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The aeration rate for the degree of purification of highly concentrated galvanic wastewater from zinc and ferrum ions was investigated using various activation methods. It is shown that the intensity of aeration has a significant effect on the quality of wastewater treatment and the characteristics of water treatment sludge. The efficiency of the use of an energy-saving method for activating the ferritization process with the use of electromagnetic pulses for the extraction of zinc ions from wastewater has been confirmed.

It was determined that with an increase in the aeration rate to 3.5 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture and the use of thermal activation of the process, the residual concentration of zinc ions remains within the range of 0.12÷0.2 mg/dm<sup>3</sup>. In this case, the concentration of ferrum ions decreases to values of 0.08÷0.14 mg/dm<sup>3</sup>. It was found that at an aeration rate of 2.5 dm<sup>3</sup>/min and the use of pulsed electromagnetic (EMP) activation, the residual concentrations of heavy metal ions decrease to values of 0.08÷0.16 mg/dm<sup>3</sup>. Comparison of the results indicates the advisability of using low rates of aeration of the reaction mixture. This, together with the use of resource-saving EMR process activation, allows to achieve a significant reduction in energy costs.

The quantitative phase composition of ferritization precipitates was determined, in which the crystalline phases of zinc ferrite Zn<sub>2</sub>Fe<sub>2</sub>O<sub>4</sub> and magnetite Fe<sub>3</sub>O<sub>4</sub>, as well as ferrum oxyhydroxide FeO (OH) and sodium sulfate Na<sub>2</sub>SO<sub>4</sub>, prevail. It is found that with an increase in the volumetric aeration rate, the proportion of the ferrite phase increases. At an aeration rate of 2.0 dm<sup>3</sup>/min, more than 85 % of the zinc ferrite phase was found in the sediments. Taking into account the qualitative and quantitative composition of precipitates, it is recommended to use them in the production of building materials.

The experimental results obtained make it possible to provide a comprehensive processing of liquid galvanic waste

**Keywords:** ferritization, zinc ions, galvanic waste water, electromagnetic pulse discharges, ferrite deposits

# INFLUENCE OF AERATION RATE AND METHOD OF PROCESS ACTIVATION ON THE DEGREE OF PURIFICATION OF ZINC-CONTAINING WASTE WATER BY FERRITIZATION

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## 1. Introduction

Among many environmental problems, a special place is occupied by the release of pollutants into the environment, including compounds of heavy metals, the main sources of which are industrial enterprises [1]. Galvanic production is one of the most environmentally hazardous, characterized by hazardous working conditions, a large amount of waste, significant volumes of wastewater containing highly toxic chemical pollution [2]. Electroplating has grown on a large scale in industry in the past and is expanding more and more. Sources of environmental pollution in galvanic production are not only flushing waste water, but highly concentrated waste solutions, in particular electrolytes. Discharges of these solutions are 10–15 % of the total amount of wastewater in size, and 70 % in terms of the total pollution content [3]. The salvo nature of such discharges disrupts the operation of

treatment facilities, leads to irrecoverable losses of valuable metals. In modern conditions, the main plan is the environmental friendliness of the technology with the provision of recovery of valuable compounds. It should be noted that among all types of galvanic zinc coatings it is 40–50 % of the total volume [4]. Annually in Ukraine, industrial enterprises generate about 100 tons of spent highly concentrated galvanizing electrolytes, which are subject to neutralization and processing [5]. In general, in the countries of Eastern Europe and Asia, the volume of this waste reaches 5 million tons [6]. As a result, with insufficiently treated galvanic wastewater, thousands of tons of highly toxic compounds containing zinc ions (Zn<sup>2+</sup>) enter water bodies annually. Thus, as a result of operations with the application of galvanic coatings with waste water, a significant amount of valuable chemical zinc-containing substances is irretrievably lost, which has a negative environmental impact. The environmental hazard

of galvanizing electrolytes (Table 1) is mainly determined by the concentration of zinc ions [7].

