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STORAGES OF INDUSTRIAL WASTE ARE DANGER AND SECONDARY RAW MATERIALS SOURCES: PATHWAYS TO USE IN THE CIRCULAR ECONOMY

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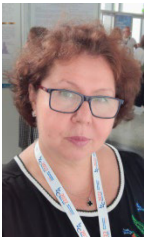

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Abstract

The work highlights the dangers caused by industrial waste that is stored for a long time in repositories. The largest waste storage site of the chemical industry in the Luhansk region is described in detail.

More than 100 types of waste are stored at the landfill. PJSC “Severodonetsky Azot” is considered the owner of the landfill, but nearby are the waste storage facilities of other largest enterprises of the region: “Rubizhansky Krasytel”, Scientific and Industrial Association “Zarya”, Lysychansk Plant of Rubber and Technical Products, and Scientific and Industrial Association “Skloplastik”.

The impact of landfill waste on the environment is determined not only by the duration of waste storage and the technical imperfection of the repository but also by the geological structure of the location region. The most dangerous impact of storage is on the state of water bodies in the region and on underground sources of drinking water supply. This fact is evidenced by long-term observations of water quality in water supply sources given in the work.

Ways of processing certain types of waste contained in the landfill are proposed. The general characteristics of solid industrial waste processing methods are given, a description of the possible utilization of certain types of industrial waste into marketable products is given.

Introduction

The war in Ukraine has been going on for a long time, but it will end and the occupied territories will have to be restored. Resource-intensive and energy-intensive industries play a key role in the formation of Ukraine's GDP, so the priorities of state policy on the path to sustainable development should be the optimization of the use of natural resources and minimization of the negative impact on the environment by transitioning to a green economy model.

The National Waste Management Strategy in Ukraine until 2030 refers to the waste problem as a large-scale problem caused by the dominance of multi-waste technologies in the national economy, as well as the lack of effective waste management. In particular, among the main trends associated with ineffective waste management in Ukraine are the following:

1 - significant amounts of waste generation and accumulation in both the industrial and household sectors;

2 - focus on landfill disposal of waste;

3- placement of waste in landfills and/or natural landfills, most of which do not meet the requirements of environmental safety.

The territory of the Luhansk region has been characterized by a tense ecological situation for quite some time. The situation is exacerbated, first of all, by the difficult socio-political situation, namely, the conduct of the antiterrorist operation in the territory of the Luhansk region, and then the war.

In 2017, the OSCE issued a technical report on the impact of military operations on the surrounding natural environment in the East of Ukraine. Among the most dangerous factors that worsen the ecological condition of the territories under the influence of military actions were the following:

- intentional or unintentional damage to production facilities;
- flooding of Donbas mines;
- disruption of industrial enterprises;
- violation of regular activities of water supply enterprises;
- fires in natural and agricultural landscapes;
- damage to nature conservation areas.

Since 2022, the influence of these factors has increased significantly, the ecological situation is becoming worse. To a large extent, the deterioration of the ecological situation is associated with another dangerous factor, namely, it's the accumulation of a significant amount of industrial waste in storage facilities of various types, which leads to a sharp deterioration in the quality of drinking groundwater, increased pollution processes in the areas where storage facilities are located, as well as to a reduction in the resource of the geological space in terms of long-term unsuitability of disturbed lands for most types of economic use.

Potentially dangerous facilities include industrial waste storage located in Luhansk and Donetsk regions. According to the UN report, the amount of accumulated industrial waste in Ukraine is one of the largest in the world. According to the results of the OSCE Report on the state of storage facilities in Donbas, there are 200 storage facilities containing 939 million tons of industrial waste in the territory of Donetsk and Luhansk regions alone.

Repositories of industrial waste are territorially close to industrially developed and mining regions, with a high level of technogenic influence on the geological environment. A classic example of such a region is the so-called Lysychansk-Rubizhne-Severodonetsk triangle. The fact that the district has been in the area of active hostilities since February 24, 2022, and is now in the occupied territory, only complicates the environmental situation.

Fig. 1 shows the layout of industry enterprises.

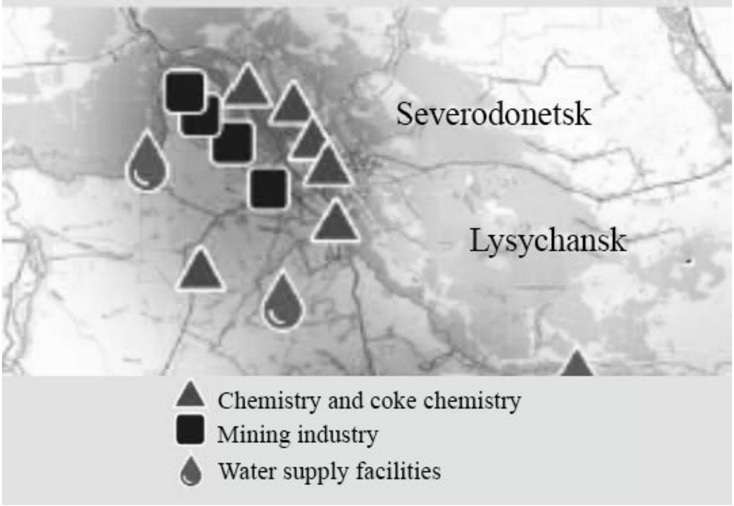

Fig. 1. Scheme of location of industry enterprises in the region

Fig. 2. Map of the location of waste storage facilities in Donbas

The largest storage of chemical industry waste in the Luhansk region: Description

Near the village of Vovchoyarivka (formerly Fugarivka) of the Popasnya district, at a distance of 0.43 km from it, on the site of the former Loskutivka sand pit, one of the largest landfills for industrial waste is located, owned by PJSC “Severodonetsk Azot”. The landfill occupies an area of 6.52 hectares and was put into operation in 1969. Next to the landfill site, other industrial enterprises of the region, for example, LLC "NVP Zarya" and LLC "NVO "Skloplastik" etc., placed their waste. It also storages the waste of already defunct enterprises namely, they are LLC "Rubizhanskyi Krasitel", Lysychansk production of rubber products, etc. Water intake facilities are located 1 km from the landfill. It`s water supply was carried out from the Berestova River through special catchments (water intake facilities), in the southern direction from the landfill.

Fig. 3. The industrial site of the landfill

Designation of storage units of the enterprises: 1 -PJSC "Severodonetsk Azot", 2 - Lysychansk production of rubber products, 3 and 4 - LLC "Rubizhansky Krasitel", 5 - NPO "Zorya", 6 - NPO "Severodonetsk Skloplastik"

Information on the accumulators of three enterprises located within the boundaries of the landfill - PJSC "Severodonetsk Azot", LLC "Rubizhansky Krasitel" and LLC "NVO Zorya" according to the data of the Register of waste disposal sites of the Luhansk region is provided in table 1. (*Register of waste generation, treatment and disposal facilities of Luhansk region (as amended in 2017)*, 2017).

The total amount of waste accumulated from the activities of these enterprises is 375,268,749 tons.

The list of waste to be disposed of at the landfill includes 139 items of industrial waste, most of which belong to the hazardous type, including spent catalysts for the production of ammonia, nitric and acetic acid, spent ionic resins, activated carbon, carbon black from the production of acetylene, sludges of various industries, that formed in the process of dissolution and filtration, waste insulating materials (asbestos, rubber), thermal insulation waste.

Table 1

The main characteristics of storage units located within the landfill (*Zvit pro vikonannya robit po ob'ektu: «Provedennya robit z monitoringu pidzemnih vod na teritoriyi oblasti.*, 2019)

№	The Characteristic	Storage of "Severodonetsk Azot"	Storage of "Rubizhansky Krasitel"	Storage of "NPO Zorya"
1	Year of commissioning	1968[45]	1969	1982 reconstruction in 1998
2	The actual period of operation as of 2020	52 years	51 years	38 years
3	Estimated useful life (as of 2020)	21 years	10 years	15 years
4	The area of the object according to the passport	6.52 hectares (project area is 11.5 hectares)	10,8103 hectares	10,3674 hectares
5	Volume of removed waste as of 2020	161 050,638 t (146409,671 m^3)	143 486,82 t (119 572,35 m^3)	70 731,291 t
6	Volume of removed waste for the previous year 2019	0	0	1 387,560 t
7	Project volume of waste removal	228 800 t (208 000 m^3)	- 325 300 m^3	- 160 000 m^3
8	Part of storage volume filling (as of 2020)	70%	37%	47 %
9	The waste, that storaged	192 appellations I-IV classes of danger[*]	149 appellations I-IV classes of danger[*]	33 appellations I-IV classes of danger[*]
10	Aggregate state of waste	solide	solid, sludge/ spread like	solid, sludge/ spread like
11	Gas evaporation	absent	Aniline nitroproducts phenol	nitrogen oxides, sulfuric anhydride, sulfuric acid

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[*] According to the Procedure for the Classification of Harmful Substances established in GOST 12.1.007-76.

