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MODIFIED FENTON METHOD AS AN EFFECTIVE TECHNOLOGY FOR FINISHING FILTRATES AT THE SECOND STAGE OF COMPREHENSIVE TECHNOLOGY

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Abstract. The paper investigates the effectiveness of the modified Fenton method for secondary treatment of solid waste landfill leachates after preliminary treatment using the aerated lagoon method. The study was conducted in laboratory and semi-industrial conditions. Based on the obtained results of reagent purification of filtrates in laboratory conditions, the optimal doses of working solutions of reagents (polyacrylamide, aluminum and iron sulfates, hydrogen peroxide) were established. The results obtained in laboratory conditions were tested and refined during field studies on a prototype of a filtrate pretreatment unit.

Keywords: landfill leachate, modified Fenton process, reagent treatment.

1. Introduction

Solid waste landfills (SWLDs) are a significant source of secondary environmental pollution. One of the most dangerous products formed at landfills is leachate - a liquid that is formed as a result of the filtration of atmospheric precipitation through the mass of waste, as well as due to the processes of decay of organic components of garbage. This leachate contains a high concentration of organic substances, ammonium nitrogen, heavy metals, toxic trace elements and pathogenic microorganisms, which pose a serious threat to the environment and public health.

The greatest environmental hazard of leachate is the risk of contamination of groundwater and surface water. If contaminated liquid enters aquifers, there is a

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steady decline in the quality of drinking water, the threat of toxic effects on ecosystems increases, and difficulties arise in restoring water resources. Leachate also causes soil degradation and can have an indirect impact on the atmosphere, especially in the case of anaerobic decomposition of pollutants with the release of greenhouse gases.

Leachate treatment is one of the key areas of ensuring environmental safety in the field of waste management. Effective treatment allows to significantly reduce the load on natural systems, prevent large-scale spread of pollution and ensure safe integration of landfills into the environment. The use of modern technologies helps to reduce the toxicity of the leachate to a level acceptable for discharge into natural water bodies or reuse.

Therefore, the treatment of MSW landfill leachate is of strategic importance for the protection of water resources, the prevention of man-made disasters, and the formation of a sustainable waste management system. It is one of the necessary measures to achieve sustainable development goals, in particular in the context of preserving ecosystems, adapting to climate change, and protecting public health.

Physical methods of leachate treatment include sedimentation, filtration, coagulation (Uthman, & Nyakuma, 2018), and the use of membrane technologies – microfiltration, ultrafiltration, nanofiltration, and reverse osmosis – which provide high efficiency in the removal of suspended solids, organics, and heavy metals (Bashir et al., 2019, Renou et al., 2008; Alakhras et al., 2023). Adsorption methods, in particular those using coal, coal processing products and activated carbon (Melnykov et al., 2024), as well as zeolites, are widely used to remove organic pollutants, but require regeneration or disposal of sorbents (Fritz Water Engineering, 2023).

Chemical processes, such as coagulation and flocculation, can effectively remove colored substances, suspended solids and organics (Kosogina et al., 2014). Among the advanced methods are the Fenton and photo-Fenton processes, which provide up to 99 % reduction in chemical oxygen demand (Jegadeesan et al., 2022). Ozonation and combined AOPs processes (e.g. O_3 /H_2O_2) contribute to increasing the biodegradability of the filtrate (Cortez et al., 2011, De Morais et al., 2022).

Electrochemical methods, in particular electrocoagulation and electrooxidation, provide deep oxidation of persistent organic compounds without the use of additional chemicals, which is an advantage in the context of environmental safety (Gao et al., 2018, Li et al., 2021, Saranya et al., 2014).

Biological methods are widely used for leachate treatment, especially with high content of biodegradable organics. Aerobic methods include SBR reactors, biofilters, and aerobic lagoons (Sarker et al., 2019). Anaerobic processes (e.g. ASBR, UASB) are effective at higher organic concentrations and reduced oxygen content (Sarker et al., 2019). Membrane bioreactors (MBR) in combination with RO membranes demonstrate high treatment efficiency (Choi et al., 2021, Lenntech et al., 2022).

Combined systems (e.g. coagulation–biotreatment–membrane treatment) combine the advantages of different technologies, achieving consistently high effluent quality (Fritz Water Engineering, 2023, Renou et al., 2008). Hydrodynamic cavitation in combination with ClO_2 allows to significantly improve the biodegradability of secondary treatment (Jegadeesan et al., 2022).

Wet air oxidation (WAO) processes combined with granular activated carbon (GAC) provide almost complete removal of organic matter, although they require significant energy costs (Singh et al., 2022). Membrane distillation (MD) and other thermal processes allow for high-quality permeate with subsequent reduction of concentrate volume (Sun et al., 2020).