Table 1

The degree of environmental hazard of the components of solutions and electrolytes of galvanizing

Purpose of solution and electrolyte, name of the technological process	MPC ( $Zn^{2+}$ ), fishery reservoirs, $g/dm^3$	Environmental hazard of solutions of components
Galvanizing in ammonia electrolytes	0.01	$1.4 \div 5.7 \cdot 10^6$
Galvanizing in acidic electrolytes		$2.7 \div 7.2 \cdot 10^6$
Galvanizing in cyanide electrolytes		$0.8 \div 3.6 \cdot 10^6$
Galvanizing in pyrophosphate electrolytes		$1.4 \div 1.8 \cdot 10^6$
Galvanizing in zincate electrolytes		$0.8 \div 2.8 \cdot 10^6$

Zinc ions have a high migratory mobility and the ability to accumulate in a living organism. They can also cause various physiological disorders, including at the genetic level [8]. In addition, salts of heavy metals interfere with the biological self-purification of reservoirs, which is associated with a violation of the biological balance of trace elements and the oxygen regime of the reservoir [9]. It should also be noted that the reuse of materials removed from electrolytes will allow the enterprise to reduce fees for storing hazardous waste, obtain additional economic benefits from the sale of new products and reduce the load on the ecosystem [10]. Therefore, the urgent task of developing effective methods for the treatment of toxic wastewater containing valuable zinc compounds, with the rational use of water, raw materials and energy in the system of galvanic production.

## 2. Literature review and problem statement

The main direction of neutralization of spent electrolytes containing zinc compounds is their regeneration for the purpose of reuse, and the other direction is their extraction in the form of chemically stable substances [11]. If the indicated progressive methods of handling these wastes are not implemented in the galvanic production, they are sent to specialized enterprises for further neutralization. In the opinion of the authors of [12], regeneration methods are preferable, since they allow the regenerated solution to be used repeatedly. Thus, the service life is significantly increased and the amount of chemicals spent on adjustments and preparation of a new working solution is significantly reduced. However, regeneration methods require the use of multistage processes using a significant amount of chemicals, electricity and require significant capital investments and control over the purity of the obtained regenerated solution. A method of extracting heavy metals from waste solutions by cementation with iron is known [13]. But this method does not allow to completely purify the solution, from heavy metal ions to MPC norms, and therefore requires further additional purification. The disadvantage of this method is the accumulation of a large amount of ferrum ( $Fe^{tot.}$ ) in solutions. More promising is the treatment of highly concentrated wastewater by hydrophase ferritization. This method has a number of advantages [14],

and its essence lies in the creation of conditions in polluted water, conducive to the rapid formation of dispersed substances with magnetic properties. This process is facilitated by the presence of ferrum ions. [15] contained in the spent sulfuric acid pickling solutions in the electroplating industry. In contrast to hydroxide precipitates of reagent purification [16], chemically stable precipitates with a crystalline structure are formed in an aqueous suspension after the ferritization process. It was shown in [17] that ferritization precipitates have a multicomponent phase composition: oxides, oxyhydrates, and ferrites of heavy metals. On this basis, the paper [18] investigated the possibility of their useful utilization. The results of research on the purification of waste technological solutions by this method are presented in [19]. A significant drawback of existing technologies based on hydrophase ferritization is the implementation of the process at temperatures above  $75^\circ C$ , which requires significant energy costs. In [20], it was shown that an alternative to thermal hydrophase ferritization is the activation of the process by electromagnetic pulse discharges at a process temperature of about  $20^\circ C$ . The course of the process of hydrophase ferritization is significantly influenced by the ratio of the concentration of ferrum ions and other heavy metals extracted from the solution [21]. At the same time, the cleaning efficiency largely depends on the pH value of the solution, the temperature and duration of the phase formation process [18]. But there were unresolved issues related to the study of the effect of the volumetric flow rate of air bubbling through the reaction mixture on the main parameters of the process of ferritization wastewater treatment. As a rule, during the process, a fixed flow rate of the air mixture is used – about  $1 dm^3/min$  [22]. However, on the basis of work [23], it can be concluded that the volume of air, and hence oxygen, bubbled through the reaction mixture, affects the processes of formation of the crystal structure of the main components of the precipitate. All this allows to assert that it is advisable to conduct research on the effect of the volumetric flow rate of the oxidizer to create an economically effective wastewater treatment by ferritization with the formation of environmentally friendly and at the same time valuable ferrite compounds.