According to Art. 7 of the recently adopted Law of Ukraine "On Waste Management" (*Law of Ukraine*, 2023) waste is divided into two classes: 1) hazardous waste; 2) harmless waste.

The term "hazardous waste" is defined by Art. 1 of the Law: hazardous waste - waste that has one or more properties that make it dangerous, specified in the List of properties that make waste dangerous (explosiveness, oxidizing capacity, flammability, irritation, selective toxicity for certain target organs, acute toxicity) .(*Law of Ukraine*, 2023).

It should be noted that the Procedure for the classification of harmful substances was established in GOST 12.1.007-76, the validity of which was terminated in Ukraine on 01.01.2019. According to this Procedure, according to the degree of impact on the human body, harmful substances were divided into four classes of danger: 1st - substances extremely dangerous; 2nd – highly dangerous substances; 3rd – moderately dangerous substances;

4th - low-hazard substances, the Standard applied to harmful substances contained in raw materials, products, semi-products and production waste, and established general safety requirements for their production, use and storage. According to GOST 12.1.007-76, waste of the first class of danger was considered the most harmful and was characterized by the maximum degree of environmental pollution. However, no regulatory document has been developed to replace this Standard. Therefore, this standard can continue to be used as an instruction, if it is not intended to make reference to it in the relevant field of activity (according to the Explanation of the Ministry of Economic Development and Trade of Ukraine on the application of standards).

Geological conditions of storage location. According to the geomorphological zoning, the waste storage of the "Severodonetsk Azot" is confined to the northern slope of the Main Waterparting of Donetsk Ridge.

The Donetsk Ridge is a geomorphological region bounded in the north by the Prydonetska terrace plain (the border runs along the right high bank of the Siversky Dinets), in the south by the Azov Upland. It has a complex and quite diverse relief, which is characterized by the presence of a dense river network. Watershed spaces are narrow, and elongated in the meridional direction. The depth of the erosion cutting here is 100 m. The density of the beam network is 0.5-1.0 kilometers per square kilometer.

The relief of the Donetsk highlands is determined by the peculiarities of the geological history of its development, geological structure, and recent tectonic movements, which played a major role in the formation of the relief. The processes of weathering, denudation, and accumulation in the later geological period gave the relief of the highlands its modern features.

The Donetsk Upland is characterized by a close connection of the relief with the geological structure. Cleavage on significant areas of the day surface of intensely dislocated deposits of the Lower and Middle Carboniferous, represented by alternating rocks (limestones, sandstones), caused the development of a peculiar Donetsk type of relief, the so-called maned. (*Zvit pro vikonannya robit po ob'ektu: «Provedennya robit z monitoringu pidzemnih vod na teritoriyi oblasti.*, 2019).

From a geostructural point of view, the territory of the landfill site belongs to the northern zone of fine folds of the Donetsk folded structure, which has a complex multiphase structure because the deforming forces here were 1.6 times greater than those of the entire Donetsk region.

A characteristic feature of the zone is the unidirectional extension of the folds and the significant development of regional thrusts that have a general extension with folded structures. The main ones are Severodonetsk, Maryinsky, Almazny, Illichivsky. Stratigraphic amplitudes of oversteps decrease with depth.

The rocks that make up the site of the landfill form a brachianticline uplift cut in the northeast direction by the Maryinsky thrust. In the upper part of the elevation, deposits of the Horlivsky Carboniferous measures (C_2^7) are exposed, which is represented by intercalation of limestones, siltstones, and argillites, with interlayers of sandstones and coal. On the southern and eastern slopes of the brachyanticline, there are significant outcrops on the M_5 limestone surface. In the quarry, where it was developed, there is a drive of JSC "Krasitel", the active filling of the first map which began in 1975-1976.

Deposits of the Horlivsky set have dip angles varying from 25-30° to 75° or more in some areas.

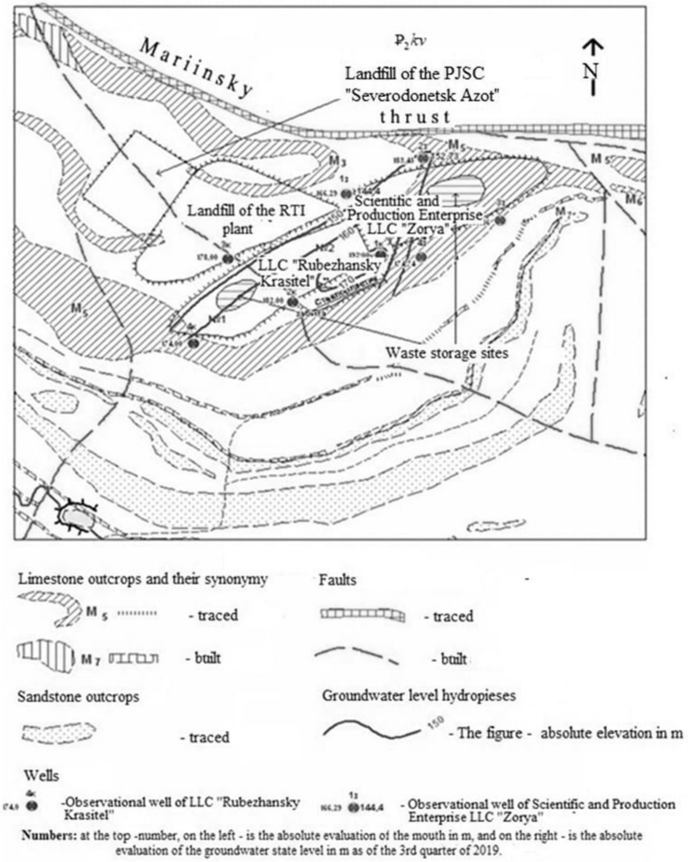
Rocks of the Horlivska set are overlapped by deposited of the Carboniferous Isayevska set (C_3^1), which are preserved only at the base of the brachianticline and can be traced on the left bank of the Berestova river, west of the village of Fugarivka. This is a stratum of mudstones and siltstones with thin layers of sandstones and limestones (I_1-I_5).

To the north of the Maryiv thrust, coal deposits are overlain by rocks of Mesozoic and Cenozoic age, which fill the core of the synclinal fold.

Near the northeastern outskirts of the village of Vovchoyarivka, on the right bank of the Berestova River, in the upper part of the geological section, there are deposits of the Santonian stage of the Upper Cretaceous K_{2S}, represented by micaceous marls and white chalk-like marls. The thickness of the Santonian layer is about 80 m. In the eastern direction, they overlap with Paleogene deposits. These are hard clays with layers of marl. Quaternary deposits are found in the form of scree and deluvium on the slopes. Modern diluvial deposits with a thickness of 2-3 m are close to the foot of the gentle slopes of the beams and are represented by loess-like loams with lenses of rubble of native rocks.

To the north of the training ground is the Maryinsky thrust. The thrust amplitude is almost 1200 m, the dip is southwest at an angle of 38-50°. It should be noted that the entire described dome structure is torn by numerous resets and thrusts in both sublatitudinal and submeridional directions.

The hydrogeological conditions of the landfill site are characterized by the presence in the upper cracked zone of the carbon weathering crust of the aquifer complex with a thickness of 15 to 20 m (Fig. 4). The average thickness of the aquifer is 17 m. The active porosity of water-bearing rocks is 0.03-0.031. Pressurized and non-pressurized water. Flow rates of wells are from 1 to 20 l/s, springs - 0.3-0.5 l/s. Groundwater is fed by precipitation. Drainage of the aquifer is carried out in streams and rivers, as well as in mining operations. Their mineralization ranges from 0.3 to 3.6 g/dm^3. The class of water in natural conditions relates mainly to calcium bicarbonate. The level and hydrochemical regime of the aquifer complex is subject to seasonal changes. The amplitude of level fluctuations reaches 5-6 m.



Numbers: at the top -number, on the left - is the absolute evaluation of the mouth in m, and on the right - is the absolute evaluation of the groundwater state level in m as of the 3rd quarter of 2019.

Fig. 4. Schematic hydrogeological map of the industrial landfill area in the village of Fugarivka

Groundwater of the aquifer complex belongs to the category of unprotected, that is, vulnerable to pollution.