One of the most promising areas is supercritical water oxidation (SCWO), which allows for the complete destruction of persistent pollutants, including per- and polyfluoroalkyl substances (PFAS), periodate and sodium percarbonate (Sukhatskiy et al., 2024), with minimal formation of harmful residues (Singh et al., 2022, Wang et al., 2016).

The most effective way to clean the leachate from solid waste landfills is to use a two-stage technology. Such approaches are implemented in most countries of the world. This allows the leachate to be cleaned of the bulk of the contaminants at the first stage, and at the final stage to achieve purification to a state that allows the treated effluents to be discharged into surface water bodies. A large number of combination schemes are known. Aerobic or anaerobic treatment is usually used at the first stage, and municipal wastewater treatment plants (Paintinget al., 2018), reagent purification (Paintinget al., 2022), biological conveyor (Paintinget al., 2021) etc.

The stage of aerobic pretreatment of filtrates has been sufficiently fully investigated by a number of scientists (Paintinget et al., 2023). The purpose of the research described in this article is to establish, in laboratory and semi-industrial conditions, the prospects for using a resource-saving reagent purification stage for the final purification of filtrates using the modified Fenton method.

2. Materials and Methods

For the final treatment studies, the filtrate of the Hrybovytskyi (Lviv) MSW landfill was used, the preliminary treatment of which was carried out in the conditions of an aerated lagoon. During the studies, changes in a number of the most environmentally hazardous filtrate parameters were monitored, the initial values of which are given in Table 1.

The research was conducted in 2 stages: in laboratory conditions and in industrial conditions at a pilot plant, which was installed directly at the Hrybovytskyi MSW landfill, which is currently undergoing reclamation.

Table 1

Initial values of controlled filtrate characteristics

Controlled leachate characteristics	Value
pH	9.71
Ammonium nitrogen (NH_4^+), mg/dm^3	186.6
Nitrogen (sum of organic and ammonium), mg/dm^3	397.2
BOD_5, mg O/dm^3	70.4
BSC_{Total}, mg O/dm^3	204.4
COD, mg O/dm^3	3724
Suspended and floating solids, mg/dm^3	219

The reagent purification method of filtrates according to the new modified Fenton method, the basic provisions of which are formulated in the works (Malovanyy at al, 2018, Malovanyy at al, 2022), involves the step-by-step addition of four reagents to a container with pre-biologically purified filtrate of aqueous solutions: a flocculant in the form of polyacrylamide or its more effective derivatives, a coagulant in the form of an aqueous solution of aluminum sulfate, as well as the simultaneous introduction of Fenton’s reagent, consisting of solutions of iron (II) sulfate and hydrogen peroxide. Therefore, the full complex of these four reagents forms a type of modified Fenton's method. The essence of the proposed method is the preliminary addition of a flocculant (PAA) and an aluminum-based coagulant to the filtrate, after which the components of the Fenton reagent are introduced. When applying the modified Fenton method in practice, the first priority is to establish the optimal concentrations of each of the four reagents, taking into account the limitations caused by the scale of implementation. In theory, increasing the concentrations of all reagents is beneficial, since under constant conditions it contributes to the maximum acceleration of chemical reactions in the filtrate and reduces the overall increase in the volume of the purified mixture. However, in real conditions there are restrictions on the maximum permissible concentrations of reagents both from the point of view of technical feasibility (viscosity, chemical aggressiveness of the medium) and from the point of view of the safety of operating personnel.

The solubility of polyacrylamide and its derivatives, as well as the effective viscosity of their aqueous solutions, are determined by both the molecular weight of the polymer and its chemical structure. The main limiting factor in working with PAA solutions is high viscosity, which complicates both the preparation of solutions and their subsequent dosing. For PAA in the form of Poly (acrylamide-co-diallyldimethyl-ammonium chloride), it has been determined that the maximum permissible concentration is 0.1 wt. % (1 g of polymer per 1 dm^3 of solution or 1000 ppm).

The solubility of anhydrous aluminum sulfate $Al_2(SO_4)_3$ in 100 g of water in the temperature range (0–20 °C) is from 37.9 to 38.4 g. The content of the active substance in the crystalline hydrate $Al_2(SO_4)_3 \times 18H_2O$ corresponds to 16 % by weight in terms of aluminum oxide Al_2O_3 or 51 % by weight in terms of the anhydrous salt. The maximum possible solubility of this crystalline hydrate at 20 °C is 75.3 g per 100 g of water. At the same time, in laboratory conditions there were difficulties associated with the slow dissolution of the crystals of the technical product, which required adjusting the choice of the concentration of the working solution. Analysis of the dissolution kinetics allowed us to establish that the optimal concentration of the working solution $Al_2(SO_4)_3 \times 18H_2O$ should not exceed 10 % by weight. in terms of technical product or 5.1 % by weight in terms of anhydrous salt.

