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INNOVATIVE TECHNOLOGY FOR JOINT PURIFICATION OF HIGHLY MINERALIZED MINE WATER AND BOILER-ROOM EMISSIONS

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INTRODUCTION

Industrial wastewater from mining and metallurgical enterprises is a large-scale source of water pollution. Suspended solids, salts heavy metals, petroleum products, and other substances contained in the polluted water can further accumulate in water bodies and aquatic organisms, causing negative environmental processes of pollution and migration.

Some promising methods for wastewater treatment from coal industry enterprises are demineralization, desalting, ultrafiltration, reverse osmosis, etc. The use of these methods makes it possible to reduce the content of mineral and salt components not only to the requirements for discharge into surface water bodies but also to use for technical and economic purposes and household needs. The reuse of treated wastewater for technical water supply will eliminate the existing shortage of freshwater resources.

The problem of reducing technogenic pressure on the hydrosphere is particularly important in the mining industry since highly mineralized waters from mining enterprises significantly disrupt the stability of aquatic ecosystems. The proposed scheme for the purification of highly mineralized mine waters using ion exchange and sedimentation methods will allow for maximum extraction of salt components from mine waters, as well as cleansing of gas emissions from an industrial boiler house. The introduction of a mine water treatment scheme at a mining enterprise will make it possible to eliminate as much as possible excess discharges of sulfates, chlorides, and other pollutants, and use purified water in technological processes or transfer it to secondary water users for technical needs.

1. Analysis of the relevant research and formulating the purpose of the study

Many works have been devoted to the influence of highly mineralized mine waters on surface water bodies. Mine waters have a significant impact on the state of surface water bodies and groundwater both locally and on a regional scale, which is reflected in various environmental risk assessments[1], although the methodology of such approaches is not always clear.

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[1] Gorova A., Pavlychenko A., Borysovs’ka O., Krups’ka L. The development of methodology for assessment of environmental risk degree in mining regions. Annual

In the paper[2], specific indicators characterizing the assimilation capacity of water resources in the Dnepropetrovsk region are analyzed. It has been established that for the water basin of the Dnipro River including tributes of Samara River and Vovcha River, this indicator is characterized as "high", which indicates significant pollution of surface water bodies with mine waters. It is not clear from the article how the mineral or organic pollution of rivers affects the calculated indicators.

Mine waters can have a negative impact even after mining operations cease. Thus, after the closure of the mine, the groundwater level rises, causing soil contamination with heavy metals and minerals[3].

The well-known phenomenon of mine acid drainage, associated with the oxidation of FeS_2 in mine waters and waste, and the release of Fe^{2+} and H^+, deserves special attention. Chemical reactions contribute to a decrease in pH and leaching of heavy metals with subsequent pollution of surface water bodies[4].

Due to the urgency of the problem of mine water, various improved treatment facilities are proposed, primarily modified mechanical settling tanks and sedimentation facilities[5] [6], the efficiency of which reaches 96-98%.

Vacuum membrane technologies with distillation are widely used, aimed at removing particles and dissolved impurities by evaporation and condensation, which imitates natural processes[7].

Combined processes of direct and reverse osmosis, the effectiveness of which depends on the effective configuration of the equipment, the chemical composition, and the structure of the membranes, have become classical methods for treating highly mineralized mine waters[8].

Scientific Technical Collection – Mining of Mineral Deposit. 2013. P. 207–209. https://doi.org/10.1201/b16354.

[2] Kulikova D., Kovrov O., Buchavy Y., Fedotov V. GIS-based Assessment of the Assimilative Capacity of Rivers in Dnipropetrovsk Region. Journal of Geology, Geography and Geoecology. 2018. № 27(2), P. 274–285. https://doi.org/10.15421/111851.

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[4] Jönsson J., Jönsson J., Lövgren L. Precipitation of secondary Fe(III) minerals from acid mine drainage. Applied Geochemistry. 2006. Vol. 21, № 3, P. 437–445. https://doi.org/10.1016/j.apgeochem.2005.12.008.

[5] Kolesnyk V., Kulikova D., Kovrov S. In-stream settling tank for effective mine water clarification. Mining of Mineral Deposits. 2013. Vol. 1, 285–289. https://doi.org/10.1201/b16354-52.

[6] Kovrov O., Kulikova D. Improvement of the mine water purification efficiency via modified settling tank. Ecological Engineering & Environmental Technology, 2022. № 23(1). 65–75. https://doi.org/10.12912/27197050/142943.