In the area of the industrial waste landfill of PJSC "Severodonetsk Azot" at a distance of 0.44 km from the landfill, the Berestova River flows, which is a tributary of the White River and flows into Siversky Donets together with it. It originates from sources that have an outlet to the south of the landfill and flows throughout the contamination zone (*Zvit pro vikonannya robit po ob'ektu: «Provedennya robit z monitoringu pidzemnih vod na teritoriyi oblasti.*, 2019).

Impact of storage on the environment. Among the environmental hazard factors associated with the features of the geological environment of the landfill site, it is possible to note its location in the zone of major tectonic disturbances, the development of dangerous geological processes as a result, as well as the presence of conditionally unprotected underground aquifers.

It should be noted that water supply to the population and enterprises of the Luhansk region is carried out mainly from underground sources. Currently, only 20-25% of the total amount of groundwater extracted for the economic and drinking needs of the region meets the standard requirements (*Sanitarni pravyla i normy*, 2010). There is a shortage of potable water in the region, which leads to the need to use substandard groundwater, especially in the north of the region.

The quality of groundwater in the territory of Luhansk region is very different due to many objective reasons (formation conditions, operation of large water intakes, man-made loading, influence of pollution sources, etc.). The main reserves of underground water used for drinking water supply are confined to the Upper Cretaceous deposits and are located on the left bank of the Siversky Donets River. Groundwater on the right bank of the river, in the territory controlled by Ukraine, is rarely used for centralized drinking water supply due to substandard quality and low productivity of aquifers. The best quality in this territory is noted for underground water confined to the carbon weathering crust zone and distributed on the northern and southern wings of the Main Syncline of Donbass. They are used as a source of local water supply. It is in the area where they lie that an industrial waste landfill is located.

Long-term operation (38-52 years) led to the loss of waterproofing properties of landfill structures, and, as a result, the ingress of harmful substances into unprotected aquifers and contamination of local water supply sources - wells in the village. Vovchoyarivka, which drains underground waters of beam alluvium and carbon weathering zones.

The presence of polluting components in the well water, which made it unsuitable for domestic and drinking water supply, is a consequence of the cumulative effect of the waste storage facilities of chemical enterprises located within the boundaries of the landfill upstream of the groundwater.

Deterioration of the composition of the water in the wells of the Vovchoyarivka village was observed starting in 1974, when the water in the wells acquired an unpleasant smell and taste. Testing carried out in 1975 showed an increased content of ammonium in the amount of 115 mg/dm^3. In a well located on the eastern outskirts of the village, the content of ammonium nitrogen reached 334.4 mg/dm^3.

Until 2013, the state of pollution at the landfill was controlled by local networks of wells drilled by each enterprise in the areas affected by storage facilities. There is a network of 12 wells in the area of the Nitrogen reservoir, one of which is located along the contour of the reservoir, the other on the right-bank slope of the valley of the Berestova River, on which the village of Vovchoyarivka is located.

According to the data of departmental regime observations, the formation of the dynamic circlets of multicomponent chemical pollution of all natural environments around waste storage facilities was monitored. An important indicator of the anthropogenic impact of reservoirs on the environment is the characteristic scale of landscape-hydrodynamic and landscape-hydrochemical redistribution of pollutants between different components of the natural environment.

The results of regular observations conducted by PJSC "Azot" indicated that practically the entire coal aquifer complex, as well as the Quaternary alluvial aquifer, became contaminated in the area of influence of the Nitrogen accumulator. Groundwater was characterized by a high dry residue, which exceeded the norm by more than 9 times. The main part of mineralization consisted of sulfates (Table 2). Ammonium content above the MPC was observed in individual wells and exceeded the MPC value by almost 40 times (well 3A). As of the IV quarter. In 2013, the area of ammonium pollution was 0.1 km^2, total salt pollution was 0.65 km^2. The concentration of nitrates and nitrites during the entire observation period had a periodic character. An increase in their concentration in groundwater was observed in the period from the II quarter to the III quarter (this trend was maintained for almost all types of pollution). The area of this contamination was stable, had local distribution and amounted to 0.02 km^2. Of the microelements, lithium was constantly present in groundwater in all monitoring wells in concentrations above the MPC, and nickel was observed in individual wells. The area of groundwater with a lithium content above the MPC was 0.5 km^2, nickel - 0.03 km^2.

There have been changes in the chemical composition of underground waters of the coal aquifer complex. It became more banded:

- mainly sodium chloride-sulfate magnesium and hydrogen carbonate-chloride-sulfate magnesium-sodium under the storage;
- around the storage – calcium-magnesium-sodium bicarbonate-chloride-sulfate and sodium-magnesium bicarbonate-sulfate-chloride.

The ionic chemical composition of water remained stable throughout the year.

According to the regime observations, it was established that the water quality in the Berestova River in terms of sanitary and chemical indicators also did not meet the regulatory requirements (Document 4630-88 "Sanitary rules for the protection of surface waters from pollution") in terms of sulfate content, dry residue all year round and in some months - by the content of chlorides, ammonium nitrogen, MPC (Table 2) (*Informacia o sostoyanii kachestva podzemnyih vod na promplotshadke PJSC «Severodonetsk Azot» i poligona TPO (c. Fugarovka») za IV kv. 2013*, 2013).

Table 2

Summary data of chemical analyzes of underground and surface waters in the area of the landfill site for 2013

Place of sampling (indicator)	Unit	Normative value, not more	Average value
Полігон ТПВ (ґрунтова вода)			
Hydrogen index	pH	not standardized	7,48
Odor at 20°C	ball	not standardized	2
Odor at 60°C	ball	not standardized	2
Color	grad.	not standardized	13,4
Transparency	cm	not standardized	29,5
Ammonia nitrogen	mg/dm^3	not standardized	24,0
Nitrates	mg/dm^3	not standardized	6,4
Chlorides	mg/dm^3	not standardized	497
Sulphates	mg/dm^3	not standardized	889
Hardness	mg-equiv/dm^3	not standardized	18,2
Dry residue	mg/dm^3	not standardized	2839
ChAO	mg O_2/dm^3	not standardized	21,0

BAO$_5$	mg O$_2$/dm^3	not standardized	<3
Berestova River			
Hydrogen index	pH	6,5 – 8,5	7,85
Odor at 20°C	ball	not standardized	0
Odor at 60°C	ball	not standardized	0
Color	grad.	not standardized	18,4
Transparency	cm	not standardized	24,8
Ammonia nitrogen	mg/dm^3	0,39	0,22
Nitrates	mg/dm^3	45	5,5
Chlorides	mg/dm^3	300	229,2
Sulphates	mg/dm^3	100	733
Hardness	mg-equiv/dm^3	not standardized	15,1
Dry residue	mg/dm^3	1000	1648
ChAO	mg O$_2$/dm^3	15	15,5
BAO5	mg O$_2$/dm^3	3,0	2,2

Therefore, in the area of Vovchoyarivka village, the water in the Berestova River is not subject to any type of water use. The use of water from wells is also prohibited.

Since the beginning of the armed conflict, regular routine monitoring of monitoring wells of the departmental network of PJSC “Severodonetsk Azot” has not been carried out, which is unacceptable from the point of view of the threat posed by the storage to drinking aquifers, there is no information about the hydrochemical situation in the area of the storage.

In 2017, "East of DRGP", according to the project "Maintenance of DEC, state accounting of the use of groundwater, monitoring of resources and reserves of groundwater in the territory of Luhansk region", one-time works were carried out to survey the state of groundwater in the area of the solid industrial waste landfill of PJSC Severodonetsk association "Azot". Water samples were taken and examined from 4 wells of the departmental monitoring network: Nos. 2A, 3A, 5A, 12A, located downstream of the groundwater flow from the industrial waste landfill in the direction of the Berestova River.

The highest water mineralization and total hardness were noted in well No. 3A, the highest indicators of ammonium, nitrates, and phenol content were in well № 5A. These wells are located right next to the storage contour. In the other two wells, located downstream of the groundwater flow, the indicators of groundwater pollution are lower, but high enough to pose a threat to local water consumers – residents of the Vovchoyarivka village.

In the area of the solid industrial waste storage facility of "NVP "Zorya" LLC, regular monitoring (quarterly) has been carried out by "Luhansk Geoecocenter" LLC for many years. Surveys were carried out on 2 observation wells No. 1z, 2z of the departmental regime network located around the storage.

As of the III quarter. In 2019 (according to the data of "Luhansk Geoecocenter" LLC), the underground water level of the coal aquifer was at a depth of 21.89-30.72 m at absolute elevations +144.4 to +152.73 m, which is 0.25-0 .57 m higher compared to the same period of 2018.