The solubility of anhydrous iron (II) sulfate $FeSO_4$ in 100 g of water at a temperature of 20 °C is 26.6 g. In iron sulfate ($FeSO_4 \times 7H_2O$), the content of iron (II) sulfate reaches at least 53 % by weight, which is equivalent to the solubility of 50.2 g of the technical product in 100 g of water. However, when the temperature decreases (for example, to 5 °C), the solubility of $FeSO_4$ decreases to 18.4 %, which corresponds to 34.7 % in terms of iron sulfate. In this case, iron (II) sulfate solutions undergo gradual oxidation by atmospheric oxygen to iron (III) sulfate, according to the equation:

$$12\ FeSO_4 + 3\ O_2 + 6\ H_2O \rightarrow 4\ Fe_2(SO_4)_3 + 4\ Fe(OH)_3 \quad (1)$$

The intensity of this reaction increases with increasing $FeSO_4$ concentration. Based on laboratory studies, it has been established that the maximum acceptable concentration is 10 % by weight in terms of the technical product or 5.3 % in terms of the anhydrous salt.

The efficiency of the Fenton reaction increases with increasing hydrogen peroxide concentration in the cleaning zone. At the same time, due to the explosive nature, high reactivity and tendency to decompose in open containers, the preparation and use of H_2O_2 solutions should be based on safety principles both in the laboratory and at the industrial level. In laboratory conditions, 10 % by weight was adopted as a safe concentration of hydrogen peroxide, with subsequent verification in pilot-industrial facilities, taking into account both safety for personnel and the impact on equipment materials.

In order to laboratory verify the stage of reagent treatment of MSW landfill filtrates, a series of experiments was conducted, during which aqueous solutions of polyacrylamide, aluminum sulfate, iron (II) sulfate and hydrogen peroxide were added to the pre-aerobic treated filtrate. Before addition, solutions with different mass concentrations were prepared. Based on the results of previous studies and the requirements determined by the pilot-industrial sample of the treatment plant, the optimal concentrations were established: – PAA: 0.1 wt.% (10–3 kg/dm^3 or 1000 ppm); – aluminum sulfate: 10 wt.% (100 g/dm^3); – iron sulfate: 10 wt.% (100 g/dm^3); – hydrogen peroxide: 10 wt.% (100 g/dm^3). Mass concentrations of salts were expressed in terms of technical products.

The main goal of a series of laboratory experiments was to determine the optimal reagent compositions in terms of maximum purification efficiency in terms of ammonium nitrogen, BOD_5 and CSD, as well as taking into account the rate of precipitation of the mixture after the introduction of reagents. Additionally, the issue of minimizing reagent consumption per unit volume of filtrate was considered, provided that the requirements of the standards stipulated by the “Rules for Accepting Wastewater to Centralized Water Drainage Systems” (Order of the Ministry of Regional Development of Ukraine dated 01.12.2017 No. 316), in particular: – pH: 6.5–9.0; – BOD_{total}: no more than 350 mg/dm^3; – CSD: no more than 500 mg/dm^3; – nitrogen (organic + ammonium): no more than 50 mg/dm^3; – suspended and floating substances: no more than 300 mg/dm^3. The composition of the reagent solution compositions that provided the highest purification efficiency is given in Table 2.

Table 2

Composition of reagent compositions in laboratory studies of reagent purification of filtrates (volume of filtrate Wf= 200 cm^3)

No. of solution	Waler solutions volume (mL)			
	PAA (0.1 wt.%)	Aluminium sulphate (10 wt.%)	Iron sulphate (II) (10 wt.%)	Hydrogen poroxide (10wt.%)
1	20	20	40	10
2	20	20	–	–
3	20	20	20	5
4	15	15	15	5
5	10	10	20	2.5
6	10	10	10	2.5
7	5	5	10	2
8	5	5	5	1

Field studies of the effectiveness of reagent treatment of leachates from MSW landfills were carried out on a pilot plant for treating leachates from MSW landfills and landfills, the schematic diagram of which is presented in Fig. 1, and the general view is in Fig. 2.