## 3. The aim and objectives of research

The aim of research is to determine the effect of the volumetric aeration rate on the efficiency of extraction of zinc and iron ions from galvanic wastewater by ferritization with different activation methods. This will improve the efficiency of wastewater treatment from zinc compounds and increase the energy efficiency of fertilization technology by using EMP activation with aeration control.

To achieve the aim, the following objectives were set:

- to investigate the degree of extraction of zinc and iron ions from wastewater by the method of ferritization at variable rates of aeration with air oxygen and thermal activation of the reaction mixture;
- to investigate the efficiency of wastewater treatment when using electromagnetic pulse activation with aeration of the reaction mixture;
- to investigate and compare the structural features of ferritization sediments, which are obtained as a result of purification of zinc-containing wastewater and give recommendations for their disposal.

#### 4. Materials and methods of research

Investigations were carried out on samples of spent acidic galvanizing electrolyte with pH=3.4 and concentration of Zn<sup>2+</sup>-ions=62.3 g/dm<sup>3</sup>. Electrolyte samples were taken at one of the leading aviation enterprises in Ukraine. To comply with rational conditions for carrying out ferritization, the electrolyte was diluted with technical water until the ratio of the concentration of ferrum ions to the concentration of zinc ion 5/1 and the total concentration of heavy metal ions 19 g/dm<sup>3</sup> [19]. For this, a 25 % solution of ferrum (II) sulfate was added. The pH value of the reaction mixture for ferritization was adjusted with a 20 % sodium hydroxide solution. The oxidation process of Fe<sup>2+</sup> to Fe<sup>3+</sup> was carried out by aeration of the reaction mixture with atmospheric oxygen.

The ferritization process was carried out in a laboratory reactor with a working volume of 1 dm<sup>3</sup>, both with traditional thermal activation [23] at a temperature of 70 °C, and with electromagnetic pulse (EMP) activation [18] of the reaction mixture at 18 °C. In the process of EMP activation, established by us in previous studies.

The determination of the influence of the volumetric aeration rate on the residual concentration of Zn and Fe ions was carried out in the range of values from 0.5 to 3.5 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture. During the experiment, the rational values of the operating parameters, the technological parameters of ferritization [18], were used: the concentration ratio of metal ions [Fe<sup>2+</sup>]/[Zn<sup>2+</sup>]=5/1, the pH of the reaction mixture was 10.5, and the process time was 25 minutes. Residual concentrations of heavy metal ions (ferrum and zinc) after purification were determined on a DR-3900 spectrophotometer (HACH Lange, Germany). The pH value of the reaction mixture was monitored with a pH-meter pH-150 (Belarus).

The structural analysis of powder samples of ferrite deposits was carried out by X-ray diffraction in a stepwise mode with Cu-Kα radiation on an Ultima IV diffractometer (Rigaku, Japan). The survey was carried out in the range of angles 2θ 6...70° and a scanning step

of 0.05° with an exposure duration at a point of 2 s. A scanning electron microscope-analyzer REMMA-101A (SEIMI, Ukraine) was used to study the microstructure of the sediment samples.

The estimation of the variance and the error limits based on the results of four measurements at each experimental point at a confidence level of 0.95 were determined by the method [24].

#### 5. Results of studies of the effect of aeration rate on the ferritization process

##### 5.1. Study of ferritization with thermal activation

The first stage of research was to study the effect of aeration rate on the efficiency of extraction of heavy metal ions by ferritization with thermal activation of the process. Since during ferritization the oxidizer has a significant effect on the course of the chemical interaction of the components of the solution, its consumption is one of the key technological parameters of the process. Therefore, the determination of its rational values is extremely necessary for the formation of a complete list of conditions for carrying out ferritization with the provision of high quality treatment of highly concentrated wastewater. The experimental data on water purification from zinc and ferrum ions are given in Table 2.

The graph of the dependence of the residual ion concentration on the aeration rate is shown in Fig. 1.