[7] Sivakumar M., Ramezanianpour M., O'Halloran G. Mine Water Treatment Using a Vacuum Membrane Distillation System. APCBEE Procedia. 2013. Vol. 5, P. 157–162. https://doi.org/10.1016/j.apcbee.2013.05.028.

[8] Thiruvenkatachari R., Su S., Cunnington M. 14-FO-RO for mining wastewater treatment. Current Trends and Future Developments on (Bio-) Membranes Reverse and

A study[9] investigated the separation of uranium from other anions present in acidic mine water using batch and column ion exchange techniques.

The anthropogenic load on water reservoirs in the region has reached a level that threatens the population’s health. A cause-and-effect relationship between the qualitative and quantitative state of the surface waters of the Samara River and certain diseases of the population living in the Western Donbas region has been presented in the paper[10].

The analysis of recent studies and publications indicates that the problem of highly mineralized mine water is one of the key ones in the range of environmental activities of mining enterprises.

Identification of previously unresolved parts of the general problem to which the article is devoted. In practice, the application of the above methods to reduce the salinity of mine waters is very problematic for two reasons. Firstly, significant capital and operating costs for the main technological processes of water treatment and the high cost of reagents. Secondly, the disposal of salt products of water treatment is a practically insoluble problem due to the lack of specialized landfills for the disposal of mineral components of mine water.

Considering the above-presented research, there is a need to search for alternative, unique, and economically feasible engineering solutions in the field of purification of highly mineralized mine waters and disposal of salt sediments.

The purpose of the study is to substantiate a comprehensive technology for the purification of mine waters and boiler room gaseous emissions using the ion exchange sorption method.

2. General information about the enterprise for design implementation

A coal mine “Ukraina” of the State Enterprise “Selydivvugillya” is located in the City of Ukrainsk (Donetsk region, Eastern Ukraine) and was put into operation in 1963 with a production capacity of 1200 thousand tons of coal per year (Fig. 1).

Forward Osmosis: Principles, Applications, Advances. 2020. P. 325–336. https://doi.org/10.1016/B978-0-12-816777-9.00014-9.

[9] Queiroz Ladeira A.C., Gonçalves C.R. Influence of anionic species on uranium separation from acid mine water using strong base resins. Journal of Hazardous Materials. 2007. Vol. 148, № 3, P. 499–504. https://doi.org/10.1016/j.jhazmat.2007.03.003.

[10] Основні технічні рішення для будівництва пілотної установки для хімічної очистки стічних вод на Східному гірничозбагачувальному комбінаті: Проєкт. Жовті Води: Український науково-дослідний та проектно-розвідувальний інститут промислової технології, 2002. Арх. № 14183. 126 с.

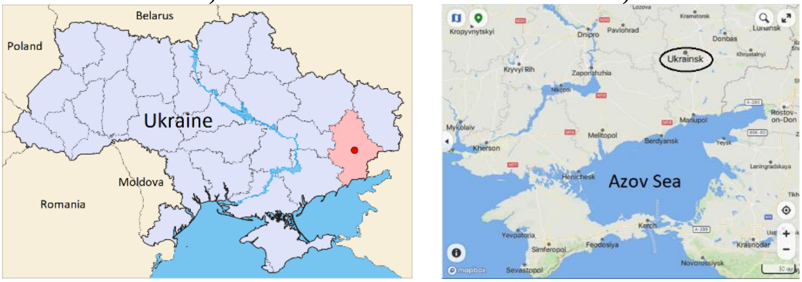
a) b)

Fig. 1. General map of Ukraine (a) and location of the Ukrainsk City (b) in Donetsk Oblast of Ukraine. The population of Ukrainsk is 10,655 residents (2022).

Source: https://mapcarta.com/13727220

The most significant source of air pollution at the mine is an industrial boiler house with a capacity of 16 Gcal/h of heat in the form of steam with a pressure of 0.3-0.5 MPa. The boiler room has 4 boilers of type DKVR-6.5/13. The maximum coal consumption is 8674 kg/h, 15.6 thousand tons/year. To purify exhaust flue gases, battery cyclones of the BC type are used with an efficiency of 80-86% to reduce emissions of solid dust particles. After partial purification, the flue gases are released into the atmosphere through a brick chimney with a height of 45 m and a mouth diameter of 1500 mm[11]. Emissions of pollutants into the atmosphere from the industrial boiler house of the Ukraine mine are given in Table 1.