In the reagent treatment facility R5 (Fig. 1), the previously biochemically treated filtrate was treated using a composition consisting of four working solutions: polyacrylamide (PAA) (R1), aluminum sulfate (R2), iron sulfate (R3) and hydrogen peroxide (R4). To increase the efficiency of the reagent treatment processes, circulating mixing of the filtrate and reagent mixtures was used, which was carried out using a portable submersible sewage pump P5 (Fig. 2). The reagent treatment facility

2 operated in a periodic mode. After the introduction of reagents, the resulting mixture was kept in a settling state for a time interval from 1.5–2 hours to 23 hours. After that, the sediment that accumulated in the lower part of the structure was removed by gravity for further disposal, and the filtrate, which met the requirements of the "Rules for Accepting Wastewater to Centralized Sewage Systems", was discharged into the city sewer network.

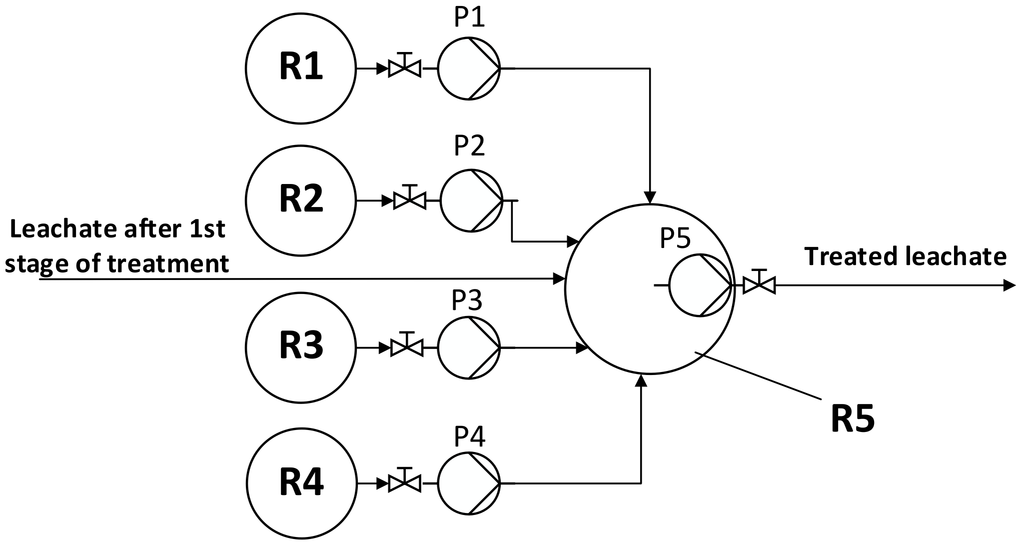

Fig. 1. Scheme of the research setupreagent treatment of leachates from solid waste landfills
(R1–R4 – solutions of reagents No.1–No.4 respectively;
P1–P4 – dosing pumps for reagents No.1–No.4 respectively; R4 – reagent leachate; P5 – submerged pump)

Fig. 2. Pilot leachate treatment plant at the pre-assembly stage (Energoresurs-Invest Corporation, Lviv)

The filtrate was supplied to the reagent purification facility P5 in portions, with a volume of 100 L per technological cycle. Using console-type pumps P1–P4 (Fig. 2), doses of PAA and aluminum sulfate solutions were sequentially supplied to the reagent purification facility, after which iron sulfate and hydrogen peroxide were simultaneously introduced.

The concentrations and volumetric doses of working solutions that were tested during studies on a pilot sample of the treatment plant are given in Table 3.

Table 3 also shows the mass concentration of active substances in the corresponding solutions: for aluminum sulfate and iron (II) sulfate, the mass fractions are indicated in terms of commercial products – crystal hydrates. In addition, the mass and molar concentrations of aluminum sulfate and iron (II) sulfate are indicated in terms of aluminum and iron (II) ions, respectively.

Working solutions of PAA, aluminum sulfate, and ferrous sulfate were prepared once a day, while the hydrogen peroxide solution was prepared immediately before each cycle of introduction into the reagent purification facility.

Table 3

Concentrations and doses of working reagent solutions in a full-scale study of reagent purification of filtrates (volume of filtrate Wf= 100 L)

No. mixture	Polyacrylamide		Aluminum sulfate		Iron sulfate (II)		Hydrogen peroxide		Reagent volume W_{Total} (dm^3)
	dose (dm^3)	C (g/m^3)	dose (dm^3)	C (g/m^3)	dose (dm^3)	C (g/m^3)	dose (dm^3)	C (g/m^3)	
1	5	50	5	405.4	10	2014.4	6	1200	26
2	5	50	4	324.3	8	1611.5	5	1000	22
3	4	40	5	405.4	8	1611.5	5	1000	22
4	4	40	4	324.3	6	1208.6	5	1000	19
5	4	40	3	243.2	8	1611.5	4	800	19
6	3	30	4	324.3	8	1611.5	4	800	19
7	3	30	5	405.4	6	1208.6	3	600	17
8	3	30	4	324.3	6	1208.6	3	600	16

The COD value was determined according to the national standard of Ukraine (DSTU ISO 6060:2003, 2004). The concentration of ammonium nitrogen was determined by the photometric method of ammonium ions with Nessler's reagent in wastewater (KND 211.1.4.030-95, 1995). A photoelectric colorimeter of the KFK-2-IHL4 brand was used.2 The determination of biochemical oxygen demand after n days (BOD) in natural and wastewater was carried out according to the method (KND 211.1.4.024-95, 1995), according to which the BOD_5 value was determined accordingly. The pH of the studied filtrates was determined using the Checker 1 HI98103 pH meter according to the corresponding instructions.

