JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(3), 132–142
https://doi.org/10.12911/22998993/177927
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.12.11
Accepted: 2023.12.29
Published: 2024.01.22

Analysis of the State of the Municipal Solid Waste Landfill in Ivano-Frankivsk, Ukraine, the Composition of the Leachate, and Promising Technologies for its Treatment

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ABSTRACT

The characteristics of the hydrogeology of the municipal solid waste landfill in Ivano-Frankivsk are given. Accumulation of waste in landfills causes environmental problems due to pollution of the atmosphere, water resources, and soil. It was established that there is practically no contamination of the water horizon with infiltrate. Commissioning of the leachate pipeline, which feeds part of the leachate to the city's treatment facilities, solves the problem of the accumulation of leachate at the landfill, however, creates an additional burden on these facilities. The composition of the infiltrate was analyzed. It was confirmed that the main harmful pollutants of infiltrates are oil products, nitrogen-containing compounds, dyes, humic compounds, and heavy metals. The main methods of cleaning of infiltrates abroad and in Ukraine are characterized. Based on the analysis of the available impurities, for the purification of the infiltrate, it is proposed to use the technology of physical-electrochemical wastewater treatment, which includes their treatment in electrocoagulators and the separation of coagulated impurities in a thin-layer settling tank. Our studies showed that during infiltrate purification up to normative indicators of its discharge to treatment plants are not reached and it is worth using additional treatment of the infiltrate with oxidizers. As a result of exploratory studies, it is proposed to carry out additional treatment with hypochlorite ions, which can be obtained during the electrolysis of the infiltrate on an inert anode. Cleaning the infiltrate using the described technology will reduce environmental pollution, which means increasing the level of environmental safety of the solid waste landfill.

Keywords: municipal solid waste, landfill, leachate, cleaning, electrocoagulation, electrooxidation.

INTRODUCTION

Urbanization, by increasing the diversity and the number of consumer goods produced by industry, causes the generation of more harmful emission effluents and the accumulation of waste. One of the main types of man-made waste that pollute the environment is human waste - domestic waste that is stored in specially equipped landfills. Accumulation of waste in the territories of household waste dumps causes environmental problems due to pollution of the atmosphere, water resources, and soils (Rudko, 2017; Burton et al., 2013; Petruk et al., 2013). The tragedy at the Lviv landfill (Hrybovychi, Lviv region) once again highlighted the problem of Municipal Solid Waste (MSW) management in Ukraine (Krykavskyi et al., 2017; Malyovanyy et al., 2017). A comprehensive approach is needed when dealing with MSW: creating conditions for the reclamation of existing landfills and ensuring a system of measures aimed at preventing environmental pollution (Tymchuk et al., 2020; Mykhaylenko et al, 2021).

In the thickness of the landfill body due to precipitation and as a result of various chemical and biochemical processes, an infiltrate containing a large number of toxic organic and inorganic components is formed. If the protective layer of the landfill structure is breached, the infiltrate can contaminate the underground horizons of drinking water (Rudko, 2017; Burton et al., 2013; Urbanas & Satin, 2016). Therefore, an important aspect of the environmental safety of the landfill is its geological location and the construction of a protective (barrier) layer, as well as the hydrogeological structure of water horizons. To control the pollution of water resources, control wells for water sampling are placed around the landfill for compliance with regulatory indicators. The accumulation of leachate in the landfills also creates an ecological danger for the entire region around the solid waste landfills. With significant precipitation, the amount of wastewater in the body of the landfill increases several times, which requires control and the need for constant or periodic disposal of infiltrates, and their cleaning. Cleaning of landfill leachates is an important problem for different regions of Ukraine. According to data (Rudko, 2017; Statistical Collection, 2021), in Ukraine in 2020, the amount of leachate generated at solid waste landfills amounted to about 12 million m^3, in particular at the landfill in the Rybne, serving the Ivano-Frankivsk, about 0.5 million m^3.