Table 1

Gross emissions from the mine boiler house

Name of pollutants	**Maximum permissible emission rates**		**Actual pollutant emission rates**	
	g/s	**t/year**	**g/s**	**t/year**
Dust with SiO_2 (20-70%)	19.6	56.89	9.4	31,878
Sulfur dioxide (SO_2)	11.9	356.1	9.7	243
Carbon monoxide (CO)	11.54	34.25	41.4	49.66
Nitrogen oxides (NO_x)	5.43	18.11	8.5	23,355

Analyzing Table 1, it can be noted that the most significant factors of negative impact on the state of the atmosphere are emissions of solid dust and

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[11] Проект шахти «Україна» ДП «Селидіввугілля». Том. 1 Пояснювальна записка. Книга 4 «Охорона навколишнього природного середовища». Дніпропетровськ: ДІ «Дніпродіпрошахт», 1999. 127 с.

sulfur dioxide, which is due to the high sulfur content of coal. At the same time, gaseous substances are not captured[12].

3. Qualitative and quantitative characteristics discharged mine water

The mineralization of mine waters primarily originates from the mineral content of groundwater, the chemical composition of which forms under the combined influence of various factors: lithological and mineralogical composition of rocks, recharge conditions of aquifers and intensity of water exchange, climate, anthropogenic factors, etc. Before underground water enters the mine, the chemical composition is formed by salts washed out during infiltration of surface waters containing free carbon dioxide and oxygen, which increase the solubility of calcium and magnesium carbonates. As a result, the water is mineralized by sulfates and chlorides after their contact with easily soluble rocks such as gypsum, halite, and mirabilite. When sodium bicarbonate water is mixed with calcium sulfate water, sodium sulfate water is formed.

The underground waters of the minefield are confined to sediments of Quaternary, Neogene, and Carboniferous ages. Groundwater of coal deposits has hydro-chemical zoning. Sulfate-sodium-calcium waters with a mineralization of 2.6-3.1 g/l are developed to a depth of about 200 m. Deeper, up to 300-350 m, sulfate-chloride-sodium-calcium waters are common, with a mineralization of 2.5-3.1 g/l. Chloride-sodium-calcium waters appear even lower.

Mine water is pumped to the surface of the mine by two drainage units. The total inflow is up to 350 m^3/hour. Mine water is used for the production needs of the “Ukraine” processing plant and the technical water supply of the mine, and the rest is discharged through the outlet collector into the clarification pond and then into the storage pond for settling suspended substances and further discharged into the Vovcha River basin, the tribute of Dnipro River.

Table 2 presents the complete chemical composition of mine waters discharged into a surface water basin of Vovcha River in comparison with maximum permissible concentrations (MPC) for general and fishery standards[13].

In 1999, the coal mine “Ukraina” discharged 1219.1 thousand m^3 of industrial wastewater containing substances whose concentrations significantly exceeded the maximum permissible concentration for fishery reservoirs.

The average volume of mine water is 1052 thousand m^3/year. Considering the use of mine water for the production needs of the mine, discharge into the

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[12] Проект нормативів гранично допустимих викидів шахти «Україна» ДП «Селидіввугілля». – Маріуполь: Громадське бюро з проектування та налагодження природоохоронної техніки «Еколог», 2001. 96 с.

[13] ДБН В.2.5-75:2013. Каналізація. Зовнішні мережі та споруди. Основні положення проектування. Київ, 2019. 96 с.

Vovcha River (Dnipro River basin) is 2327 thousand m^3/year. The qualitative composition of mine waters indicates excess levels of chlorides and sulfates, the high concentrations of which are due to the groundwater’s natural content.

Table 2

Chemical content and discharge of mine water

Pollutants	**MPC, mg/l**		**Discharge rates**	
	Common-use water bodies	**Fishery water bodies**	**2020**	
			mg/l	**t/year**
1. Weighted substances	10.0	10.0	20.0	24.2
2. pH	6.5-8.5		7.6	
3. COD	15.0	-	8.36	10.1
4. BOD full.	6.0	3.0	3.94	4.8
6. Ammonium salt.	-	0.5	1.0	1.2
7. Nitrites	3.3	0.08	0.08	0.1
8. Nitrates	45.0	40.0	5.6	6.8
9. Dry residue	1000	1000	3391	4094
10. Chlorides	350	300	467	564
11. Sulfates	500	100	1419	1713
12. Mercury	0.0005	0.00001	n/a	n/a
13. Cadmium	0.001	0.0005	n/a	n/a
14. Lead	0.03	0.1	0.039	0.047
15. Arsenic	0.05	0.05		
16. Chrome (VI)	0.05	0.001	0.04	0.048
17. Iron (total)	0.3	0.005	0.3	0.366
18. Manganese	0.1	0.01	0.117	0.141
19. Zinc	1.0	1.0	0.03	0.036
20. Nickel	0.1	0.01	0.028	0.034
21. Copper	1.0	0.001	0.012	0.015
22. Phenols	0.001	0.001	0.018	0.0022
24. Petroleum products	0.3	0.05	0.64	0.773
25. Potassium			12.0	12.6
26. Sodium			500.0	526.0
27. Calcium			300.0	315.6
28. Magnesium			175.0	184.1
29. Hardness (mg-eq/l)			29.3	30.8