3. Results and Discussion

3.1. Laboratory studies

The optimal doses of working reagent solutions were determined in laboratory conditions using previously biochemically purified filtrate. The criterion for establishing the optimal composition of the working solutions was the values of the main indicators of contamination of the filtrate after reagent treatment, which should not exceed the relevant hygienic standards for discharge into centralized wastewater systems in Ukraine (Rules for accepting…, 2017).

In all laboratory experiments, the volume of the previously biochemically purified filtrate remained unchanged and was Wf = 200 cm³. The procedure for modeling the reagent purification process was carried out in laboratory glass cylinders with a volume of 500 cm³.

The composition of the reagent compositions used during the laboratory reagent purification of filtrates is presented in Table 2. All reagent mixtures, except for composition No. 2, included all four reagents. In mixture No. 2, rapid and fairly effective clarification of the filtrate sample was recorded even before the introduction of iron sulfate and hydrogen peroxide. At the same time, the insufficient effectiveness of using an incomplete set of reagents in reducing the indicators of chemical oxygen demand (COD), ammonium nitrogen and total nitrogen was confirmed.

Graphical dependences of the values of COD and total biochemical oxygen demand (BOD) for reagent-treated and settled mixtures No. 1–No. 8, as well as the corresponding effects of reagent purification, are shown in Figs. 3 and 4, respectively.

Chemical oxygen demand (COD) is the most critical indicator of pollution from the point of view of compliance with hygienic standards for wastewater discharge into the city sewer network. It is worth noting that with an increase in the doses of working reagent solutions, a decrease in the COD level is observed, but at the same time there is a certain increase in the content of suspended solids and a significant decrease in the value of the hydrogen indicator (pH) of the environment. Such a decrease in pH can lead to an excess of the permissible range, which is undesirable. In addition, increasing the doses of reagents is also unprofitable from a technical and economic point of view, since it causes an increase in the costs of reagent purification.