According to the chemical composition, the groundwater had a dry residue of 1180-1960 mg/dm^3, total hardness - 6.4-11.2 mmol/dm^3, chloride concentration - 232.2-500 mg/dm^3, sulfate concentration - 345-395.5 mg /dm^3, ammonium concentration - 0.8 - 1.50 mg/dm^3, nitrate - 11.2-46.5 mg/dm^3, iron concentration - 2.0-2.9 mg/dm^3. Phenols, amino nitro products are not found.

According to the chemical composition, underground waters belong to the class of sulfate-hydrocarbonate-chloride calcium-sodium and chloride-sulfate-hydrocarbonate calcium.

The highest water mineralization, total hardness, concentration of chlorides, ammonium nitrates, and iron are noted in well No. 1z, located near the western corner of the storage contour, downstream of the groundwater flow, the highest rate of sulfates is in well No. 2z.

Compared to 2018 in III quarter In 2019, there was an increase in the indicators of dry residue (2420 mg/dm^3 in well No. 1z), sulfates (425.3-486 mg/dm^3 in wells Nos. 1z, 2z), chlorides (758.3 mg/dm^3 in well No. 1z), and iron (5.3 mg/dm^3 well No. 2z). The fairly high content of ammonium (0.8-1.50 mg/dm^3), iron (2.0-2.9 mg/dm^3), which is direct evidence of the impact of the storage on underground water, attracts attention. A comparison of the given indicators with the normative values of DSanPiN 2.2.4-171-10 (*Sanitarni pravyla i normy*, 2010) showed an excess of such indicators as dry residue (1.3 MPC), total hardness (1.1 MPC), chlorides (1.4 MPC) and iron (2 ,9 MPC).

Areas of groundwater contamination by various components in the zone of influence of the industrial waste storage facility of LLC

"NVP "Zorya" were not counted (*Zvit pro vikonannya robit po ob'ektu: «Provedennya robit z monitoringu pidzemnih vod na teritoriyi oblasti.*, 2019).

According to the interviews, in 2014-2015, there were active military actions in the area of the training ground, the territories adjacent to the facility were mined, but there is no information about damage to the training ground structures as a result of projectiles.

In 2019, under the project of the OSCE Project Coordinator in Ukraine "Strengthening the Capacity for monitoring and Management of water resources in the East of Ukraine", a study of the current state of tailings storage facilities in the Donbas was conducted regarding their possible emergency impact on water bodies, the task of which was to investigate the current state of storage tanks of industrial waste, determine hazard factors and identify existing threats to the environment in probable emergency scenarios.

A comprehensive study of the storage facilities, which included a review of the natural conditions of the territory and the specifics of the location of the storage facilities of enterprises, determination of the volume and toxicity of waste, study of the current state of the facilities and analysis of the available monitoring results, made it possible to outline the following types of landfill hazards:

- fire - the presence of gaseous, liquid, and solid substances, materials or mixtures capable of sustaining combustion;
- chemical - the presence of toxic, harmful, highly effective poisonous substances, poisonous chemicals, chemical means of plant protection and mineral fertilizers;
- ecological - the possibility of an adverse effect on the environment of man-made and natural factors, as a result of which the adaptation of living systems to the usual conditions of existence is disturbed (I Nikolayeva et al., 2021).

Internal factors of ecological danger included:

- probable unsatisfactory state of structures (instability of dams, loss of waterproofing properties), associated with a long period of operation of storage tanks (38-52 years);
- the presence of hazardous substances in the composition of waste: metals, non-metals and their compounds, salts of perchloric acid and nitrous acid, organic solvents, ethers, etc.;
- gas evaporation: aniline, nitro products, phenol, nitrogen oxides,

sulfuric anhydride, sulfuric acid;

- a significant total amount of accumulated waste.

The cited results of monitoring observations and complex studies indicate that even in the absence of direct discharge of pollutants directly from the reservoirs, the anthropogenic load from their long-term operation led to a change in the state of underground and surface waters. In addition, the location of industrial waste storages of various chemical enterprises on the same site of the landfill can lead to an increase in their influence and the successive occurrence of accidents at these facilities. The location of the pumping station of the Western Filtering Station next to the landfill in the event of an accident at the landfill can lead to disruption of the water supply to the region.

Therefore, in the near future, it is necessary to develop and implement appropriate technical and management measures that will lead to the minimization of the ecological threat of the industrial waste landfill to the environment. One of these measures is the search for ways of further handling of accumulated waste: reuse and/or neutralization of waste.

Main directions of waste processing. The directions of waste processing are determined by the demand for waste components and the possibility of obtaining products of commercial quality from them. In the case of chemical processing, a number of typical technological operations are used: dissolution, sedimentation, and filtration, which allow to separation of waste components from each other for further processing.

Approximately from the end of the 60s to the beginning of the 70s, in connection with the aggravation of the energy and raw material problems of developed foreign countries, there has been an acceleration of growth in the use of production and consumption waste. And this becomes an important task for the development of their economy. The process of growth in the volume of waste processing was determined by a number of factors: firstly, the negative impact of accumulated waste on the ecological situation in certain regions and in the world as a whole; secondly, the increase in economic interest in the processing of secondary raw materials, which is mainly due to the depletion of mineral deposits and the increase in the price of natural raw materials; thirdly, by political factors related to the desire of states to increase independence from the import of natural raw materials.

A significant obstacle in the way of waste disposal was the slow improvement of the technique and technology of their processing. The traditional problem of waste processing is wasteability. Waste usually differs from primary raw materials in terms of chemical composition and contains other types and amounts of impurities. Therefore, in order to obtain the same products, a change in technology and a complex approach are needed - the use of not only the most valuable component, but also all the others with the aim of their as complete utilization as possible.

The most common types of hazardous waste of the 1st class of danger are:

- lead batteries are damaged or worn out;
- fluorescent lamps and waste containing mercury.

Disposal of these products, which have lost their consumer value, has long been successfully carried out in many countries of the world.

Lead is an important metal for the industrial development of the automotive industry, for storage and backup power in the field of alternative energy. The processing of lead in the developed countries of the world significantly exceeds its extraction from the sources of primary raw materials. Spent lead-acid batteries are intensively processed, their component part in recycled materials is about 85%.

The first acid batteries were proposed in 1860 by G. Plante. Until now, they are widely used due to the simplicity and stability of work. Their body was originally made of ebonite, now it is made of acid-resistant plastics. The electrolyte is an aqueous solution of sulfuric acid (density 1.28-1.30 g / cm^3 or 37.5 - 39 wt. %). The cathode is made of ribbed lead plates, and the anode is made of lead grids, the cells of which are filled with PbO2 paste.

Spent lead paste consists of lead sulfate (~60 wt.%), as well as lead dioxide (~28 wt.%), lead oxide (~9 wt.%) and a small amount of metallic lead (~3 wt.%).

The operation of a lead-acid battery is described by the following total chemical reactions:

In case of battery discharge

$$Pb+PbO_2+H_2SO_4 \rightarrow 2PbSO_4+2H_2O \quad (1)$$

In the case of charging the battery, the course of the reverse reaction is carried out.

The utilization of lead batteries is as follows:

- First, the electrolyte is drained, which is an aggressive acid solution.
- The plastic case is cut or crushed to remove the metal parts.
- Plastic is separated from metal on a special device.
- Smelting takes place for the production of secondary raw materials.

Traditional disposal of pastes can be carried out in two (Zhang et al., 2016) ways:

1 - Direct smelting, in which the lead paste was directly processed in a melting furnace at a temperature above 1000 °C to decompose and melt the lead compounds with or without desulfurization in the furnace.

2 - Desulfurization at lower temperatures followed by melting. The spent paste is treated with a desulfurizing agent such as Na_2CO_3 or NaOH in aqueous solutions close to ambient temperatures. A common feature is the use of aqueous solutions of NaOH or Na_2CO_3 to fix S as soluble Na_2SO_4, which can be crystallized as a commercial by-product. Insoluble $PbCO_3$ or $Pb(OH)_2$ is collected in the form of sludge and sent to the smelter.

It is now practiced to harvest and recycle fluorescent lamps on an industrial scale for mercury separation and safe disposal (Dhawan & Tanvar, 2022). However, processing phosphor powder rich in rare earth compounds is still developing. A luminophore consisting of several rare earth minerals (Y, Eu, Ce, Tb, La) can be considered as a potential secondary raw material. The latest scientific publications indicate that research tends towards combined pyrohydrometallurgical processes as the most effective.

The phosphors in fluorescent lamps are a source of critical rare earth elements such as Y, Eu, Tb, and Ce, and almost 79% and 63% of the global consumption of Y and Eu are from phosphors, so their recycling is crucial for resource conservation (Hua et al., 2019).

