw consumption up to 10 kg per 1 m^2 of surface. Application to the dusty surface was carried out by scattering.

Fixing dusty surfaces with a specially prepared composition consists of laying a fixing material in the form of a clay solution with additives (see Fig. 2, c). Clay, black soil, sawdust, lignosulfonates or GIPAN, water, fertilizers, plant seeds were used as ingredients. Consumption is 12-15 liters per 1 m^2. It is advisable to fix dusty surfaces of the tailings dump with compositions containing: water, fertilizer, grass seeds, GIPAN and mulching additives (clay and sawdust) or water, fertilizer, grass seeds, GIPAN and mulching additives (clay, CHPP ash and sawdust). The soil mixture was prepared at the tailings dump before its application. At tailings dumps where the pH of the tailings is within 6.5-7.5, biological fixation of the dusty surface is possible by applying fertile soil mixtures to their surface, consisting of clay, ashes from thermal power plants, mulching and gluing additives, grass seeds and fertilizers. The application of such a mixture is carried

out using a hydroseeder, based on tracked or wheeled tractors, airplanes or helicopters, which are used by the Ministry of Emergency Situations of Ukraine to suppress fires. Reclamation work (mining and technical reclamation) at the mothballed tailings dump of the Mining and Metallurgical Plant (Zhovti Vody, Ukraine) is shown in Fig. 3[22].

a

b

c

Fig. 2. Fixing dusty surfaces in ditches with tailings (photo: general view): a - chemical fixing; b - processed pellets (granules) based on soil mixtures; c - specially prepared composition

Fig. 3. Reclamation works at the tailings storage facility of the Mining and Metallurgical Plant Zhovti Vody, Ukraine (photo: general view)

Dust suppression technology. Dust suppression is carried out by applying a thin layer of bitumen emulsion to the dusty surface. The consumption of bitumen emulsion is 0.12 kg / m^2, i.e. to protect the required, for example, 1,000,000 m^2 of dusty dam surface, about 120.0 tons of bitumen emulsion per year are required. To prepare 120.00 tons of emulsion, about 60 tons of bitumen, 60 tons of water and 3.6 tons of emulsifier are required. The bitumen emulsion is prepared using a special emulsion generator. The dust protection period is

one year. The layer of emulsion applied to the alluvial beach does not create an anti-seepage screen, i.e. does not reduce the stability of the dam, does not pollute the seepage water with oil products or other harmful substances, i.e. it is environmentally safe. As a result of the dust suppression works performed, according to the sanitary and epidemiological service, the dust content in the air above and around the tailings dump is below the maximum permissible concentrations. For stationary application of the technology, the following equipment and structures are required: emulsion generator; bitumen emulsion warehouse; equipment for loading and unloading emulsion; vehicle, tractor or helicopter; attachments for emulsion spraying. The disadvantage of this technology is its short service life (one year), as well as the low strength of the surface layer of the storage facility, which will complicate the process of reclamation of this tailings dump.

Dust suppression technology based on a solution of natural bischofite. Industrial studies of the efficiency of the proposed technology for fixing the surface of tailings based on a solution of natural bischofite (RPB) were conducted on dry beaches of the operating tailings dumps of the mining and processing plants of Arcelor Mittal Kryvyi Rih OJSC and Northern GOK OJSC, Ukraine. As industrial studies have shown, the efficiency of the technology proposed for fixing dry surfaces of operating tailing dumps in the conditions of JSC "Northern GOK", Ukraine has seen a decrease in air pollution by dust from 4.6 to 17 times.

Dust control. The use of RPB to control dust emission is carried out during transportation of rock mass by rail, during mass blasts in quarries, on quarry roads and at tailings dumps. The duration of ore transportation from mining enterprises to metallurgical plants located in Ukraine and abroad is within 6-96 hours, and the train speed can exceed 20 m/s. At such a speed, internal vortex flows arise inside the gondola car, which blow away dust from the surface of the ores [23]. Studies have shown that the concentration of dust in the air near the railway, at a train speed of more than 20 m/s, exceeds the permissible dust levels by 6-8 times. It is proposed to reduce dust blowing to a concentration of 2.0 mg/m^3 by wetting the ore surface in the RPB car at the following flow rate (Table 4).