4. Development of the technological scheme for joint purification of mine water and boiler room gaseous emissions

Within the framework of this article, a comprehensive solution to the environmental problems of the mine is proposed through the introduction of chemical water treatment (CWT) technology for a boiler room. The main technical solutions for the pilot industrial chemical water treatment plant of the boiler at the coal mine “Ukraina” of the State Enterprise “Selydivvugillya” were made based on the initial data.

Technological facilities of the water treatment plant are designed for the purification of mine waters to a quality that allows the use of purified water for feeding steam boilers and domestic needs of the mine and the City of Ukrainsk, irrigation of farmlands and discharge into fishery reservoirs with associated purification of flue gases from dust, sulfur dioxide SO_2, nitrogen oxides NO_x and carbon dioxide CO_2.

The CWT technology of a mine boiler house includes the following buildings and structures (Fig. 2): a one-story treatment building with overall dimensions of 42x18 m^2 with an evaporation facility, a laboratory and auxiliary premises; radial settling tank-thickener with a diameter of 25 m; two containers with a volume of 40 m^3 each for receiving and storing 42% of sodium hydroxide solution; tank for washing water with a volume of 200 m^3; ion exchange and washing columns; plate absorbers for adjusting the pH of the purified water, as well as for preparing a regenerating solution (8% sodium bicarbonate NaH_2CO_3) by absorbing carbon dioxide CO_2 with a NaOH solution; pump equipment; pipeline rack from the treatment building to the boiler room and radial thickener.

Two options for recycling liquid waste generated because of purification using the ion exchange method are considered. To process liquid salt waste, the first option provides for an evaporation plant and a landfill for dry salt disposal. According to the second option, an evaporation pond with a capacity of 2500 m^3 with an operating period of 10 years is provided for storing liquid wastes[10].

The technological scheme for purifying mine water is based on the ion exchange method. Mine water from the existing horizontal three-section settling tank ($V = 700\ m^3$) in the amount of 120 m^3/h is supplied by pumps to the boiler room water treatment plant. The mine water purification technology includes the following technological operations.

1. Sorption of anions (Cl^- and SO_4^{2-}) in a sorption pressure column (SPC) on an AM brand anion exchanger. The operation of anion exchange extraction of chloride and sulfate ions is carried out in a quasi-continuous cycle (with the movement of portions of anion exchange resin through the regeneration and washing zones into the working area) in devices with an upward flow of water and solutions. Main characteristics of the ion exchange process: anion exchanger capacity – 700 mEq/l; filtration rate – 20 m/hour; layer height is 6 m. Water from the column is supplied for the precipitation of Ca^{2+} and Mg^{2+} cations, and the saturated anion exchanger is used for regeneration.

2. Regeneration of the anion exchanger with an 8% solution of sodium bicarbonate Na_2CO_3 in a countercurrent ion exchange column (CIEC). Main characteristics of the ion exchange process: anion exchanger/solution ratio = 1:1.5; filtration speed – 2 m/hour; layer height is 6 m. The regenerative solution from the column goes to an evaporation unit (Option 1) or to an evaporation pond (Option 2), and the anion exchanger goes to washing.