The phosphor used for luminescence is up to 2 wt.% of the lighting fixture and contains 9 to 26% REE, which is significantly higher than in REE ore deposits. Currently, recycling rates in some major lamp producing countries are 4%, Canada 7%, Japan 9%, USA 20% and South Korea 28%.

A typical technological scheme of crushing and separation of used FD components on an industrial scale is presented in fig. 5.

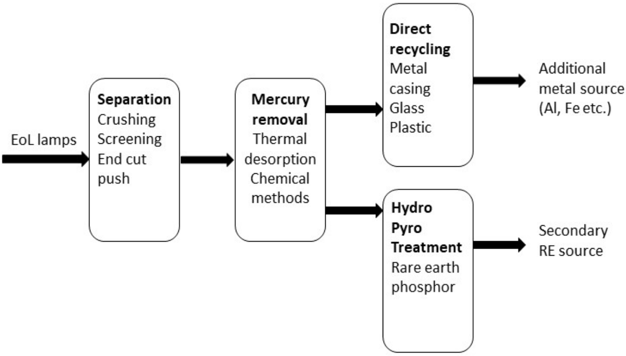


Fig. 5 Typical technological scheme of recycling fluorescent lamps

There are two widely used FL recycling processes:

1) Method of end pushing. With this method, the end caps made of aluminum in the FL are removed or cut off, and phosphor waste on the inner walls of the glass is pushed out using a scraper, high-pressure air, or water. Metallic mercury and phosphor are captured and mercury vapor is captured by activated carbon filters. Metal caps and glass are crushed to extract metals and make glass products or new lamps. The luminophore collected by this method does not contain impurities. The disadvantage of this process is the use of manual operations and considerable processing time. On an industrial scale, the process has reached a productivity of 300 million lamps per year. Several companies have commercialized this method, namely Mercury Recovery Technology Company in Holland, WEREC, OS-RAM, BISON and OSRAM (owned by Siemens).

2) Another method was implemented by companies in Germany, Switzerland, and Finland. This method involves wet crushing, in which the tubes are crushed in ethanol or 30% aqueous acetone to capture mercury vapor and prevent environmental contamination. However, many small glass particles contaminate the phosphor. Therefore, the extracted phosphor requires additional resources to remove these impurities. Around the world, companies like Eco Re-

cycling Ltd. in India, Fluorescent Lamp Recyclers Technologies Inc. in Canada, AERC Recycling Solutions, Veola Environmental Services in the US, and Lampcare in the UK have developed special crushing equipment to avoid mercury leakage (*Eco Recycling Limited Lamp Recycling*, n.d.).

One of the most important properties of waste, which determines possible successful processing, is not only the presence of valuable components in the waste but also a stable chemical composition. These requirements are met by spent catalysts, which make up a fairly large part of the waste of chemical industry enterprises. The landfill contains not only catalysts used at PJSC "Severodonetsk Azot" but also catalysts and metal-containing waste from other enterprises in the region are stored there. Spent catalysts have lost their active properties due to the processes carried out in the technological equipment. The loss of catalytic activity is a consequence of the action of temperature, pressure, and the action of so-called catalytic poisons – compounds that form a surface layer of inactive substances with the catalyst components. Examples of such poisons can be residual sulfur contained in natural gas, which enters for conversion in the production of ammonia. Also, the most common cause of the loss of catalytic activity is the formation of a carbon layer on the surface of the catalysts, which is formed from the components of the reaction mixture.

Spent catalysts are classified as a waste of hazard classes 1-3, depending on their chemical composition.

The waste contains vanadium, copper, nickel, cobalt, molybdenum, and platinum group metals.

The amount of generated waste catalysts depends on their service life and the size of the equipment. Usually, the service life (Scott, 2018) of catalysts ranges from several months to several years. The volume of the spent catalyst depends on the production capacity, type, and operating conditions of the catalyst. But for more than 50 years of operation of the industrial waste landfill, their number is already quite large. The estimated amount of waste is indicated in the regional reports of the Department of Ecology and Natural Resources and the registers created by this organization (*Register of waste generation, treatment and disposal facilities of Luhansk region (as amended in 2017)*, 2017).

Unfortunately, the open information is quite concise and does not contain all the necessary data to decide on the choice of disposal method. However, some information on the chemical composition of the waste can be obtained from the registers using the names of the processes and the catalysts used to carry out these processes.

Thus, by the information from the above-mentioned register, information on spent catalysts stored at the sites of individual enterprises was determined: Thus, spent catalysts of the hydrogenation process of natural gas in the production of ammonia are stored at the landfill, mostly aluminum-cobalt-molybdenum containing the components CoO - 2-6%, MoO_3 10-16%. More precisely, unfortunately, it is impossible to find out the chemical composition, because the manufacturers of catalysts for the entire period of existence of the waste storage landfill are unknown. Vanadium-containing catalysts at sites owned by LLC "Zorya" and PJSC "Severodonetsk Azot" differ in chemical composition and content of active components. At the first enterprise, the catalysts were used for contact oxidation of sulfur (IV) oxide and contained 7-10% V_2O_5, at another enterprise they were used for cleaning exhaust gases from nitrogen oxides and contained 12-15% V_2O_5.

Silver catalysts contain 7-20% silver, depending on the process in which they were used at Zorya LLC.

Many researchers have been engaged in the processing of catalysts to extract the most expensive and valuable components, proposing mainly the hydrometallurgical method (Sittig, 1980) as a series of sequential leaching and precipitation operations, as well as the possible use of ion exchange processes and electrochemical purification.

Table 3

Components of some spent catalysts

Spent catalyst	Source	Active Componenets	Клас небезпеки
Spent silver catalyst	Government Plant "Zorya"	Ag	4
Catalyst of sulfuric acid production AVC-10 IC-1-6	LLC "Zorya"	V2O5	4

Catalysts of manufactures of ammonia, nitric acid, acetic acid, methanol RKS-2-7H, RKS-2P, NCM-1, NCM-1C, NCM-C, GO-70, CNM-У, RKN-3, GPC-4Ш, IT-305 etc.	PJSC “Severodonetsk Azot”	Co, Mo, Ni, Cu, Zn, Cr, C, Al, V	1, 2, 3, 4

One of the limitations of the use of waste is related to the possibility of obtaining products of commercial quality from it. Thus, the processing of spent catalysts into fresh ones does not always give a positive result due to the difficulty of extracting some impurities that reduce the catalytic activity of such materials.

Obtaining nano-sized materials can help in solving such a problem. Particle size affects three main groups of properties of any material. Firstly, on structural characteristics (lattice symmetry and cell parameters), secondly, on electronic properties of oxides. Structural and electronic properties determine the third group of properties: physical and chemical.

The spent catalyst disposal scheme can be seen on the example of spent alumina-nickel catalyst (Korchuganova et al., 2020) (Fig. 6).

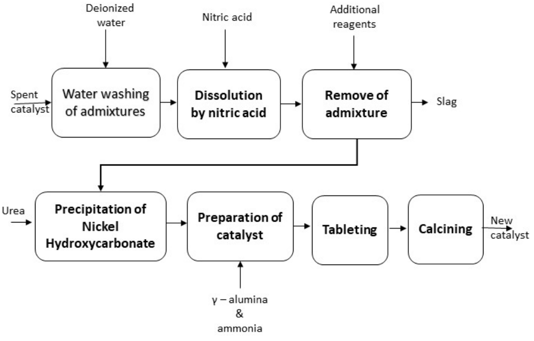


Fig. 6. Scheme of disposal of spent aluminum-nickel catalyst

Each stage of the production process generates a certain type of waste. Each waste product requires a specific management solution.

Processing of industrial waste is carried out using various technologies, the main of which are (Arockiam JeyaSundar et al., 2020): physico-chemical, thermal, and biotechnologies.

Physico-chemical technologies are not universal but can lead to the best result for the use of waste as secondary raw materials. By physicochemical methods, some types of industrial waste are processed into fertilizers, building materials, ceramics, etc.

Thermal technologies are used to dispose of many types of solid, soluble, liquid, and gaseous waste. The method consists in heat treatment of waste with a high-temperature coolant, which uses combustion products, a plasma stream, molten metal or oxide, and microwave heating of waste. Products of thermal decomposition undergo oxidation and other chemical interactions with the formation of non-toxic products.

Biotechnologies used in the processing of metal-containing waste and low-grade ores, such as chalcopyrite, are among the most promising waste disposal and processing technologies (Dong et al., 2020). Recently, a direction in non-ferrous metallurgy - biohydrometallurgy has been developing quite actively.