Table 4. Change in RBP consumption from train speed

Train speed, m/s	Up to 7,0	7,0 – 15,0	15,0 – 20,0	More then 20,0
RPB consumption, kg/m^2	0,5	1,0	1,5	2,0

The surface treated with water dries quickly, the amount of blown dust increases and after 3-4 days reaches 200 g/m^2, which corresponds to dry dust (Fig. 1). The amount of dust blown off the surface of ore treated with bischofite is stable (5-12 g/m^2) for seven days, after which it begins to increase noticeably. This is explained by partial evaporation of bischofite.

During mass explosions in quarries, a large amount of fine dust is emitted into the atmosphere, the concentration of which in the dust and gas cloud exceeds the permissible standards by hundreds of times [24]. One of the main sources of dust emission is drilling dust, which is located near the well within a radius of 2.5 - 3.0 m, and during a mass explosion is blown away by the gases of explosives, polluting the atmosphere. To reduce dust emission, it is suggested to wet the surface of drilling dust with RPB with a density of 1250 – 1270 kg/m^3 and a flow rate of 4.5 – 5.0 l/m^2. Due to its oily structure and high hygroscopicity, bischofite reliably fixes the surface of drilling dust, preventing atmospheric pollution.

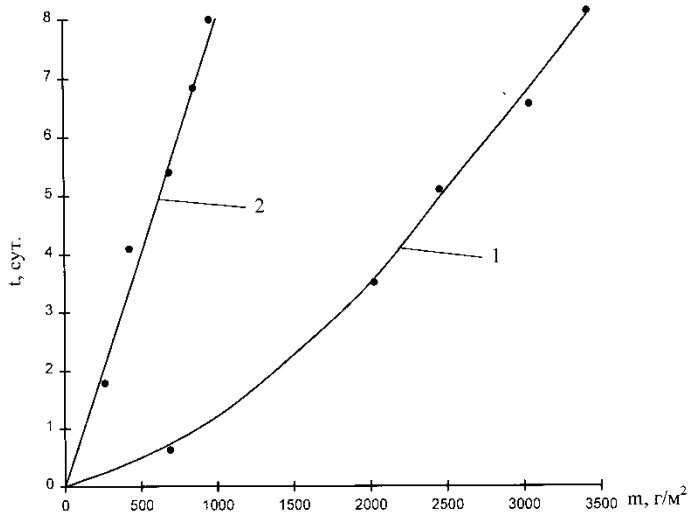

Fig. 4. Increase in the amount of dust blown off over time from the surface of ore in a wagon treated with water (1) and bischofite (2) at an air speed of V = 12.5 m/s

One of the main sources of dust emission is drilling dust, which is located near the well within a radius of 2.5 - 3.0 m, and during a mass explosion is blown away by explosive gases, polluting the atmosphere. To reduce dust emission, it is proposed to wet the surface of the drilling dust with RPB with a density of 1250 - 1270 kg / m^3 and a flow rate of 4.5 - 5.0 l / m^2. Due to its oily structure and high hygroscopicity, bischofite reliably fixes the surface of the drilling dust, preventing pollution of the atmosphere. More than 70% of the iron ore mined in Krivoy Rog (Ukraine) is processed at five mining and processing plants (MPPs). Beneficiation waste (tailings) are stored in tailings dumps, the area of which is about 7,000 hectares. The volume of tailings that are annually stored in tailings dumps is 30-40 million m^3. The height of some tailings ponds reaches 100 m, which contributes to the action of wind erosion and does not allow maintaining the water level above the surface of the tailings. Most of the tailings contain silicosis-hazardous dust with a particle diameter of less than 50 microns (up to 90%). When inhaled, such dust leads to silicosis, bronchitis, etc. To prevent the negative impact of existing tailings ponds on human health, various authors propose to fix the dry areas of tailings ponds with oil refining waste, latex, polymers and other materials that create a thin film on the surface of the tailings. However, they have not found application due to the low mechanical strength of the film, toxicity, impossibility of use in winter, high cost, etc. Industrial studies at the existing tailings ponds of PJSC Severny GOK and PJSC ArcelorMittal Kryvyi Rih (PJSC AMKR) have shown that the most effective and cost-effective technology for fixing the surface of existing tailings ponds was the RPC (Table 4) [25].