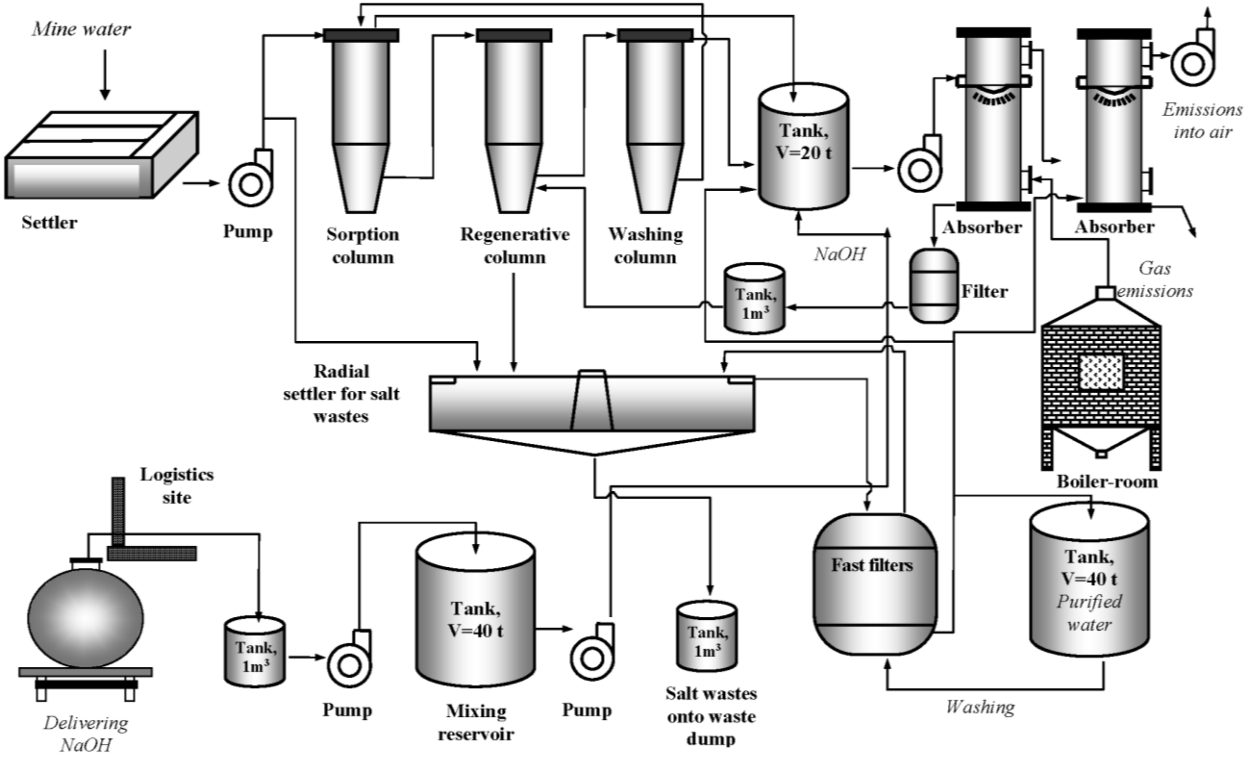

Fig. 2. Technological scheme for joint purification of mine water and boiler room gaseous emissions

3. Washing the anion exchanger with purified water in the CIEC column. Main characteristics of the process: filtration rate – 10–15 m/hour; washing time – 20-30 minutes. The washed anion resin is returned to the ion exchange column for sorption, and the wash water is used to prepare a regenerating solution of sodium bicarbonate NaH_2CO_3.

4. Precipitation of hardness cations Ca^{2+} and Mg^{2+} from water with a 42% NaOH solution in a peripherally driven thickener (D=25 m), followed by settling of the water. The water that has passed the working zone of the ion exchange installation is supplied to the alkalization operation to pH values of 11.5-11.7, which ensures the effective formation of precipitates of magnesium hydroxide $Mg(OH)_2$ and calcium carbonate $CaCO_3$. Main characteristics of the process: process pH – 11.5-11.7; the rate of precipitation of suspensions is 0.5 mm/s. The solid phase after settling the suspension can be discharged (7.5 m^3/hour) or mixed with the spent regenerate of the sorption unit (to increase the pH value of the resulting suspension and, accordingly, the filtrate undergoing the evaporation operation). Alkalinization is carried out in a mixing tank, from which the suspension is sent to the settling operation and then to filtration. The last two operations are carried out respectively in a radial settling tank and a clarification filter with quartz sand or expanded clay.

5. Control filtration of suspended matter in rapid filters loaded with clay or anthracite. Filtration speed – 10 m/h. The sludge from the thickener is periodically pumped out to the mine dump.

6. Adjustment of pH of purified water using flue gases from the boiler room in a plate absorber. Water filtered from suspended particles (no more than 1–5 mg/l) with a pH of 11.5-11.7 is supplied to the stage of neutralization with carbon dioxide contained in the flue gases of the boiler room. The operation is carried out in a spray absorber equipped with perforated or tubular type sink plates. For preliminary purification of boiler room flue gases from sulfur and nitrogen oxides, an absorber of a similar type and design is provided, where a 5–10% NaOH solution is used as an absorption liquid. The gas mixture leaving this absorber enters the inlet of the second absorber. As a result of the reaction of CO_2 and NaOH, a 5–10% solution of NaH_2CO_3 is formed, which enters the tank for storing the regenerating solution and is used for desorption of chloride and sulfate ions in the ion exchange extraction of mine water anions.