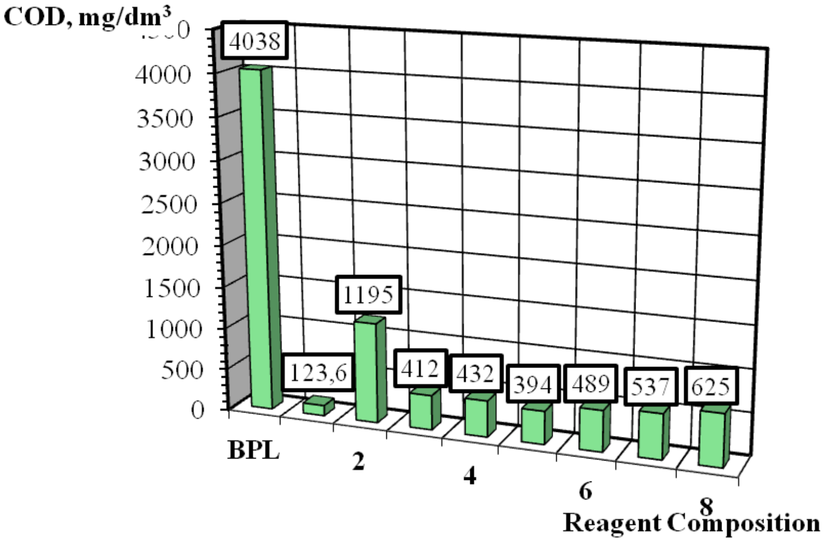

Fig. 3. COD of reagent-treated and settled mixtures No. 1–No. 8

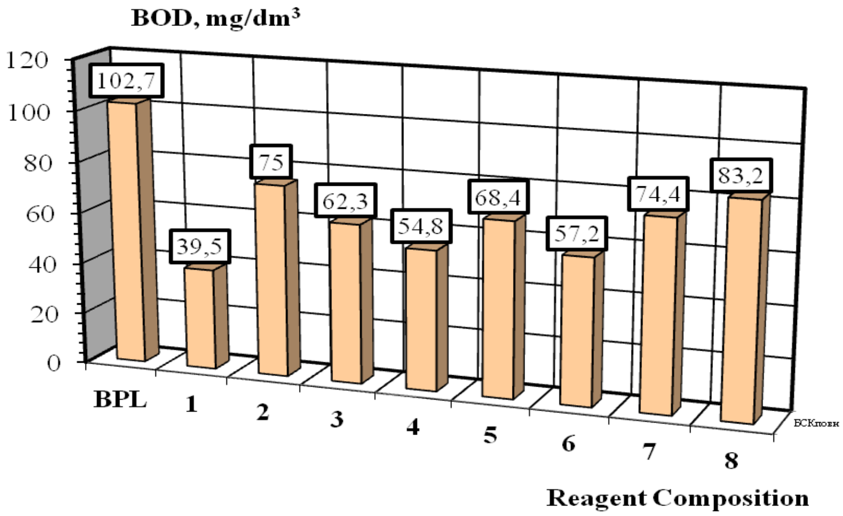

Fig. 4. BSCtotal of reagent-treated and settled mixtures No. 1–No. 8

3.2. Pilot plant research

Table 3 presents the concentrations of working reagent solutions, as well as the composition of their compositions used during the field experiment on reagent purification of filtrates. Table 4 contains summarized data on the concentrations of the main polluting components before and after the introduction of the reagent purification stage for various reagent mixture systems.

The filtrate purification effect at the reagent treatment stage was calculated using Formula (2):

$$E = \frac{P_{en} - P_{ex}}{P_{en}} \times 100\% , \qquad (2)$$

where P_{en}, P_{ex} is the contamination parameters before and after reagent cleaning, respectively.

Histograms of changes in the effect of filtrate purification from the main types of contaminants as a result of the reagent purification process are shown in Figs. 5–7.

Table 4

Actual values of contamination indicators in the filtrate before (upper part of the cell, red font color) and after the reagent purification stage (lower part of the cell, green font color) on a pilot sample of the purification plant

Indicator name	Reagent mixture number							
	1	2	3	4	5	6	7	8
pH	9.71	9.79	9.73	9.76	9.8	9.71	9.72	9.72
	6.26	6.63	6.54	6.78	6.67	6.57	6.7	6.81
Ammonium nitrogen (NH_4^+), mg/dm^3	186.6	184.9	172.7	177.2	174.4	178.5	168.8	179.6
	14	16.3	17.4	15.5	13.4	22	24.9	32.5
Nitrogen (sum of organic and ammonium), mg/dm^3	397.2	382	392.9	367.3	390.2	397.1	396.7	359.8
	27.3	30.1	32.4	30.2	25.7	39.4	45.8	56.2
BOD$_5$, mg O/dm^3	70.4	56.9	49.3	68.1	53.5	53.1	51.7	55.3
	15.8	17.1	17.9	20.4	26.5	25.2	23.7	28.8
BSC$_{Total}$, mg O/dm^3	204.4	210.8	193.1	209.7	204.4	191.3	204.1	217.6
	62.7	59.6	57.5	71.8	76.9	95.1	72.1	87.9
COD, mg O/dm^3	3724	3809	3801	3732	3897	3599	3610	3681
	371	405	387	390	459	520	631	615
Suspended solids, mg/dm^3	219	224.8	223.8	224.9	219.2	222.5	222	225.2
	82.5	97	103.2	106.9	78.6	86.1	115.1	91.5