Table 4. Indicators of surface fixation of tailings storage facilities of the RPC

Card No.	Temperature, °C	Relative humidity of air, %	Wind speed, m/s	Time after card processing, days	Tailings humidity, %		Air dustiness, mg/m^3		Presence of precipitation
					processed RPB	control chart	processed RPB	control chart	
1	-4.8	70	3-4	13	5.52	4.61	0.16	2.6	snow
1	-3.0	75	5-7	27	6.97	0.96	0.3	116	no precipitation
1	7.0	68	5.7-6.0	3	10.0	0.9	1.06	125	no precipitation
9	14.2	82	6-7	11	-	-	0.8	26.0	no precipitation
10	12.2	86	4-6	14	-	-	0.3	15.5	rain
14	12.0	70	3.8-4.0	15	-	-	0.43	2.3	no precipitation
15	8.0	84	5.4-6.0	16	11.3	1.6	1.13	6.0	short-term rain
9	25.0	63	4.4-4.8	44	9.1	1.3	1.0	4.6	short-term rain
10	25.0	63	4.4-4.8	43	6.53	1.3	0	4.6	short-term rain
12	25.0	63	3.8-4.0	38	5.36	1.3	0.27	4.6	short-term rain
13	25.0	63	4.0	29	4.0	1.3	0.27	4.6	short-term rain
14	25.0	63	4.0	37	4.1	1.3	0.27	4.6	short-term rain
15	25.0	63	4.0	30	8	1.3	-	4.6	short-term rain
16	25.0	63	3.5-4.0	26	3.24	1.3	0.4	4.6	short-term rain
9	26.0	60	2.5-3.0	75	8.8	0.15	0.26	4.5	dry
10	26.0	60	2.5	74	6.0	0.15	0.44	4.5	dry

As industrial studies of the efficiency of the proposed technology for fixing dry surfaces of operating tailings storage facilities in the conditions of PJSC Severny GOK (Kryvbas, Ukraine) have shown, there is a decrease in air pollution with dust from 4.6 to 17 times. Unlike other technologies and means, RBP can be used throughout the year and does not require special equipment. RBP was applied to the surface of the beaches by hydraulic monitors mounted on the basis of BelAZ 7648 vehicles (Fig. 5), which, moving along the dams, fixed the surface of the tailings (Fig. 6).

The range of the jet, taking into account the wind direction, was within 50-120 m, which made it possible to process the entire surface of the map with the RPC (see Fig. 6). The height of the RPB droplets falling on the surface of the card exceeded 1 m, the optimal costs were accepted within 1.5-2 l/m^2. During the research, 9 cards with a total area of over 200 hectares were fixed at both enterprises. During the experiments, it was established that the use of RPB with a density of at least 1250 kg/m^3 has the longest fixation effect (at least 70 days).

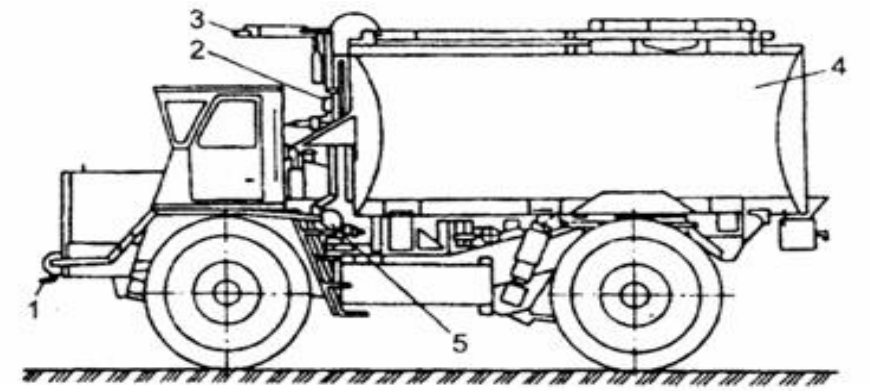

Fig. 5. Vehicle for applying RBP: 1 - sprinklers for watering roads; 2 - hydraulic control system; 3 - hydraulic monitor; 4 - liquid tank; 5 – pump