The regenerate of each block of the treatment plant in the amount of 10 m^3/h is concentrated in a three-stage evaporation unit.

Water with pH 7.5-8.0 at the outlet of the absorber is sent to the consumer to feed DKVR 6.5/13 steam boilers or, after mixing with the original mine water, it is used to irrigate farmlands.

7. *Water disinfection is carried out by active chlorine.*

The results of the calculation of the chemical treatment technology by the ion exchange method, carried out in accordance with the current standards for the design of industrial wastewater treatment facilities, are presented in Table 3.

Considering that the boiler house provides for wet cleaning with two absorbers with a cleaning efficiency of 99%, solid dust in the amount of 56.89 tons/year will be captured and transported to the rock dump in the form of sludge.

The use of an anion exchange unit will reduce the content of sulfates and chlorides in purified mine water by 98-99% (according to design indicators, the total content of these ions will not exceed 50 mg/l). Considering the efficiency of the ion exchange unit with a highly basic anion exchanger of the AM brand, the discharge of sulfates will decrease by 1460.2 tons/year, chlorides – by 455.7 tons/year.

Predicted results of the effectiveness of the use of CWT technology for a boiler room emissions and mine water treatment are presented in the Table 3.

To mix HCO^{3-}ionized water with caustic soda solution, it is recommended to use two tanks equipped with mixers that ensure uniform distribution of the introduced alkali solution in the shortest possible time period. The volume of each tank is around 60-70 m^3.

The settling of the resulting suspension and removal of calcium and magnesium hydroxide sludge is carried out in a radial settling tank with a central drive and a diameter of 25 m (the rate of precipitation of the suspended mineral components u_0 is 0.5 mm/s.

Table 3

Calculation results of ion exchange devices for the boiler room chemical treatment plant

No.	Indicators	Units	Indicator values
1.	*For sorption of anions:* – productivity of purified water, *Q* – total content of Cl^-, SO_4^{2-}, $\sum C_{anions}$ – working exchange capacity of anion exchanger, *a*	 m^3/h g/m^3 $g\text{-}eq/m^3$	 120 2060 700
	– filtration rate of source water, W_f – residence time of the anion exchanger in the column, t_o – ratio of the height of the anion exchanger layer in the sorption column to its diameter, B_o	m/h h dimensionless	25 5 2.5
2.	*For anion desorption:* – productivity of regenerating solution, Q_{reg} – concentration of the regenerating solution NaH_2CO_3, *C* – filtration rate of NaH_2CO_3 solution, W_p – residence time of the anion exchanger in the regeneration column, t_r – ratio of the height of the anion exchanger layer in the column to its diameter, B_p	m^3/h % m/h h dimensionless	10 8 3 4 3.75
3.	*To wash the anion resin:* – washing water productivity, Q_{out} – filtration rate of washing water (at a time of supply to the column that ensures the volumetric flow rate of washing water), W_{out} – ratio of the height of the anion exchanger layer to the diameter of the column, *V* – residence time of the anion exchanger in the column, *t*	 m^3/h m/h b/r h	 15-20 10-15 3.75 4

Clarified water from the sump goes to a mechanical filter filled with quartz sand (expanded clay, crushed anthracite). The total filtration area is 13 m^2 (at a filtration rate of 10 m/h), and the number of filters is 3. Considering the total wastewater flow, for one block of the treatment plant it is recommended to use three clarification filters with a diameter of 2.6 m with a backfill height of 1.0 m.

The filtrate of a mechanical filter with a suspended particle content of no more than 1-1.5 mg/l and a pH value of 11.5-11.7 is supplied to the operation of its acidification with CO_2-containing gases. Acidification is carried out in two absorbers by contacting the NaOH absorption solution with a gas mixture that has undergone the first stage of purification from ash and sulfur oxides. The diameter of each absorber is 0.75 m, the height (from the nozzle to the drain mirror) is 1.0 m, the flue gas capacity (Q_{gas}) is 8000 m^3/h, and the solution (water) capacity is 40 m^3/h. Gas residence time (in the zone of contact with the solution) 0.3 s. The number of failure plates is 3 pieces, located 300-400 mm from each other.