Reducing the amount of waste, we generate is a priority today. This means changing our consumption patterns, for example by choosing products that use recycled material (“Waste at Every Stage,” 2002). It also means recycling – sorting, collecting, processing, and reusing materials that would otherwise be treated as waste.

Recently, various countries have been using waste as materials for artificial geochemical barriers (Perel’man, 1986):

- mining complex waste (overburden, beneficiation tailings) containing chemically active minerals;
- mixtures of chemically active or differently modified minerals;
- products and wastes of deep chemical and metallurgical processing of ores and concentrates.

There are different ways of applying geochemical barriers:

- arrangement of anti-filtration screens;
- filtration of solutions through a barrier with deposition of pollutants;

-adding a barrier substance to the solution (in natural reservoirs, tailings ponds, settling tanks, etc.).

Among the areas of use of artificial geochemical barriers, in addition to the purification of natural and wastewater from heavy metals, radioactive elements, and petroleum products, the following can be distinguished:

- extraction of valuable components from natural and man-made raw materials by physical and chemical methods;
- waterproofing of tailings and sludge storage facilities, accumulators, sedimentation tanks, etc.;
- oil consolidation in construction.

Of the natural minerals, carbonates have found the most widespread use for geochemical barriers. Examples of successful use of calcite, dolomite, and magnesite are considered in several studies (Bennett et al., 2000).

In addition to natural carbonates, there is a fairly large amount of waste containing them. An example of such waste can be the liming sludge of natural water treatment and wastewater treatment plants. Lime sludges usually contain more than 70% calcium carbonate. Quite acceptable methods are the use of sediments in the natural environment to be applied to the soil to reduce acidity (Cheng et al., 2014), or in the man-made environment to improve wastewater treatment (Hua et al., 2019). In (Hua et al., 2019), a water treatment method of reusing the upper clarified part of lime sludge to simultaneously remove COD, nitrogen, and phosphorus was investigated. The upper clarified part of the lime sludge is alkaline wastewater containing a high concentration of calcium ions, alkalinity, biodegradable chemicals, and ammonium nitrogen. Using the method in denitrification processes allows you to fully compensate for alkalinity for nitrification, as well as save the costs of phosphorous precipitators, external carbon, and alkalinity. Therefore, this method is technically and economically effective.

It is also shown that water purification can be effectively carried out with the help of carbonate-containing tripels. Carbonate cherts with a 20-30% calcite content are highly effective sorbents of heavy and non-ferrous metal ions, radionuclides Sr, and Cs (Yurmazova et al., 2016).

Various layered hydrosilicates have also found widespread use as geochemical barrier materials.

Different types of barriers with anti-filtration and anti-migration properties are used to prevent the spread of toxic elements in natural waters and to protect the environment in areas where ground waste storage facilities are located.

The authors substantiated the following priority directions for the use of waterproofing compositions based on nepheline:

- construction, repair and operation of wells in the oil and gas industry;
- solidification of liquid waste, including those containing various toxic and radioactive substances;
- creation of anti-filtration curtains in loose and cracked rocks in quarries, dams, dams, in the roof of various gas, oil, and waste storage facilities;
- isolation of sand-gravel foundations and rock fissures from the surface for waste storage, creation of artificial reservoirs; - neutralization and dehydration of acidic effluents of chemical enterprises.

In addition to the use of chemically active rocks and minerals, it is possible to use their artificial mixtures. Thus, in the work (Chanturiya et al., 2011) a mixture of serpentine and carbonates is proposed.

Amorphous silica can also be considered as a large-tonnage by-product of the acid processing of many ores and concentrates. The use of active silica as a barrier ensures the formation of a precipitate of mainly non-ferrous hydrosilicates, for example, nickel and cobalt. Carbonate in the barrier plays the role of an environment regulator, neutralizing the sulfuric acid formed during the synthesis of hydrosilicates and ensuring a stable alkaline reaction of the solutions. This barrier is also effective in natural and wastewater treatment technologies (Labus et al., 2020).

One of the most popular areas of research is the use of waste as raw materials for building materials, such as bricks and cement.

Brick is a widely used building and construction material all over the world. It is common knowledge that the production of bricks is extremely energy-intensive and emits a significant amount of greenhouse gases. Production of 1 kg of product requires about 1.5 kWh of energy and results in emissions of about 1 kg of CO_2 into the atmosphere. At the same time, in many areas of the world there is already a shortage of natural raw materials for the production of bricks (Chen et al., 2011).

Cement production accounts for about 7% of all CO_2 emissions (Gjorv & Sakai, 1999). Thus, the production of concrete bricks also consumes a lot of energy and emits a significant amount of CO_2.

For environmental protection and sustainable development, many researchers have studied the possibility of using waste for brick production (Chou et al., 2001).

A wide range of wastes were studied, including fly ash, mine tailings, slag, construction and processing industry waste, wood sawdust, cotton waste, limestone powder, paper residues, waste oil sludge, kraft pulp residues, cigarette residues, tea waste , rice husk ash, rubber crumb and dust for cement kilns.

There are several groups of methods for producing bricks from waste:

- high-temperature (firing, etc.);
- cementation (using binding materials);
- geopolymerization.

High-temperature methods involve the use of waste to replace part or all of the clay (primary raw material) and then bricks are made in the traditional way. Thus, the use of iron ore tailings (Chen et al., 2011) and ash with clay for the manufacture of bricks has been tested. Lingling et al. (Lingling et al., 2005) investigated the production of fired bricks using fly ash to replace most of the clay. Fired bricks with a high ash content are characterized by high compressive strength, low water absorption, no cracking and high frost resistance.

In addition to bricks, there are developments in the production of other building materials. Thus, the authors of the work (Sahu et al., 2017) developed a technology for manufacturing paving tiles from a mixture of ash and lime sludge. The optimal composition of the mixture of ash and sludge was determined. The composite turned out to be strong, without leaching of heavy metals and suitable for designing flexible pavements. A mixture of ash and water treatment sludge is also used to make bricks. The organic component is first burned from the sludge, and then mixed with ash and further processed (Minh Trang et al., 2021).

A large number of works(Lin & Lin, 2005; Pavlík et al., 2016) are devoted to the possibility of using sludge in cement production. The authors of the work (Pavlík et al., 2016) suggest replacing part of the cement with calcined sediment, unfortunately, the results of these studies revealed that the technological properties of the waste are not good enough. The publication (Lin & Lin, 2005) gives the results of experiments on the production of eco-cements using waste, including water treatment. The waste was pre-calcined to burn out the organic component. According to the results of the research, the best quality was cement made with the addition of limestone.

Alkaline activation of aluminosilicates is a technology often called geopolymerization. It was first developed in the 1970s by Joseph Davidowitz. It involves a chemical reaction between oxides of aluminosilicates and solutions of alkaline silicates under conditions of high alkalinity. This gives amorphous or semi-crystalline polymer structures of Si-O-Al bonds. Geopolymers demonstrate good physical, chemical, and mechanical properties: among them low density, micro- and nanoporosity, low shrinkage, high mechanical strength, good thermal resistance, durability, surface hardness, and fire, and chemical resistance. Given these desirable properties, they are considered potential alternative materials for industrial applications such as construction, transportation, aerospace, mining, and metallurgical engineering (Barbosa & MacKenzie, 2003; Swanepoel & Strydom, 2002). Alkaline activation of aluminosilicate material can be described as the reaction of a liquid with a high alkaline concentration and a solid with a high proportion of reactive silicate and aluminate. Ash geopolymers harden quickly at room temperature, they are characterized by high strength. Large-scale application of such geopolymers is much more difficult, but high-performance geopolymer concretes are beginning to be commercialized (Van Deventer et al., 2012).

Coal ash, which is produced after burning coal, is a very powerful industrial and energy solid waste (Blissett & Rowson, 2012). Ash is a mixture of combustion products of inorganic and organic components of coal. It usually contains the following oxides in decreasing order of their content in the ash

$$SiO_2>Al_2O_3>Fe_2O_3>CaO>MgO>K_2O>Na_2O>TiO_2.$$

Ashes of different origins are quite different from each other in terms of the content of the listed oxides. Depending on its chemical and mineralogical composition, several main directions of its use are proposed. One of the most common is the use for cement production. There is also a direction of use called geotechnical. It covers its use as an asphalt filler, creating a road surface base, filling structures, changing soil properties (González et al., 2009). Ash is used as a soil stabilizer because of its properties. It was found that the addition of ash to soils, as a rule, reduces the tendency to absorb water into the soil. High water absorption of soils can lead to cracking of pavements, basements, driveways, pipelines and foundations. As a result of adding ash to the soil, through the pozzolanic reaction, the soil becomes more granular and contains less water (Zha et al., 2008).