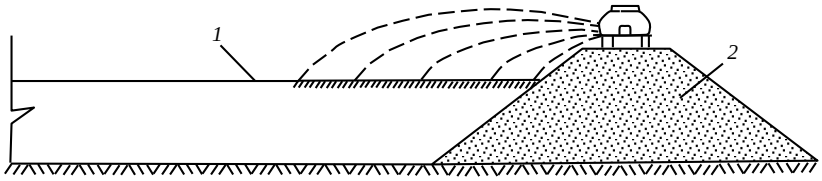

Fig. 6. Scheme of applying the RPB to the map of the tailings storage facility: 1- map surface; 2 – slope reinforcement

The authors have established that despite periodic rains and other adverse weather conditions, the RPB applied to the tailings surface continues to maintain high humidity in the upper part of the tailings storage facility by binding fine dust.

Combating ice on roads in quarries. The technology of preliminary RPB treatment has shown high efficiency in preventing winter slipperiness and dusting of roads in quarries for the extraction of iron ore raw materials in Kryvbas (Ukraine). Industrial studies have shown that the treatment of roads in the Kryvyi Rih quarries should begin from the surface at an atmospheric air temperature of up to minus 3.0 °C, at a quarry depth of more than 100 m at an atmospheric air temperature below minus 3.0 °C, and at a quarry depth of more than 200 m - below minus 5.0 °C [26].

During preventive treatment of quarry roads with RPB, carried out using watering machines before the appearance of winter slipperiness during the period of predicted sharp drop in air temperature to minus 2–5 °C. After the air temperature increases, quarry roads treated with RPB do not produce dust for a long time when vehicles move along them. After receiving information about the decrease in air temperature, the volume of the required RPB is determined. Treatment of the road surface with RPB using watering machines with a specialized distribution device begins no later than three hours before frost. Fig. 4 shows the dependence of the freezing temperature of the rock mass ($t_з$, °C) on the content of aqueous RPB in it ($C_б$, %). RPB consumption (Q_b) is determined by the formula

$$Q_б = 2{,}6 \cdot \delta \cdot l_ш \cdot l_д \cdot t_n,$$

where δ, $l_ш$, $l_д$ are, respectively, the thickness of the crushed stone, the width and length of the quarry road, m; t_n is the negative air temperature, °C.

In other sectors of the national economy

In construction. Bischofite is used in the production of xylalite for self-leveling floors and tiles. Bischofite is also used in the production of glass-magnesium sheets. As noted above, RPB is also used as an anti-icing agent. It quickly melts the ice layer on road surfaces, roofs of buildings and other structures. A functional relationship (Fig. 7) has been established between the freezing temperature of the rock mass ($t_з$, °C) and the content of an aqueous solution of natural bischofite ($C_б$, %) in it.

In agriculture. Bischofite is used for feeding, first of all, crops with large green biomass: corn, sugar beet, soybeans, sargo, potatoes, etc. To increase seed germination, their resistance to diseases and pests, as well as yield, pre-sowing treatment of grain crops with bischofite is used. Spraying garden trees and shrubs with a bischofite solution is carried out in the spring before the buds open. In animal husbandry, the

effectiveness of bischofite additives in feed ensures an increase in live weight for calves by 15 - 17% and young pigs by 16.5%. The fight against weeds: ragweed is an allergen that can lead to death, so it is included in the list of quarantine objects. Ragweed is very prolific. One ragweed bush produces from 30 to 150 thousand seeds per season, the germination of which is maintained for 40 years. A brief analysis of known methods of ragweed control shows that they can be used in limited conditions, are not effective enough and are not cost-effective. A method of weed control based on the use of water RPB has been developed and tested in industrial conditions [27].