In the following works, the composition of leachates from different landfills of solid waste in Ukraine was analyzed, namely in Lviv (Haydin et al., 2013; Moroz et al., 2017; Tymchuk et al., 2020; Urbanas & Satin, 2016), Poltava (Samoylik & Molchanova, 2018), Zhytomyr (Korbut et al., 2023), Dergachi, Kharkiv region (Stalinska, 2016), Mariupol (Mykhaylenko & Kapustin, 2013) and some others (Dushkin et al., 2022). As studies show, the concentration of pollutants in the leachates of solid waste landfills often exceeds the maximum permissible standards (MRLs) several times, which does not allow leachates to be discharged into water resources. Among the most dangerous are the higher content of ammonium nitrogen, nitrates, heavy metals, and organic compounds (oil products, dyes, humates, and others). However, a different composition of the infiltrates of different landfills is often observed, which is primarily related to the duration and conditions of landfill operation and the type of additional (for example, industrial) waste. Therefore, the use of unified approaches for their purification is often difficult (Petruk et al., 2013).

There are various technologies for cleaning leachates collected by landfill drainage systems. In general, solid waste landfill leachates are complex water systems that differ in composition from municipal or industrial wastewater. Therefore, 3 groups of leachate cleaning methods are distinguished: discharge into the sewer for further combined treatment with municipal wastewater; biological treatment (aerobic and anaerobic), and chemical-physical treatment (chemical precipitation, chemical oxidation, adsorption, reverse osmosis, etc.) (Petruk et al., 2013). The lack of treatment facilities at the landfill often forces the leachate to be transported and mixed with municipal wastewater. Co-treatment of filtrates with the wastewater is allowed only in cases where the volume of filtrate does not exceed 5% of the sewage supply to the treatment plant. Large volumes of filtrate pumped for mixing cause to decrease in the quality of sewage treatment, increase the corrosion of treatment plant nodes, etc. (Tymchuk et al., 2020; Petruk et al., 2013).

Methods of biological purification of leachate are widely used. The methods of biological treatment of infiltrates in aerobic lagoons for the treatment of leachate from the Hrybovychi landfill are presented in works (Tymchuk et al., 2020; Malovanyy et al., 2018; Moroz et al., 2017). Anaerobic filtration technologies may be accompanied by additional biogas production. However, the anaerobic process is more sensitive to changes in temperature and pH, as well as to various toxic substances contained in the leachates. Reverse osmosis technology (Tymchuk et al., 2020; Petruk et al., 2013) and ion exchange methods (Kostenko et al., 2017) are also used in many countries to clean landfill leachates or, more often, their finishing treatment. The technologies make it possible to achieve a high degree of purification, drain the purified leachate into surface reservoirs, and return the concentrate (10–20% of the volume) to the landfill body. The main disadvantages of the technologies are significant capital costs for the manufacture and commissioning of installations and operating costs for ensuring the processes.

The work (Franco et al., 2021) describes the use of sorption technologies for cleaning filtrates from heavy metals using sorbents. There is the absorption of many polluting components, although often this is not enough to discharge these waters into natural objects. Therefore, they are used in the final stages of purification.

Coagulation methods of impurity removal are often used for wastewater treatment in industry. The high efficiency of coagulants based on aluminum and iron compounds is due to their ability to form multi-charged polynuclear complexes with high sorption properties as a result of dissolution. Chlorides, sulfates of aluminum and iron, as well as aluminum chloride hydroxide, sodium aluminate, and iron polysilicate, are widely used in industry due to their availability and relative cheapness. Such physical-chemical cleaning methods are often used in complex methods at the stage of the so-called Chemically Enhanced Primary Treatment (CEPT) followed by, for example, biological cleaning (Shewa & Dagnew, 2020). The authors (Kurylets et al., 2022) experimentally confirmed the effectiveness of reagent cleaning of dairy effluents under the condition of alternate introduction of coagulant ($FeSO_4$) and flocculant (polyacrylamide) in amounts of 120 and 40 mg/m^3, respectively. It was shown that when using ultrasound, it was possible to significantly reduce the interaction time and the amount of $Ca(OH)_2$ suspension. The positive effect of the use of ultrasound was also shown in the treatment of wastewater from meat processing enterprises (Savchuk et al., 2017). To reduce the cost of coagulation wastewater treatment, coagulants obtained from waste from other industries are used (Vasiichuk et al., 2022).