The method of "disposing of waste using other waste" seems very promising. An example of such a method is coal ash.

Thanks to its chemical and mineralogical composition, ash can perform the role of a sorbent. In the paper (Panday et al., 1985), its adsorption properties in gaseous and aqueous media were studied. The use of ash mixtures with different chemical compositions for the removal of various metal wastes was recently evaluated: Cu (Alinnor, 2007), Pb (Cho et al., 2005), Zn (Itskos et al., 2010), Mn, Cd, Cr, and Ni (Mohan & Gandhimathi, 2009). A recent review of the use of low-cost adsorbents for the removal of heavy metals from industrial wastewater concluded that fly ash has great potential for wastewater treatment; this potential is limited by the variability of ash chemistry and the large volumes that may be required for its effectiveness (Ahmaruzzaman, 2011).

Aksu and Yener (1999) investigated the potential for using fly ash instead of activated carbon for phenol adsorption. They reported the adsorption capacity compared to the properties of activated carbon. Flue gas desulfurization sorbents were obtained by mixing $Ca(OH)_2$ with ash (Lee et al., 2021). The results show that the desulfurization properties of the sorbents increase with the ash/$Ca(OH)_2$ ratio. This field of application promises to be a promising direction, since the process of gas formation will lie in close proximity to the generation of ash.

Considering the chemical and mineralogical composition of zeolites, there are many attempts to produce zeolites from them (Querol et al., 2002).

The next method of using waste is to extract the most valuable components from it. Ash contains 30-35% silica, 5-15% aluminum, some titanium and other elements.

Several methods of extracting aluminum from ash have been proposed. Direct leaching with sulfuric acid of low concentration and at ambient temperatures (Matjie et al., 2005). A more effective option, according to which preliminary treatment is carried out: ash is granulated with fine coal and lime, then aluminum is leached with sulfuric acid.

Shabtai and Mukmenev (Shabtai & Mukmenev, 1996) described a new process for extracting titanium and aluminum. The authors used concentrated sulfuric acid for extraction. Extraction of titanium was carried out simultaneously with the process of biomagnetic adsorption. *Rhodococcus* bacteria were cultured and added to a suspension containing magnetic particles, resulting in the adsorption of the bacteria on the magnetic particles. As titanium falls out of solution, it is adsorbed together with magnetite on the bacteria.

Another example of the implementation of this direction is the recycling of coagulants from the sludge of water treatment plants, which are a necessary component of water treatment and wastewater treatment processes. Recycling is usually performed by acid leaching of iron or aluminum compounds and subsequent separation of the mixed solution. In the work (Petruzzelli, 2000) it is proposed to carry out separation with the help of ion-exchange resins, in this way the solutions are purified to a conditioned state. The authors of the paper (Jangkorn et al., 2011) tried to reduce the use of fresh coagulants by adding sludge to the coagulation process.

For the comprehensive utilization of ash, it is proposed to produce several products from it (Little et al., 2008): concrete, fertilizers, mesoporous silicate material/zeolite. The authors show how by placing an ash processing plant in the center of an industrial ecosystem, waste generation is limited. Sodium hydroxide, anode process waste, and limestone are used as additional raw materials.

Conclusions

Therefore, waste processing can solve not only the problems of raw material sustainability but also reduce anthropogenic impact on the natural environment, and improve the condition of water bodies and the quality of drinking water.

Of course, not all waste is acceptable in terms of recyclability, it depends on several reasons and characteristics of the waste.

Yes, spent catalysts are convenient for processing, their advantages for recycling are stability of composition, limited number of components, ease of storage, and transportation. However, the stability of the composition is also a characteristic feature of some other wastes, including sludges from water treatment and wastewater treatment from metal impurities. An approximate list of components of spent catalysts is presented in the table

Accumulation of industrial waste from various chemical enterprises in one area of the landfill can lead to successive accidents at these facilities and provoke an increase in their impact, causing the so-called "domino" effect.

As a result of hostilities, it is quite likely that industrial enterprises will be disrupted and emergencies will arise. With the beginning of hostilities, the observation posts for water and air quality stopped working.

References

1. **Ahmaruzzaman, M**. (2011). Industrial wastes as low-cost potential adsorbents for the treatment of wastewater laden with heavy metals. Advances in Colloid and Interface Science, 166(1–2), 36–59. https://doi.org/10.1016/j.cis.2011.04.005
2. **Alinnor, I. J.** (2007). Adsorption of heavy metal ions from aqueous solution by fly ash. Fuel, 86(5–6), 853–857. https://doi.org/10.1016/j.fuel.2006.08.019
3. **Arockiam JeyaSundar, P. G. S., Ali, A., Guo, D., & Zhang, Z.** (2020). Waste treatment approaches for environmental sustainability. In Microorganisms for Sustainable Environment and Health (pp. 119–135). Elsevier. https://doi.org/10.1016/B978-0-12-819001-2.00006-1
4. **Barbosa, V. F. F., & MacKenzie, K. J. D. (**2003). Thermal behaviour of inorganic geopolymers and composites derived from sodium polysialate. Materials Research Bulletin, 38(2), 319–331. https://doi.org/10.1016/S0025-5408(02)01022-X
5. **Bennett, P. J., Longstaffe, F. J., & Rowe, R. K.** (2000). The stability of dolomite in landfill leachate-collection systems. Canadian Geotechnical Journal, 37(2), 371–378. https://doi.org/10.1139/t99-110
6. **Blissett, R. S., & Rowson, N. A.** (2012). A review of the multi-component utilisation of coal fly ash. Fuel, 97, 1–23. https://doi.org/10.1016/j.fuel.2012.03.024
7. **Chanturiya, V., Masloboev, V., Makarov, D., Mazukhina, S., Nesterov, D., & Men'shikov, Y.** (2011). Artificial geochemical barriers for additional recovery of non-ferrous metals and reduction of ecological hazard from the mining industry waste. Journal of Environmental Science and Health, Part A, 46(13), 1579–1587. https://doi.org/10.1080/10934529.2011.609435
8. **Chen, Y., Zhang, Y., Chen, T., Zhao, Y., & Bao, S. (**2011). Preparation of eco-friendly construction bricks from hematite tailings. Construction and Building Materials, 25(4), 2107–2111. https://doi.org/10.1016/j.conbuildmat.2010.11.025

9. **Cheng, W., Roessler, J., Blaisi, N. I., & Townsend, T. G**. (2014). Effect of water treatment additives on lime softening residual trace chemical composition – Implications for disposal and reuse. Journal of Environmental Management, 145, 240–248. https://doi.org/10.1016/j.jenvman.2014.07.004

10. **Cho, H., Oh, D., & Kim, K. (**2005). A study on removal characteristics of heavy metals from aqueous solution by fly ash. Journal of Hazardous Materials, 127(1–3), 187–195. https://doi.org/10.1016/j.jhazmat.2005.07.019

11. **Chou, M.-In. M., Patel, V., Laird, C. J., & Ho, K. K.** (2001). Chemical and Engineering Properties of Fired Bricks Containing 50 Weight Percent of Class F Fly Ash. Energy Sources, 23(7), 665–673. https://doi.org/10.1080/00908310152004764

12. **Dhawan, N., & Tanvar, H.** (2022). A critical review of end-of-life fluorescent lamps recycling for recovery of rare earth values. Sustainable Materials and Technologies, 32, e00401. https://doi.org/10.1016/j.susmat.2022.e00401

13. **Dong, B., Jia, Y., Tan, Q., Sun, H., & Ruan, R.** (2020). Contributions of Microbial "Contact Leaching" to Pyrite Oxidation under Different Controlled Redox Potentials. Minerals, 10(10), 856. https://doi.org/10.3390/min10100856

14. Eco Recycling Limited Lamp Recycling. (n.d.). ECORECO. https://ecoreco.com/services-lamp-recycling.aspx

15. **Gjorv, O. E., & Sakai, K.** (Eds.). (1999). Concrete Technology for a Sustainable Development in the 21st Century (0 ed.). CRC Press. https://doi.org/10.1201/9781482272215

16. **González, A., Navia, R., & Moreno, N.** (2009). Fly ashes from coal and petroleum coke combustion: Current and innovative potential applications. Waste Management & Research: The Journal for a Sustainable Circular Economy, 27(10), 976–987. https://doi.org/10.1177/0734242X09103190

17. **Hua, Z., Geng, A., Tang, Z., Zhao, Z., Liu, H., Yao, Y., & Yang, Y**. (2019). Decomposition behavior and reaction mechanism of Ce0.67Tb0.33MgAl11O19 during Na2CO3 assisted roasting: Toward efficient recycling of Ce and Tb from waste phosphor. Journal of Environmental Management, 249, 109383. https://doi.org/10.1016/j.jenvman.2019.109383

18. **I Nikolayeva, H Lenko, D Averyn, & O Lobodzinsky.** (2021). Review of the Current State of Tailing Storage Facilities in Donetsk and Luhansk Oblasts. Summary (p. 51). Organization for Security and Co-operation in Europe. https://www.osce.org/files/f/documents/9/9/486259.pdf

19. Informacia o sostoyanii kachestva podzemnyih vod na promplotshadke PJSC «Severodonetsk Azot» i poligona TPO (c. Fugarovka») za IV kv. 2013. (2013). OOO "Vostokgeologia."