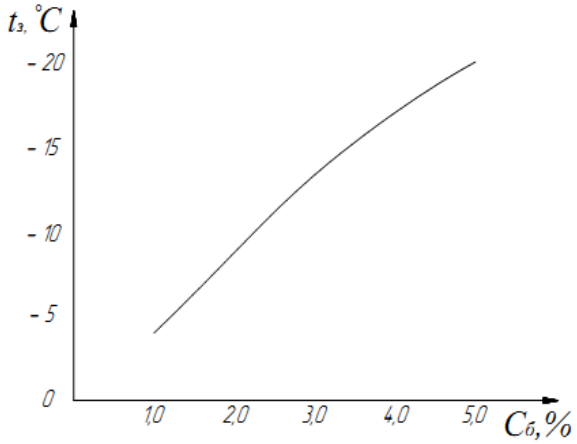

Fig. 7. Dependence of the freezing temperature of the rock mass (t_s, °C) on the content of the aqueous solution of natural bischofite (C_b, %) in it

The treatment of ragweed leaves with RPB can be carried out at any stage of its development from germination to flowering in dry weather. It is not advisable to treat during the flowering period due to the appearance of pollen and seed growth. RPB, which has the fourth hazard class and is used in medicine as a therapeutic agent, can be used to combat ragweed in cities, resorts, near roads, around fields, etc.

4. Efficiency of the research

The developed technology for preventing dust emission from the surface of tailings storage facilities is effective at wind speeds of up to 8.0 m/s at positive and negative air temperatures. Experience in using the technology has shown that at high air temperatures (above 25 °C) and relative air humidity of less than 60%, RPB can evaporate. As a result, a crust that is difficult to blow off forms on the surface of the tailings. However, due to the high hygroscopicity of bischofite, when the relative air humidity increases to more than 65%, the crust dissolves and retains moisture.

A technology is proposed for preventing winter slipperiness and dusting of quarry roads with reagents of an aqueous solution of natural bischofite using watering machines before winter slipperiness occurs during a predicted sharp drop in air temperature to minus 2–5 °C. Recommendations are given for dust control on roads, waste dumps and tailings dams of mining and processing plants, using RPB and bitumen emulsion, allowing to effectively fix dusty surfaces from blowing off dust, using specially developed equipment.

A promising method is also biological fixation of dusty surfaces of mining and processing plant tailings dams, with a soil mixture consisting of clay, seeds of perennial grasses, mineral and organic fertilizers, film-forming materials, mulching additives, ash from a heat and power plant and water.

The recommended consumption of RPB should be at least 0.08 l per 1 kg of ragweed biomass with a density of at least 1250 kg/m^3. At a lower density, it is necessary to increase the consumption of the solution. The cost of processing ragweed with RPB of average overgrowth density of 5.0 kg/m^2 at the current cost of the solution of 960 UAH/t does not exceed 40 UAH. per 100 m^2 (hundred square meters).

5. Perspective research directions

The authors have shown that bischofite is a unique tool and is already widely used to obtain magnesium, to treat various diseases and to improve safety and efficiency of work [28].The authors have developed technologies and technical means at the level of inventions and patents for the further application of the phenomenon of water RBP in the field of mining, ecology and medicine, as well as other sectors of the national economy [29].Their use will improve the economic efficiency and environmental safety of the

processes of blasting rock mass in quarries and storing waste from ore enrichment in tailings dumps, freezing and freezing of the ore mass during its transportation to enrichment plants [30].