Many modern studies on water and wastewater treatment technology are devoted to the Electrochemical Advanced Oxidation Process (EAOP), which is based on the electrolysis of aqueous solutions (Comninellis & Chen, 2010). These include electrochemical oxidation technologies, Fenton electroprocesses, and photoelectrocatalysis (Rajoria et al., 2022; Fu et al., 2023). Electrocoagulation is one of the most promising industrial methods of wastewater treatment. The method is used in local wastewater treatment systems contaminated with finely dispersed and colloidal impurities (Comninellis & Chen, 2010; Hakizimana et al., 2017). Also, cleaning is carried out from various emulsions, oils, fats, petroleum products, compounds of nickel, chromium, and other heavy metals (Helesh et al., 2023; Nayır & Kara, 2018; Wei et al., 2019; Chelyadyn et al., 2018). The mechanisms of the processes that occur during electrocoagulation are complex, due to the flow of parallel and/or sequential electrochemical, chemical, and physical processes, namely anodic oxidation and/or cathodic reduction of metal ions, water molecules, impurities of organic and inorganic substances. In the process of electrolysis, a change in pH and redox potential (ORP) is possible. It is also possible to undergo secondary processes caused by electrolysis products, as well as adsorption, coagulation, flotation, etc. (Rajoria et al., 2022). Iron or aluminum soluble anodes are used in electrocoagulation technology due to their cheapness, good sorption properties, low solubility of electrolysis products, and non-toxicity. Aluminum is commonly used for drinking water treatment and iron for wastewater treatment (Comninellis & Chen, 2010; Smotraiev, R., 2022). Electrocoagulation is recommended to be carried out in a neutral or weakly alkaline environment with a current density of 10...30 A/m^2, a distance between electrodes of no more than 20 mm, and a liquid rate of at least 0.5 m/s (Helesh et al., 2023). The application of the method is appropriate for the relatively high electrical conductivity of wastewater (Comninellis & Chen, 2010). However, alongside issues of structural and technological improvement of electrochemical installations at water treatment plants, it is necessary to carry out a comprehensive analysis of their safe operation. (Filypchuk & Shatalov, 2014). A restraining factor in the use of electrocoagulation is the increased consumption of electricity, sheet iron, and aluminum. Therefore, the need to use this method in each specific case must be economically justified.

MATERIALS AND METHODS

Many scientific and practical works are devoted to the issue of placement of landfills and processing of waste at these landfills, especially regarding the Lviv municipal solid waste landfill. There is practically no data on the Ivano-Frankivsk landfill. The structure of the article includes three parts: a description of the landfill, an analysis of infiltrate, and a description of the results of research to improve the efficiency of physical-electrochemical technology (Chelyadyn et al., 2020) for leachate treatment. To analyze the dynamics of changes in the composition of leachate in settling tanks by year (since 2012) and by different periods of the year, the results of analyses of leachate samples were used. Analyzes were carried out at the Department of Chemistry and Technology of Inorganic Substances of the Lviv Polytechnic National University, the Department of Laboratory Control of Municipal Enterprise "Ivano-Frankivskvodoekotekhprom" of the Ivano-Frankivsk City Council, and the Water Monitoring Laboratory of the Western Region of the State Water Resources Agency of Ukraine. Standard methods were used for the analysis. Preliminary research on leachate purification by using the physical-electrochemical method was carried out at the Department of Environmental Protection Technologies and Labor Safety of the Ivano-Frankivsk National Technical University of Oil and Gas. The scheme of the laboratory installation, methods of research, and analyses are described in the work (Chelyadyn et al., 2020). In order to improve this technology by using additional stages of leachate purification, trial studies of the effectiveness of various reagents (coagulants, oxidizers, pH regulators) in the process of leachate purification from pollution were carried out. Studies of the reagents' influence were carried out under visual control of the rate of settling of the coagulated sediment in the glass cylinders (1 l).

The study of the effect of the addition of sodium hypochlorite alkaline solution to the infiltrate was carried out in glasses (0.25 l). A dose (10 ml) of a concentrated hypochlorite solution was added to 80 ml of the infiltrate and mixed. Changes in pH and ORP of the studied infiltrate and solutions were recorded using a pH-meter "pH-301" (Ukraine) with a combined electrode 10601/7. The study of the simultaneous effect of a dose of hypochlorite solution and a coagulant ferric sulfate on the infiltrate purification was checked during settling in cylinders (1 l). The dose of the hypochlorite solution was added to the certain volume of infiltrate, and mixed. Then a dose of iron sulfate solution was added and the resulting solution was left for clarification. The data of cyclic voltammetry (CV) were used to explain the change in the redox properties of the infiltrate (Slyuzar & Kalymon, 2020). Platinum ($S=72$ mm^2) or steel (80 mm^2) working electrodes and a platinum counter electrode were used. The research was carried out using the Mtech PGP-550M potentiostat (Ukraine). All values of potentials (ORP or CV) are given relative to the Ag/AgCl reference electrode.