20. **Itskos, G., Koukouzas, N., Vasilatos, C., Megremi, I., & Moutsatsou, A**. (2010). Comparative uptake study of toxic elements from aqueous media by the different particle-size-fractions of fly ash. Journal of Hazardous Materials, 183(1–3), 787–792. https://doi.org/10.1016/j.jhazmat.2010.07.095

21. **Jangkorn, S., Kuhakaew, S., Theantanoo, S., Klinla-or, H., & Sriwiriyarat, T.** (2011). Evaluation of reusing alum sludge for the coagulation of industrial wastewater containing mixed anionic surfactants. Journal of Environmental Sciences, 23(4), 587–594. https://doi.org/10.1016/S1001-0742(10)60451-2

22. **Korchuganova, O., Tantsiura, E., Ozheredova, M., & Afonina, I.** (2020). The Non-Sodium Nickel Hydroxycarbonate for Nanosized Catalysts. Chemistry & Chemical Technology, 14(1), 7–13. https://doi.org/10.23939/chcht14.01.007

23. **Labus, K., Cicha-Szot, R., & Falkowicz, S.** (2020). Injected silicate horizontal barriers for protection of shallow groundwater—Technological and geochemical issues. Applied Geochemistry, 116, 104577. https://doi.org/10.1016/j.apgeochem.2020.104577

24. **Lee, X. J., Ong, H. C., Gao, W., Ok, Y. S., Chen, W.-H., Goh, B. H. H., & Chong, C. T.** (2021). Solid biofuel production from spent coffee ground wastes: Process optimisation, characterisation and kinetic studies. Fuel, 292, 120309. https://doi.org/10.1016/j.fuel.2021.120309

25. **Lin, K.-L., & Lin, C.-Y.** (2005). Hydration characteristics of waste sludge ash utilized as raw cement material. Cement and Concrete Research, 35(10), 1999–2007. https://doi.org/10.1016/j.cemconres.2005.06.008

26. **Lingling, X., Wei, G., Tao, W., & Nanru, Y.** (2005). Study on fired bricks with replacing clay by fly ash in high volume ratio. Construction and Building Materials, 19(3), 243–247. https://doi.org/10.1016/j.conbuildmat.2004.05.017

27. **Little, M. R., Adell, V., Boccaccini, A. R., & Cheeseman, C. R.** (2008). Production of novel ceramic materials from coal fly ash and metal finishing wastes. Resources, Conservation and Recycling, 52(11), 1329–1335. https://doi.org/10.1016/j.resconrec.2008.07.017

28. **Matjie, R. H., Bunt, J. R., & Van Heerden, J. H. P.** (2005). Extraction of alumina from coal fly ash generated from a selected low rank bituminous South African coal. Minerals Engineering, 18(3), 299–310. https://doi.org/10.1016/j.mineng.2004.06.013

29. **Minh Trang, N. T., Dao Ho, N. A., & Babel, S**. (2021). Reuse of waste sludge from water treatment plants and fly ash for manufacturing of adobe bricks. Chemosphere, 284, 131367. https://doi.org/10.1016/j.chemosphere.2021.131367

30. **Mohan, S., & Gandhimathi, R.** (2009). Removal of heavy metal ions from municipal solid waste leachate using coal fly ash as an adsorbent. Journal of Hazardous Materials, 169(1–3), 351–359. https://doi.org/10.1016/j.jhazmat.2009.03.104

On Waste Management. (2023). https://zakon.rada.gov.ua/laws/show/2320-20#top

31. **Panday, K. K., Prasad, G., & Singh, V. N.** (1985). Copper(II) removal from aqueous solutions by fly ash. Water Research, 19(7), 869–873. https://doi.org/10.1016/0043-1354(85)90145-9

32. **Pavlík, Z., Fořt, J., Záleská, M., Pavlíková, M., Trník, A., Medved, I., Keppert, M., Koutsoukos, P. G., & Černý,** R. (2016). Energy-efficient thermal treatment of sewage sludge for its application in blended cements. Journal of Cleaner Production, 112, 409–419. https://doi.org/10.1016/j.jclepro.2015.09.072

33. **Perel'man, A. I.** (1986). Geochemical barriers: Theory and practical applications. Applied Geochemistry, 1(6), 669–680. https://doi.org/10.1016/0883-2927(86)90088-0

34. **Petruzzelli, D**. (2000). Coagulants removal and recovery from water clarifier sludge. Water Research, 34(7), 2177–2182. https://doi.org/10.1016/S0043-1354(99)00357-7

35. **Querol, X., Moreno, N., Umaña, J. C., Alastuey, A., Hernández, E., López-Soler, A., & Plana, F**. (2002). Synthesis of zeolites from coal fly ash: An overview. International Journal of Coal Geology, 50(1–4), 413–423. https://doi.org/10.1016/S0166-5162(02)00124-6

36. Register of waste generation, treatment and disposal facilities of Luhansk region (as amended in 2017). (2017). Luhansk War Civil Administration. ecolugansk.gov.ua/2013-12-12-00-50-06-3/2013-12-12-00-50-06/povodzhennya-z-vidkhodami

37. **Sahu, V., Srivastava, A., Misra, A. K., & Sharma, A. K.** (2017). Stabilization of fly ash and lime sludge composites: Assessment of its performance as base course material. Archives of Civil and Mechanical Engineering, 17(3), 475–485. https://doi.org/10.1016/j.acme.2016.12.010

38. **Scott, S. L.** (Ed.). (2018). A Matter of Life(time) and Death. ACS Catalysis, 8(9), 8597–8599. https://doi.org/10.1021/acscatal.8b03199

39. **Shabtai, Y., & Mukmenev, I.** (1996). A combined chemical-biotechnological treatment of coal fly ash (CFA). Journal of Biotechnology, 51(3), 209–217. https://doi.org/10.1016/S0168-1656(96)01598-2

40. **Sittig, M.** (1980). Metal and inorganic waste reclaiming encyclopedia. Noyes Data Corp.

41. **Swanepoel, J. C., & Strydom, C. A. (**2002). Utilisation of fly ash in a geopolymeric material. Applied Geochemistry, 17(8), 1143–1148. https://doi.org/10.1016/S0883-2927(02)00005-7

42. V**an Deventer, J. S. J., Provis, J. L., & Duxson, P.** (2012). Technical and commercial progress in the adoption of geopolymer cement. Minerals Engineering, 29, 89–104. https://doi.org/10.1016/j.mineng.2011.09.009

43. Voda pytna, hihiienichni vymohy do yakosti vody tsentralizovanoho hospodarsko-pytnoho vodopostachannia. (2010). K.: Vyd-vo standartiv.

44. Waste at every stage. (2002). Vital Waste Graphics. http://www.grid.unep.ch/waste/index.html

45. **Yurmazova, T., Shakhova, N., & Tuan, H. T.** (2016). Adsorption of inorganic ions from aqueous solutions using mineral sorbent—Tripoli. MATEC Web of Conferences, 85, 01017. https://doi.org/10.1051/matecconf/20168501017

46. **Zha, F., Liu, S., Du, Y., & Cui, K**. (2008). Behavior of expansive soils stabilized with fly ash. Natural Hazards, 47(3), 509–523. https://doi.org/10.1007/s11069-008-9236-4

47. **Zhang, W., Yang, J., Wu, X., Hu, Y., Yu, W., Wang, J., Dong, J., Li, M., Liang, S., Hu, J., & Kumar, R. V.** (2016). A critical review on secondary lead recycling technology and its prospect. Renewable and Sustainable Energy Reviews, 61, 108–122. https://doi.org/10.1016/j.rser.2016.03.046

48. Zvit pro vikonannya robit po ob'ektu: «Provedennya robit z monitoringu pidzemnih vod na teritoriyi oblasti. (p. 265). (2019). ShId DRGP.