In our opinion, a promising direction is biological reclamation for accelerated greening of reclaimed tailings (covered with a layer of clay and chernozem), which in the conditions of Kryvbas, Ukraine, showed the best results, in particular, gives kochia bernichnaya. It reliably fixes the surface of the tailings with roots and stems for 1.5-2 months, forming a large biomass, a continuous reliable coating that prevents blowing off silicosis-hazardous dust of tailings. Promising is considered to be the fixation of dusty surfaces of the tailings of hydrometallurgical production waste to carry out soil mixtures in the form of pellets, which were made of clay, straw (reed), sawdust, bonding additives (GIPAN, lignosulfonates) and water in the following ratios of ingredients, mass.%: clay - 68-75; crushed straw, reed or sawdust - 3-8; lignosulfonates or GIPAN - 0.3-1; plant seeds, water - the rest. Pellets consumption – 8 -10 kg per 1 m2. The specified technology has been tested in industrial conditions and has shown positive results at the site of the operating tailings storage facility (Zhovti Vody, Ukraine) [4].

6. Conclusions

Methods have been developed for forming a charge of water-filled explosive (Patents of Ukraine No. 13592 (19) UA and No. 54915 (19) UA and by replacing the water supplied to eliminate the plug with RPB with a density of more than 1250 kg/m^3, which does not dissolve ammonium nitrate and has a cost an order of magnitude lower than grammonite 79/21. This allows for a reduction in explosive consumption by 1.4–1.5 times and a reduction in harmful gas emissions by 20–30%.

A method for dust suppression during a mass explosion in a mine (Patent of Ukraine No. 32542 A) has been proposed by replacing water with bischofite, which allows for a reduction in gas emissions during a mass explosion in a mine by 1.3–1.4 times.

A means for preventing freezing and sticking of bulk materials (Patent of Ukraine No. 26522 A) during their transportation to processing plants by preventive treatment of the inner surface of RPB railway cars is recommended. A functional dependence between the freezing temperature of the rock mass ($t_з$, °C) and the content of an aqueous solution of natural bischofite ($C_б$, %) in it is established. A method for fixing the surfaces of dry beaches of operating RPB tailings ponds (Patent of Ukraine No. 31847 A) was also tested under the conditions of PJSC Severny GOK (Kryvbas, Ukraine) and made it possible to reduce air pollution with dust from 4.6 to 17 times.

A method for treating common ragweed with water-based RPB (Patent of Ukraine No. 13592 (19) UA) at different stages of its development, from June to November, has been developed and tested in industrial conditions on the chernozem of Ukraine and has shown positive results. One of the promising areas for further research is the use of large volumes of man-made underground voids formed during the leaching of bischofite for storing useful liquid substances or for waste disposal at a depth of more than 1500 m.

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References

[1] **x x x,** 1997
Natural Bischofite Solution (RPB) TU 25 Ukraine 22529511-003-97. (in Ukrainian)

[2] **Chernov A.P.**, et al., 2001
Mining and Processing of Uranium Ores in Ukraine. Monograph. Under the general editorship of ***A.P. Chernova.*** *K.: Adef – Ukraine,* 238 p. (in Ukrainian)

[3] **Serdyuk A.M. Stus V.P., Lyashenko V.I.,** 2011
Ecology and Livelihoods of the Population in the Industrial Regions of Ukraine. *Dnipropetrovsk. Vidavnitstvo "Thresholds"*, 486 p. (in Ukrainian)

[4] **Lyashenko V. I., Golik V. I.,** 2017
Scientific and Design/ Technological Support for the Development of Uranium Production. Achievements and Tasks // Mining Information and Analytical Bulletin, No. 7, pp. 137/152, [in Russ]. DOI: 10.25018/0236/14932017/7/0/137/152

[5] **Kuzmin E.V., Svyatetsky V.S., Markovets V.V.,** 2018
Thickening of Uranium Ore Processing Waste to Produce Paste for Underground Placement // Mining Journal. – No. 7, pp. 73–77 [in Russ]. DOI: 10.17580/gzh.2018.07.14.

[6] **Lyashenko V.I., Dyatchin V.Z., Lisovoy I.A.,** 2017
Improving the Safety of Mining Operations Based on Effective Management of Waste from Mining and Processing of Ore Raw Materials // Occupational Safety in Industry, No. 11, pp. 16–22, [in Russ].

[7] **Gurin A.A., Lyashenko V.I.,** 2018
Improving the Methodology for Assessing the Impact of Mass Emissions in Quarries on the Environment // Occupational Safety in Industry, No. 1, pp. 35–41, [in Russ].