RESULTS AND DISCUSSION

Solid waste landfill in Ivano-Frankivsk

The municipal solid waste landfill of the territorial community of Ivano-Frankivsk is located in the area of the village Rybne of Tysmenytsya district. The landfill site is operated by the Municipal Enterprise "POLIGON TPV" of the Ivano-Frankivsk City Council (territorial community). One of the main directions of the company's activity is the disposal of municipal solid waste and the landfill operation. One more activity of the enterprise is constant monitoring of the impact of the landfill on the environment and the selection of soil samples for research. The landfill has been operating since the 1960s and covers an area of about 40 hectares (Fig. 1).

The landfill is equipped with a sorting station and biogas gathering system (59 gas gathering wells). Biogas is used for combustion and electricity generation. The storage of waste at the landfill takes place after the sorting of waste from plastic PET bottles and polymer packaging materials, also medium-sized solid metal and concrete objects in a cylindrical separator. After that, the waste is transported to the landfill area and leveled with a bulldozer in a layer 0.2...0.3 m thick and compacted. The next layer of MSW is placed on the compacted layer. However, the volume of domestic waste accumulation at the landfill already significantly exceeds the normative values. To obtain the necessary stock and the possibility of further storage of waste - the height and angle of the slope of waste storage at the landfill - it is necessary to increase the height of the dam and arrange a protective layer of the appropriate material, as well as fill the adjacent territory with neutral materials (soil, clay).

The filtrate from the landfill is collected in two reservoirs (tanks), both of which are equipped with intake chambers with valves. About 20,000 m^3 of leachate is formed every year. The capacity of the reservoirs is limited, therefore, to reduce the amount of accumulated leachate, it was removed by special transport, or every two years a collection (nonstationary) pipeline was installed for pumping leachate to the sewage collectors of the city micro-district Pasichna. The city sewage treatment facilities are situated near the Yamnytsya (Fig. 1). In 2023, the construction of a stationary pipeline of filtrate with a length of 13.5 km was completed. With the construction of a

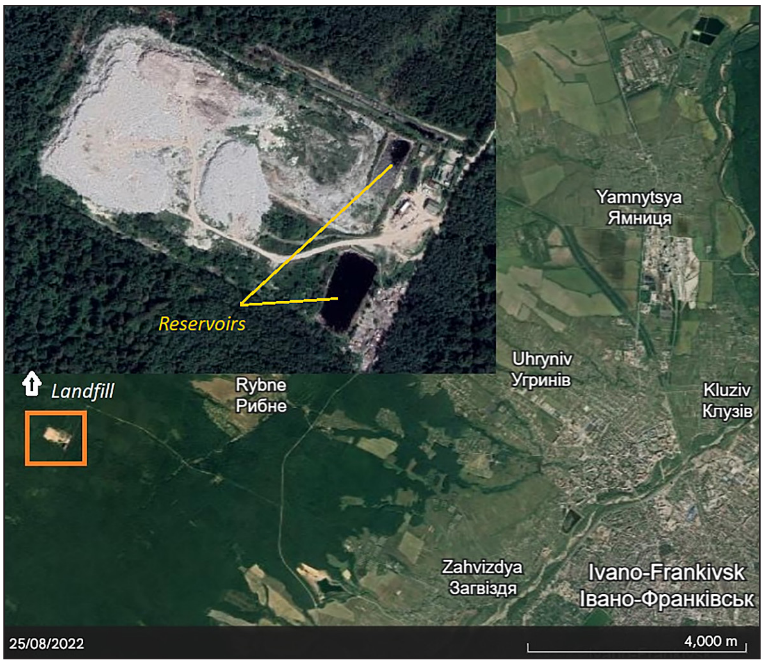

Fig. 1. Map-scheme of the solid waste landfill in Ivano-Frankivsk; source: base map – Google Earth

leachate pipeline at the landfill, the issue of leachate accumulation has practically been resolved, but the issue of its cleaning/decontamination has not been resolved. Batch mixing of leachate with municipal wastewater is a permissible process, although this will place an additional burden on the municipal biological treatment facilities.