For the first stage of cleaning the exhaust flue gases of the boiler room from sulfur dioxide SO_2 and nitrogen oxides NO_x, as well as obtaining a regeneration solution of sodium bicarbonate Na_2CO_3 with a concentration of 8-10%, an absorber of similar dimensions is used as at the stage of acidifying the filtrate of a mechanical filter. The total resistance on the gas line is 250-300 mm water column for three absorbers.

Each absorber unit for producing sodium bicarbonate solution and acidifying the filtrate is equipped with a special container with a stirrer.

Regenerates of the anion exchange unit for extracting mine water components in an amount of 10 m^3/h contains the following compounds:

chloride ions (Cl^-) – 7.45kg/m^3;
sulfate-ions (SO_4^{2-}) – 10.0 kg/m^3;
bicarbonate ions (CO_3^{2-}) – 38.4 kg/m^3;
sodium ions – 24.0 kg/m^3;
pH value – 8.5.

The regenerate, constituting 8% of the total salts (or 5.3% of sodium bicarbonate), is subjected to a concentration operation in an evaporation plant (Option 1) or sent to an evaporation pond (Option 2).

To concentrate the specified solution with an initial sodium bicarbonate concentration of 5-15%, you can use a three-effect evaporation plant with a direct-flow evaporation scheme, an initial heating steam pressure of 4 atm, and $t_o = 143^{\circ}C$.

5. Environmental impact assessment

The pilot industrial chemical water treatment plant for the boiler house proposed for use is an environmental protection facility to supply heat to the enterprise, purified mine water is used as a coolant, which is currently discharged without treatment into the Vovcha River.

When implementing the project, emissions of boiler room flue gases into the atmosphere will be significantly reduced. As a result of the introduction of two-stage wet cleaning, ash, and dust are completely removed from flue gases, and acid oxides (SO_2, NO_x) are removed by 95-99%, which are converted into a liquid state in the form of slightly diluted acids.

The physicochemical composition of mine water before and after treatment is given in Table 4.

Table 4

Physicochemical composition of mine water before and after treatment

No.	**Pollutants**	**Unit**	**Concentration, mg/l**	
			Primary water	**Purified water**
1.	Suspended solids	mg/l	20.0	10.0
2.	pH value		7.8	7-8.5
3.	Calcium (Ca^{2+})	mg/l	333	0.2-1.5
4.	Magnesium (Mg^{2+})	mg/l	267	
5.	Chlorides (Cl^-)	mg/l	465	25
6.	Sulfates (SO_4^{2-})	mg/l	1490	25
7.	Salinity	mg/l	3640	<1000
8.	Purified water performance	th. m^3/year m^3/hour	- -	3066 350

Approximately 100 m^3/h of the total amount of mine water is used for the technical needs of the mine, the rest is used in the warm season to irrigate farmlands, or it is discharged into the Vovcha River in cold time.

The boiler room reduces the concentration of harmful substances in the atmospheric air due to the capture of SO_2, NO_x, and solid particles of ash and soot when adjusting the pH of the water and preparing the regenerating solution.

The main waste stuff from the waste treatment plant is sulfates, chlorides, and calcium and magnesium carbonates. Two alternative options for storing and processing liquid waste are offered. Option 1 provides for the construction of an evaporation plant, an additional boiler unit with a capacity of 10 tons of steam per hour, and a landfill for storing dry salts. Option 2 provides for the construction of an evaporation pond with a capacity of 2,500 thousand m^3. The sludge of calcium and magnesium carbonates from the radial thickener in the form of pulp is transported to the overburden dump located near the coal mine.

6. Qualitative composition of mine waters

The total amount of pumped mine water is 3066 thousand m^3/year. Considering the use of mine water for the production needs of the processing plant and mine, discharge into the Vovcha River (Dnipro River basin) is 2327 thousand m^3/year.

Finally, the application of the proposed technology of deep mine water treatment will decrease the gross emissions of pollutants into the atmosphere (Fig. 3) and minimize the discharge of mine water pollutants into the water streams (Fig. 4).