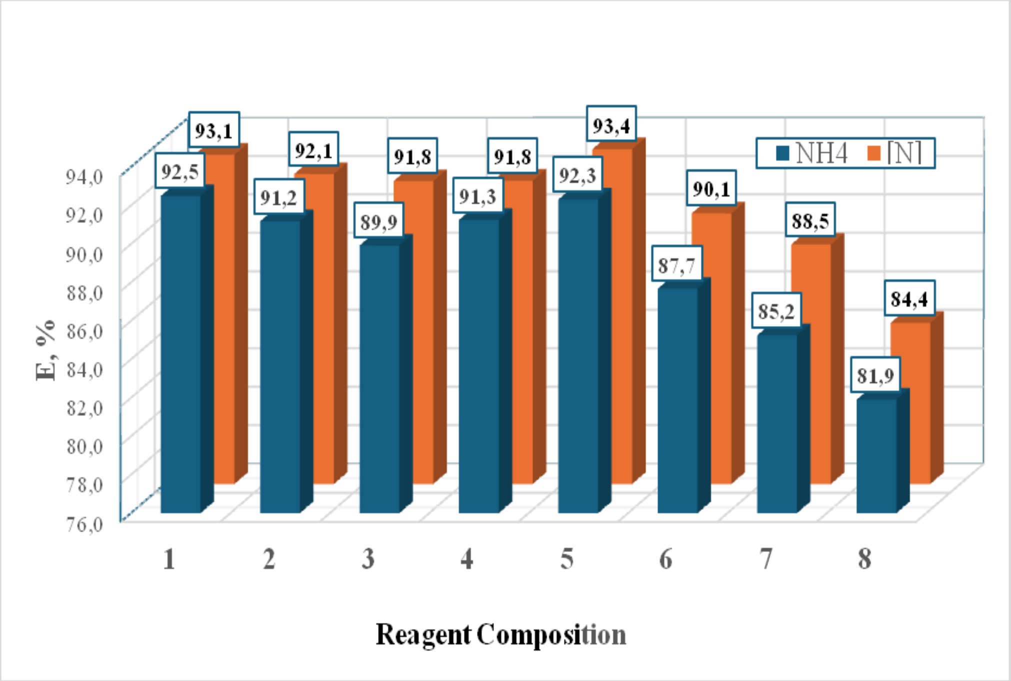

Fig. 5. Histograms of the change in the effect of cleaning the filtrate from ammonium and total nitrogen as a result of the reagent cleaning process, %

As can be seen from Fig. 5, the efficiency of leachate purification from ammonium nitrogen, as well as from total nitrogen (which includes the sum of organic and ammonium nitrogen), changes according to the same patterns for different combinations of reagent mixtures. These changes demonstrate similar trends in all reagent treatment options. During the study, it was found that for reagent mixtures No. 1–No. 7, the concentration of total nitrogen in the leachate after purification is lower than the established limit value for discharge into sewer networks, which is 50 mg/l. Only in the case of using reagent mixture No. 8, a slight excess of this standard value was recorded – 56.2 mg/l, which is given in Table 4.

Fig. 6 presents histograms of the change in the filtrate purification effect for BSC and CSC as a result of the reagent purification process.

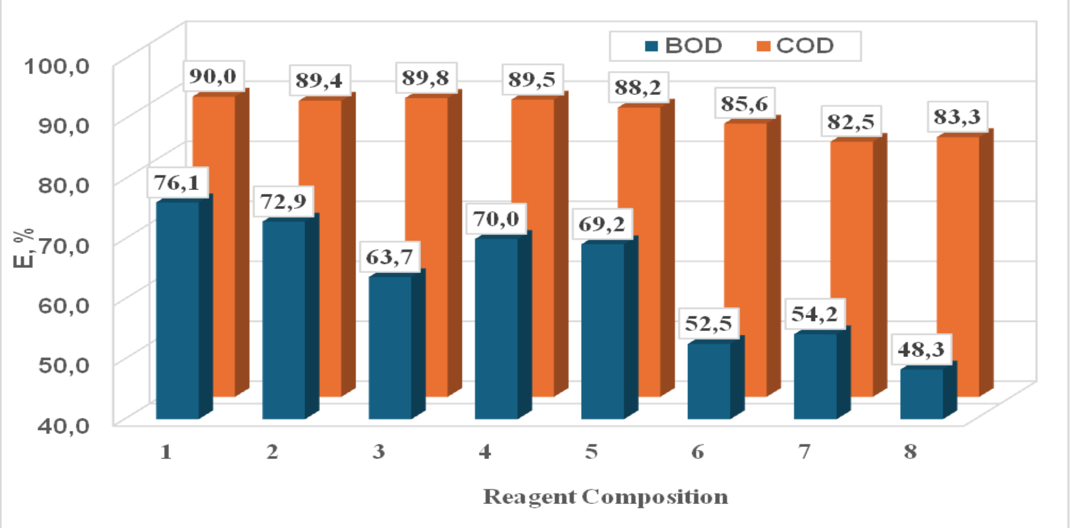

Fig. 6. Histograms of changes in the filtrate purification effect for BOD and COD as a result of the reagent purification process, %

For the filtrate that was tested at the experimental treatment plant, the value of total biochemical oxygen demand (BOD) after passing through the aerobic treatment stage remained consistently significantly lower than the corresponding regulatory indicator established by the hygienic standard (HS), which is 350 mg/l.

The most problematic indicator of pollution from the point of view of compliance with hygiene standards remains chemical oxygen demand (COD). Thus, when using reagent mixtures No. 6, No. 7 and No. 8, the established limit value of 500 mg/l was exceeded, which is clearly illustrated in Fig. 7.