That is why there is a need to install local treatment facilities, which can ensure the proper level of leachate purification before discharging it into the sewer network and later a waste processing plant, on the territory of the landfill, which can ensure the reclamation of the landfill and the appropriate level of environmental protection. As the analysis results (quarterly for the 2021 year, water monitoring laboratory of the Western region of the State Water Resources Agency of Ukraine) showed, the contamination of water samples from observation wells and the discharge control plant in the Pavelcha River according to the investigated indicators (pH, BOD, COD, chlorides, copper, lead, etc.) did not exceed the discharge requirements, which confirms the effectiveness of the landfill protective layer.

Analysis of the infiltrate

The analysis of the content of pollutants in the samples of the leachate of the solid waste landfill in Ivano-Frankivsk showed that the leachate contains different types of pollution (mechanical, chemical, biological), and the indicators of the ingredients differ both annually and quarterly. Table 1 shows the results of the analysis of the infiltrate for some types of pollution, as well as the Standards of Environmental Limit Values (ELV) of the wastewater quality in Ukraine for discharge to treatment plants.

As the results of the analyses indicated, the infiltrate is strongly colored (brown color, 7000–9000 degrees), characterized by a high content of suspended organic substances. Among inorganic substances, sodium chloride dominates (1.5–3 g/dm^3), which makes up a significant share of amounts of dissolved mineral salts. High COD (chemical oxygen demand) values of the filtrate indicate that its chemical composition corresponds to the phase of stable methanogenesis. COD indicators of the infiltrate, as well as the concentration values of ammonium and nitrate nitrogen, heavy metal ions, etc. several times exceed the permissible values for discharge into water resources. Analysis of the pH and redox potential of the infiltrate showed that the infiltrate is weakly alkaline (pH = 7–9), and ORP = -69 – -85 mV indicates weak redox properties.

These studies of the leachate composition, as well as the analysis of the results of other researchers' studies of landfill leachates (Dushkin et al., 2022, Haydin et al., 2013), showed that the leachate contains a high content of heavy metals, which is due to the presence of metal-containing

Table 1. Indicators of the quality of leachate of the solid waste landfill and the limit requirements for discharge

No.	Indicator	Units	Analysis results according to dates					Standards of ELV
			2012[1]	2014[1]	Sep 15, 2022[2]	Feb 09, 2023[2]	May 23, 2023[2]	
1.	pH		8.4	7.17	8.9	8.44	8.04	6.5–9.0
2.	Color	Degrees	-	-	7068	9126	8601	-
3.	COD	mgO_2/dm^3	4610	6558	6200	5650	6980	450
4.	Ammonium Nitrogen	mg/dm^3	233.7	861.3	955.0	990.0	968.5	30
5.	Chlorides	mg/dm^3	1447.2	1747.4	1685	1591	2977	350
6.	Total Iron	mg/dm^3	45.0	94.4	20.4	28.1	67.0	2.5

Note: Analysis results by: [1]Department of laboratory control of "Ivano-Frankivskvodoekotekhprom", [2]Water monitoring laboratory of the Western region of the State Agency of Water Resources of Ukraine.

substances capable of corroding at the landfill. Therefore, such infiltrates require a certain complex technology for their cleaning, since their composition is multi-component. To clean the infiltrate, it was decided to apply the physical-electrochemical technology of wastewater treatment using electrocoagulation (Chelyadyn et al., 2020), which has demonstrated its effectiveness in cleaning wastewater contaminated with oil products. Table 2 shows the results of the leachate treatment of the solid waste landfill in Ivano-Frankivsk using this technology.