[8] **Gurin A. A., Shapovalov V.A.**, 2022
Assessment of Technologies and Technical Features for the Recovery of the Phenomenon of Natural Bichofite in Galusia Ecology and Mining Industry // Bulletin of the Krivorizky National University: zb. Sci. fuck off. – Krivy Rig. - VIP. 55. – pp. 76–82, (in Ukrainian).doi: 10.31721/2306-5451-2022-1-55-76-82

[9] **Lyashenko V.I., Vorobiev A.E., O.E. Khomenko O.E., Dudar T.V.,** 2022
Development of Technologies and Technical Means to Reduce the Impact on the Environment in the Zone of Influence of the Tailings Storage Facility// Bulletin of Magnitogorsk State Technical University named after G.I. Nosov, Vol. 20, No. 1, pp. 25–41, [in Russ]. DOI: 10.18503/1995-2732-2022-20-1-25-41

[10] **Lyashenko V.I., Gurin A.A.**, 2016
Environmental Protection Technologies and Means for Dust Suppression of Tailings Storage Surfaces // Ferrous Metallurgy. Bulletin of Scientific, Technical and Economic Information, No. 4, pp. 10-17, [in Russ]

[11] **Gurin A.A., Shapovalov V.A., Lyashenko V.I.**, 2020
Technology for Improving the Safety of Quarry Roads and Preventing Dusting of Mining and Processing Plant Tailings by Treating Them with an Aqueous Solution of Natural Bischofite // Ferrous Metallurgy. Bulletin of Scientific, Technical and Economic Information. 76 (11): 1089-1096, [in Russ].https://doi.org/10.32339/0135-5910-2020-11-1089-1096

[12] **Lyashenko V.I., Golik V.I., Dyatchin V.Z.**, 2020
Improving Environmental Safety by Reducing Technogenic Load in Mining Regions // News of Universities. Ferrous Metallurgy. Vol. 63, No. 7, pp. 529-538, [in Russ].https://doi.org/10.17073/03680797-2020-7-529-538

[13] **Osipov Yu.V., Koshelev A.E., Voznesensky A.S.,** 2020
Experimental Studies of Deformation Properties of Bischofite // Ferrous Metallurgy. Mining Information and Analytical Bulletin. - No. 10, pp. 5-15, [in Russ]. DOI: 10.25018/0236-1493-2020-10-0-5-15

[14] **Glebov A.**, 2017
Selection of Gathering Auto Transport for the Systems of Cyclical-and-Continuous Technology. Mining of Mineral Deposits, 11(4), 11-18, (in Ukrainian).https://doi.org/10.15407/mining11.04.011

[15] **Stupnik, M., Kalinichenko, V., Fedko, M., Kalinichenko, O., Pukhalskyi, V., Kryvokhin, B.**, 2019
Investigation of the Dust Formation Process when Hoisting the Uranium Ores with a Bucket. Mining of Mineral Deposits, 13(3), 96-103, (in Ukrainian), https://doi.org/10.33271/mining13.03.096

[16]. **Kofanov, O., Vasylkevych, O., Kofanova, O., Zozul'ov, O., Kholkovsky, Yu., Khrutba, V, Borysov, O., Bobryshov, O.**, 2020
Mitigation of the Environmental Risks Resulting from Diesel Vehicle Operation at the Mining Industry Enterprises. Mining of Mineral Deposits, 14(2), 110 – 118, (in Ukrainian), https://doi.org/10.33271/mining14.02.110

[17] **Kulikova E.Yu., Vinogradova O.V.**, 2020
Risks as a Reason for the Decrease in Industrial Safety during the Construction of Underground Structures // Mining Information and Analysis Bulletin, No. 7, pp. 146-154, [in Russ]. DOI: 10.25018/0236-1493-2020-7-0-146-154