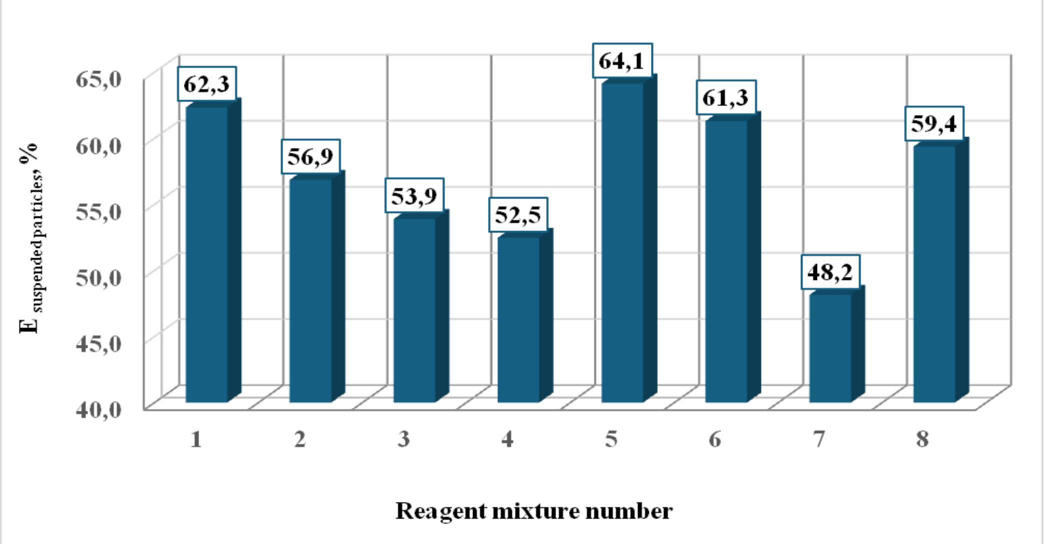

Fig. 7. Histograms of the change in the effect of cleaning the filtrate from suspended particles, %

Regarding the efficiency of treatment in terms of suspended solids content, the results obtained at the experimental facility formally look moderate and do not exceed 65 % (Fig. 7). However, it should be emphasized that during the reagent treatment process, sediment formation is actively occurring due to the introduction of coagulants, flocculants and Fenton's reagent. Due to this, the actual efficiency of treatment in terms of suspended solids – taking into account their peak content immediately after the addition of reagents – is significantly higher and exceeds 90 %.

In no case of using different reagent mixtures did the content of suspended solids in the filtrate after pre-treatment exceed 120 mg/l, which is significantly lower than the corresponding limit regulatory value established by the National Water Quality Commission – 300 mg/l.

Certain additional difficulties in implementing the reagent stage of filtrate purification are associated with the fact that the use of high doses of reagents leads to acidification of the environment, which, in turn, can cause the pH indicator to go beyond the regulatory permissible range, which is from 6.5 to 9.0. In particular, for reagent mixture No. 1, which is distinguished by the highest concentrations of reagents used and at the same time demonstrates the best results in terms of other pollution indicators (such as COD, total BOD and total nitrogen), a pH value of 6.26 was recorded. This value does not comply with the established limit standards for the discharge of treated wastewater into the sewage system.

4. Conclusions

Based on the results obtained from reagent purification of filtrates in laboratory conditions, the following conclusions can be drawn regarding the optimal doses of working reagent solutions:

1. Water that has undergone aerobic purification (PAA) at a mass concentration of 0.1 % – 10–20 cm^3 per 200 cm^3 of filtrate (0.05–0.1 mg/dm^3).

2. Water with the addition of aluminium sulphate 10 % mass concentration – 10−20 cm^3 per 200 cm^3 of filtrate (0.05−0.1 mg/dm^3).

3. Water with the addition of iron (II) sulphate 10% mass concentration –15−20 cm^3 per 200 cm^3 of filtrate (0.075−0.1 mg/dm^3).

4. Water with the addition of solid sulphuric acid 10% mass concentration – 2.5–5 cm^3 per 200 cm^3 of filtrate, which is 1.25–4.0 % of the dose.

These dosages are optimal for achieving the most effective purification of the filtrate, in particular, for reducing the concentration of pollutants and bringing the pH to the desired level for further disposal or discharge.

The results obtained in laboratory conditions were tested and refined during field studies on a prototype of a preliminary filtration purification unit.

Analysis of the results of field testing of the reagent purification stage of the filtrate on a prototype purification unit allows us to draw the following conclusion:

- There is a decrease in the concentration levels of acetamine, acid sulfamides, BOD and COD in the purified filtrate with an increase in the achieved values of the reagent solution;
- This, in turn, determines the optimal use of working solutions at the level of salt solutions No. 4 and No. 5, which were used;
- On the other hand, the reduced values of the achieved results lead to a decrease in the pH level of the purified filtrate below the minimum level for discharge into the sewerage system (pHmin = 6.5), which requires additional adjustment of the filtrate after purification.

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