The research results testified that the treatment of infiltrate by electrocoagulation (sequential treatment of the solution in electrocoagulators with Fe and Al anodes) method and the separation of coagulated impurities in a thin-layer sedimentation tank (TLST) makes it possible to achieve sufficiently high degrees of purification in terms of Color and COD, but the final indicators of the infiltrate are insufficient for discharge to treatment facilities. It is obvious that taking into account the complexity of infiltrate pollution, it is necessary to use additional stages for effective purification of infiltrates, namely additional precipitation of heavy metal ions and stages of oxidation of effluents and destruction of organic substances and, possibly, final sorption of compounds on sorbents.The presence of chlorides in the infiltrate led to the idea of the possibility of hypochlorite synthesis during electrolysis. During the electrolysis of low-concentration chloride solutions at a current density of 0.8–1.5 kA/dm^2 it is possible to obtain hypochlorite solutions. During the electrolysis of the infiltrate, the oxidation and destruction of organic substances on the electrodes are also not excluded (Nayır & Kara, 2018; Slyuzar & Kalymon, 2020). Trial studies of some reagents' (coagulators, oxidizers, and precipitants) effect on the purification of the infiltrate showed that the reagents have different pH, and redox properties (Table 3). They also have different effects on the change in the pH and ORP of the infiltrate (Table 4). A visual comparison of settled solutions demonstrated that greater cleaning efficiency is observed when using an oxidizer and one of the coagulants (1+4+2 or 1+4+3). In order to confirm the correctness of our judgments, we conducted approbation studies of the influence of infiltrate treatment with sodium hypochlorite solutions on its purification. Infiltrate with the following parameters: pH = 7.5; COD = 934.3 mgO_2/dm^3; ammonium nitrogen 36.0 mg/dm^3, nitrites 6.8 mg/dm^3; chlorides 372.6 mg/dm^3; sulfates of 808.6 mg/dm^3 were treated (3 attempts, the initial volume of the infiltrate was 80 ml) with

Table 2. Infiltrate cleaning indicators

No.	Before cleaning		After cleaning		Degree of cleaning, %	
	Color, degrees	CO, mg/dm^3	Color, degrees	COD, mg/dm^3	Color	COD
1.	7708.6	5206.7	770.1	1200.7	90.0	76.7
2.	6980.5	3650.2	550.8	958.3	92.1	73.7
3.	8917.3	6980.5	208.6	1830.7	97.7	73.8
4.	8860.1	4208.6	193.6	1020.8	97.6	75.7
5.	5765.4	3086.1	286.0	760.7	95.0	75.4

Table 3. Study of pH and ORP of the infiltrate and reagents

No.	Reagents	ORP, mV	pH
1.	Infiltrate	-83	8.3
2.	$FeSO_4$ (100 g/dm³)	408	2.3
3.	$AlCl_3$ (100 g/dm³)		4.1
4.	Hypochlorite solution (active Chlorine ~ 40 g/dm³ and NaOH ~ 10 g/dm³)	-431	11.3
5.	Lime milk $Ca(OH)_2$		12.4

a concentrated hypochlorite solution (Table 3). The results are presented in Figs. 2 and 3.

The results of the research showed that the pH and ORP values of the infiltrate first change more sharply, and then they are set at a fairly high dose of concentrated hypochlorite solution to the infiltrate (40–50 ml: 80 ml). A pH of ~ 10 and a low ORP value of ~ -250 mV is reached, which can cause reduction processes in such an oxidizing environment. The next addition of a coagulant - a solution of iron (II) sulfate (100 g/dm³, pH = 2.34, ORP = 408 mV, dose 10 ml) and settling made it possible to obtain a settled (clarified), slightly colored solution (Fig. 4a). Part of the sediment settled, and part floated. The formation of floating sludge is explained by the high pH value of the filtrate (Mnykh et al., 2023). At the same time, the boundary between the clarified solution and the "sediment" layer was clear, which indicated the high efficiency of the filtrate purification. Therefore, treatment of the infiltrate with concentrated

Table 4. Change in pH and ORP of the infiltrate when reagents are added

Added reagents*	1+2	1+3	1+4	1+5	1+4+2	1+4+3	1+4+5
pH	8,07	8,40	8,10	8,74	8,07	8,12	8,50
ORP, mV	-46	-84	-48	-110	-46	-51	-88

Note: the figure of added reagent corresponds to the serial number of the solution in Table 2.

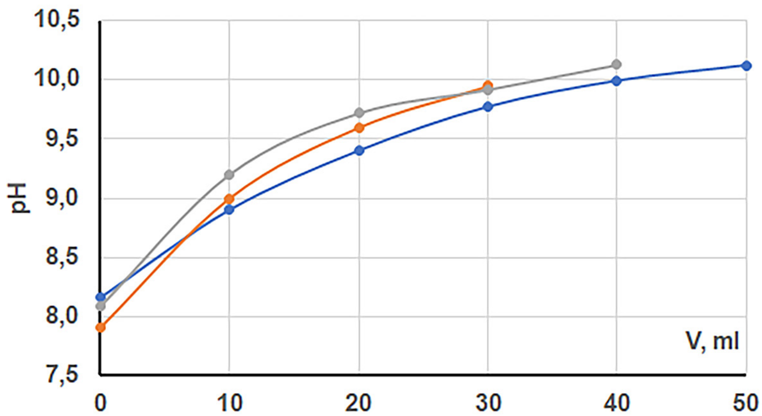

Fig. 2. Effect of additions of concentrated hypochlorite solution on the change in pH of the infiltrate