[18] **Qi Sun, Jian Lu, Jun Wu,** 2019
Guangcan Zhu Catalytic Ozonation of Sulfonamide, Fluoroquinolone, and Tetracycline Antibiotics Using Nano-Magnesium Hydroxide from Natural Bischofite. / Water, Air, & Soil Pollution volume 230, Article number: 55

[19] **Piven V.O., Krivosheev O.V., Storchak A.S., Nemirovsky G.I., Gurin A.O., Ratushny V.M.,** 2005
Patent for vinahid No. 54915A 19 (UA) IPC F42D3/4. E21B 37/00. A method for forming a charge of water-based vibrator. / Publ. 09/15/2005. Bull. No. 9

[20] **x x x,** 2024
Construction of a tailings dam at the Los Pelambres copper-molybdenum mine in Chile. URL: http//mineral.ru/News/34680.html (date accessed: 15.08.2024)

[21] **Gurin A. A., Davidov A.V., Morgun O.V., Krivenko Yu.Yu.,** 2006
Patent for corisna model No. 68911 MPK F42D 1/08 (2006), F42D 3/4 (2006). Method for molding a solid-wine charge. / Publ. 04/10/2012, Bull. No. 7, (in Ukrainian)

[22] **Gurin A. A., Krivenko T.A., Gurin K.Yu.,** 2019
Patent for corisna model No. 13592 (19) UA IPC (2019.01) A 0159/06. Method of processing full-leaf ambrosia / Bulletin no. 13, 07/10/2019, (in Ukrainian)

[23] **Clemens S.**, 2006
Toxic Metal Accumulation, Responses to Exposure and Mechanisms of Tolerance in Plants // Biochimie, Vol. 88, pp. 1707–1719, [in Russ]

[24] **Rosenfeld C.E., Chaney R.L., Tappero R.V., Martínez C.E.,** 2017
Microscale Investigations of Soil Heterogeneity: Impacts on Zinc Retention and Uptake in Zinc-Contaminated Soils // Journal of Environmental Quality, Vol. 46, No. 2, pp. 373–383, [in Russ]

[25] **Lyashenko V.I.,** 2015
Nature Protection Technologies for Development of Mineral Deposits // Mine Surveyor's Bulletin, No. 1, pp.10-15, [in Russ]

[26] **Nekhunguni, P. M., Tavengwa, N. T., Tutu, H.**, 2017
Sorption of Uranium (VI) onto Hydrous Ferric Oxide-Modified Zeolite: Assessment of the Effect of pH, Contact Time, Temperature, Selected Cations and Anions on Sorbent Interactions. Journal of Environmental Management, 204, 571–582, [in Russ].doi: http://doi.org/10.1016/j.jenvman.2017.09.034

[27] **Jung, H. B., Xu, H., Konishi, H., Roden, E.E.**, 2016
Role of Nano-Goethite in Controlling U(VI) Sorption-Desorption in Subsurface Soil. Journal of Geochemical Exploration, 169, 80–88, doi: http://doi.org/10.1016/j.gexplo.2016.07.014

[28] **Petlovanyi, M., Kuzmenko, O., Lozynskyi, V., Popovych, V., Sai, K., Saik, P.**, 2019
Review of Man-Made Mineral Formations Accumulation and Prospects of their Developing in Mining Industrial Regions in Ukraine. Mining of Mineral Deposits, 13(1), 24-38, (in Ukrainian). https://doi.org/10.33271/mining13.01.024

[29] **Blyuss, B., Semenenko, Ye., Medvedieva, O., Kyrychko, S., Karatayev, A.**, 2020
Parameters Determination of Hydromechanization Technologies for the Dumps Development as Technogenic Deposits. Mining of Mineral Deposits, 14(1), 51-61. (in Ukrainian). https://doi.org/10.33271/mining14.01.051

[30] **Moshynskyi, V., Malanchuk, Z., Tsymbaliuk, V., Malanchuk, L., Zhomyruk, R., Vasylchuk**, **O.**, 2020
Research into the Process of Storage and Recycling Technogenic Phosphogypsum Placers. Mining of Mineral Deposits, 14(2), 95-102, (in Ukrainian). https://doi.org/10.33271/mining14.02.095.