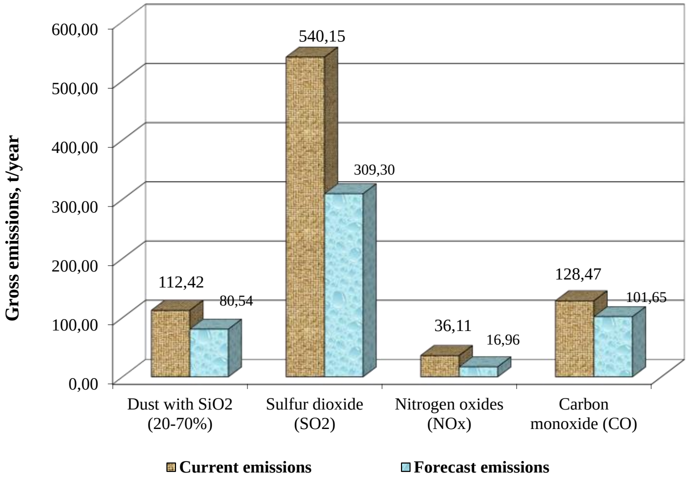

Fig. 3. Gross emissions of pollutants into the atmosphere

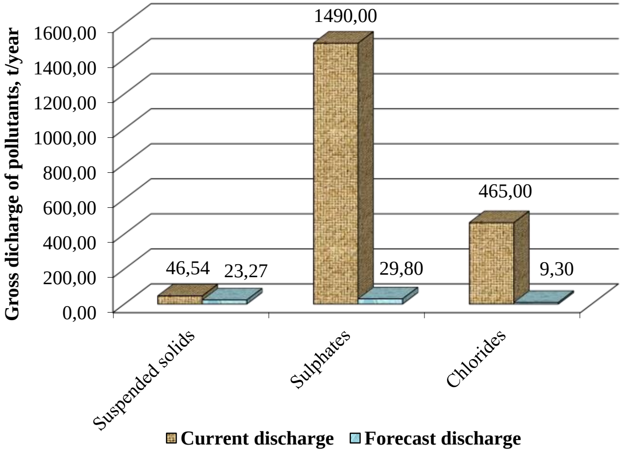

Fig. 4. Gross discharge of pollutants with mine water into the surface water streams

CONCLUSIONS

Implementing a chemical water treatment project in practice can provide the following advantages:

– a significant reduction in the discharge of insufficiently treated wastewater into the hydrographic network with the maximum possible extraction of mineral components;

– the possibility of using purified water for the technological needs of the enterprise and feeding steam boilers of city boiler houses;

– reducing the use of drinking water in technological processes;

– associated cleaning of flue gases from a mine boiler house from gaseous components;

– a significant reduction in fees for environmental pollution.

The novelty of the research lies in the fact that the use of complex chemical water treatment technology will simultaneously reduce emissions of pollutants into the atmosphere from an industrial boiler house, as well as the content of sulfates and chlorides in treated mine water by 98-99%.

The proposed option for mine water purification significantly expands the boundaries of the traditional use of the ion exchange method. In the near future, the use of ion-selective sorbents will make it possible not only to purify wastewater, but also to selectively extract valuable components from it.

The presented research results are the basis for making engineering decisions in the field of reducing the discharge and purification of highly mineralized mine waters. The introduction of such technologies with the effective disposal of salt sediments will reduce the level of pollution of surface water bodies with mineral substances and increase the environmental efficiency of mining technologies.

SUMMARY

Purification of industrial wastewater from mining and metallurgical enterprises is a complex and important task, especially in the context of ensuring environmental safety standards and rational use of water resources.

The paper presents the results of experimental studies conducted in laboratory conditions for conditioning of mine waters. Based on the design and calculations, the technological scheme for the treatment of mine water at the coal mine “Ukraina” of the State Enterprise “Selydivvugillya” is recommended, which consists in filtering the discharged mine water with high content of chloride and sulfate ions through a layer of highly alkaline HCO_3-anionite, treating the filtrate with sodium hydroxide solution (NaOH), filtering of obtained suspension and acidifying the filtrate with gas mixture from the boiler-room that contains 3–8% CO_2. The regeneration of saturated anionite is carried out with a solution of sodium bicarbonate Na_2CO_3 obtained through absorption of CO_2 by solution of NaOH. As a result of successive cleaning

operations, the calcium and magnesium ions in the water do not exceed 2-5 mg/l, chloride and sulfate ions – 50 mg/l respectively, which allows use of purified water for household and technological needs of the enterprise. When designing industrial treatment of mine water with a capacity of 350 m^3/h, it is recommended to install three water purification units with a capacity of 120 m^3/h for each block. Depending on the method of disposal of the generated salt wastes, two options are proposed for the disposal of wastewater regenerate: evaporation of salt wastes with further disposal of dry salts or alternative storage of liquid regenerate in an evaporation pond. Implementation of the proposed mine treatment flow chart will allow: significantly reduce the discharge of insufficiently treated mine water into a hydrographic network with maximum extraction of salt components; carry out associated purification of gas and dust emissions from the mine boiler-room from solid and gaseous emissions; use purified water for technological needs of the enterprise.

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