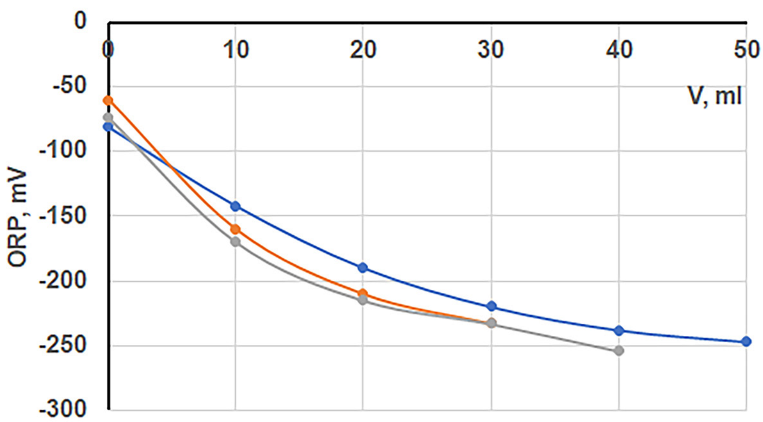

Fig. 3. Effect of additions of concentrated hypochlorite solution on the change in ORP of the infiltrate

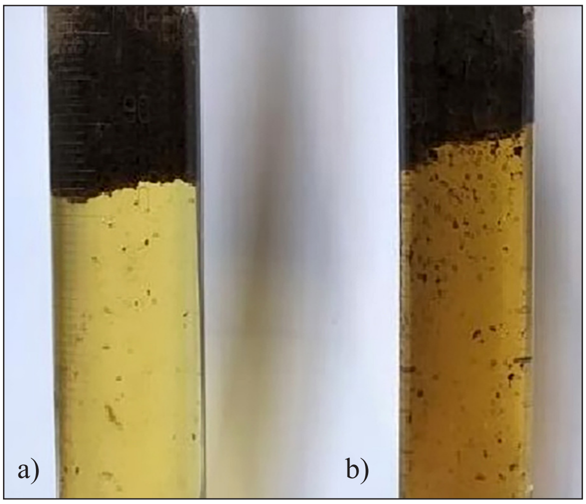

Fig. 4. Results of the infiltrate cleaning with hypochlorite solutions and the coagulant

hypochlorite solutions followed by treatment with a coagulant allows the purification of the infiltrate. The dose of the oxidizer will be determined by the requirements for the permissible residual content of active chlorine in the solution. It is obvious that in the real conditions of using the physical-electrochemical technology, the addition of hypochlorite solution should be replaced by the dosage of hypochlorite solution, which can be obtained during electrosynthesis from chloride ions contained in the infiltrate.

The redox behavior of the components of the infiltrate during electrolysis at different potentials can be seen on the cyclic voltammetric curves (Figs. 5 and 6). Two oxidation peaks (1st within 1.1–1.4 V, 2nd: 1.5–1.7 V) and two reduction peaks (3rd: -0.1– -0.6 V and the 4th: -0.8– -1.1 V) are observed on the CV curve on the Pt electrode (Fig. 5). In general, several compounds exhibit redox properties within the limits before oxygen release (up to ~ +1.7 V) and before hydrogen release (up to ~ -1.1 V). The first peak on the CV curves appears only in the 2nd and 3rd cycle and this indicates that certain reducing forms (perhaps of an organic nature) are generated in the solution, which can be irreversibly oxidized. Obviously, within peak 2, chloride oxidation processes are taking place. Peaks of currents 3 and 4 indicate the irreversible reduction of compounds contained in the infiltrate. A probable reaction is the reduction of Iron ions at the potentials of the 3rd peak. The character of the CV curves practically does not change in cycles 2 and 3.

Other properties are exhibited by the components of the infiltrate on the steel electrode (Fig. 6). During scanning to the anode side, anodic oxidation/dissolution of metal (Fe) is observed already at a potential of ~ -0.1 V. The process occurs practically without passivation. This is facilitated by the presence of chlorides in a low concentration. During the reverse course of the CV curve (on a cathodically polarized metal) at a potential of ~ -1.0 V, the release of hydrogen begins.

On the basis of the conducted approbation studies, it was proposed to implement a three-stage physical-electrochemical technology for cleaning infiltrates. In the electrocoagulators (1st stage), electrochemical processes will take place with the formation of coagulants, which ensure the maximum efficiency of separation of coagulated suspended pollutants from the filtrate in the sewage treatment plant (2nd stage). In TSHV, it is also possible to float some of the impurities due to the formation of gases in electrocoagulators. In the 3rd stage, it is proposed to process the infiltrate in an electrolyzer with an inert anode. Due to the

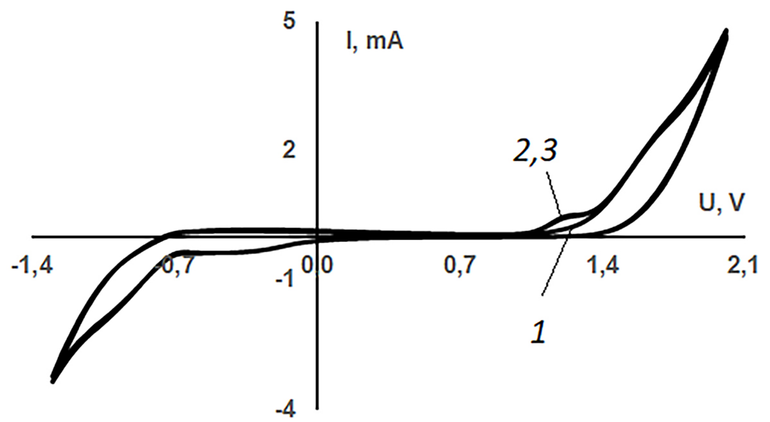

Fig. 5. Cyclic voltammogram (3 cycles) of the platinum electrode in the infiltrate (scan rate - 10 mV/s, direction - to the anode side)

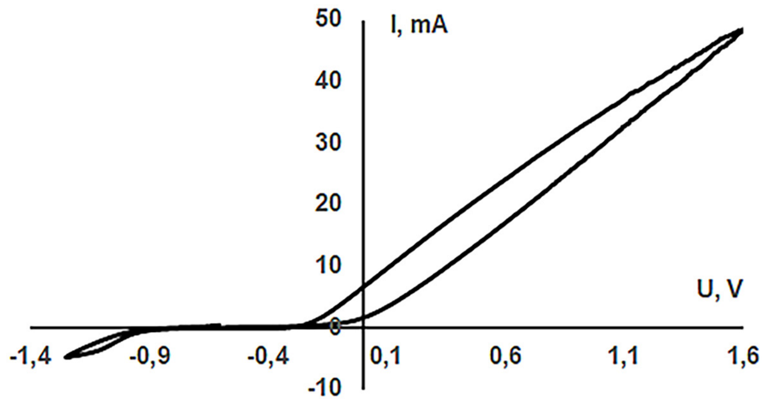

Fig. 6. Cyclic voltammogram of the steel electrodes in the infiltrate (scan rate - 10 mV/s, direction - to the anode side)

content of chlorides in the infiltrate, hypochlorite solutions will be formed on the inert anode of the electrolyzer, which ensures more effective oxidation of organic pollutants in the infiltrate. If it is necessary to achieve higher degrees of purification by components, it is worth carrying out the stage of additional sorption of pollutants on sorbents.

CONCLUSION

Necessary measures to reduce ecological pollution of the environment are carried out at the Ivano-Frankivsk solid waste landfill. The protective layer of the solid waste landfill in Ivano-Frankivsk does not allow infiltration into open water resources (Pavelcha River). Constant removal of leachate from settling tanks controls its accumulation, although will not ensure its purification. Solid waste landfill leachate contains various types of pollution (mechanical, chemical, biological), which requires the use of complex technologies for its purification. According to almost all indicators, the infiltrate is not suitable for being discharged to sewage treatment facilities. The physical-electrochemical technology of leachate purification, which combines electrocoagulation and the separation of impurities in a thin-layer sedimentation tank, does not sufficiently reduce pollution according to indicators – color and chemical oxygen demand. This forces the use of additional stages of leachate purification. The use of an oxidizer together with a coagulant allows for the achievement of a sufficient level of leachate purification. For this, it is necessary to introduce an additional stage of physical-electrochemical technology – the electrochemical synthesis of hypochlorite ions on an inert anode.

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