Table 2

Results of purification of galvanizing electrolyte by ferritization with thermal activation

Sample no.	Air mixture flow rate Q, [dm <sup>3</sup> /min per 1 dm <sup>3</sup> g.f.]	Residual concentration C, [mg/dm <sup>3</sup> ]		Purification degree α, [%]		Normative MPC for galvanic needs, mg/dm <sup>3</sup>					
		Zn <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Fe <sup>2+</sup>	I cat.		II cat.		III cat.	
						Zn <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Fe <sup>2+</sup>
1.1	0.5	0.12	0.53	96.996	99.996	5.0	0.3	1.5	0.1	0.2	0.05
1.2	1.5	0.13	0.28	99.995	99.998						
1.3	2	0.14	0.14	99.995	99.999						
1.4	2.5	0.17	0.18	99.994	98.999						
1.5	3.5	0.2	0.08	99.993	99.999						

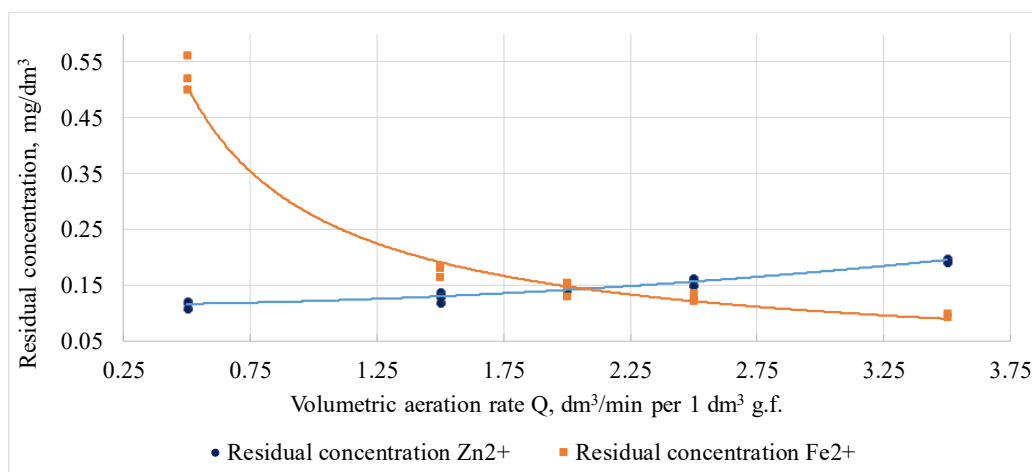


Fig. 1. Dependence of the residual concentrations of heavy metal ions on the volumetric aeration rate during thermal activation of the solution

The dependence of the residual concentrations of zinc and ferrum ions on the consumption of the oxidant during thermal activation of ferritization is non-linear. The experimental data obtained differ from each other (Fig. 1): the zinc concentration practically does not change with an increase in the air flow rate, and the ferrum concentration decreases. The residual concentrations of these ferrum and zinc ions in the solution after ferritization are in the range of 0.08–0.53 and 0.12–0.20, respectively.

**5. 2. Study of ferritization with electromagnetic pulse activation**

At the second stage of research, attention is paid to the influence of the air mixture flow rate on the ferritization process with electromagnetic pulse activation. The results of experiments to determine the dependence of the efficiency of extraction of heavy metal ions from the reaction mixture on the aeration rate during electromagnetic pulse activation of the ferritization process are given in Table 3 and Fig. 2.

The obtained values (Table 3) of the concentrations of heavy metals show that the residual content of ions of both ferrum and zinc decreases with an increase in the aeration rate. The residual concentrations of these ions in the solution after ferritization are in the range of 0.08–1.24 and 0.16–1.97, respectively.

The resulting solution in terms of its quality in most of the experiments carried out meets the requirements of category 1 water for galvanic production with respect to the maximum permissible concentrations (MPC) of ferrum and zinc ions. This water can be used to rinse parts after coating. A suitable quality of purified water is achieved when using an aeration rate of more than 2.0 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture for both components.

To study the dependence of the extraction of heavy metal ions on the intensity of aeration of the reaction mixture (Fig. 1, 2), mathematical models developed in [27] are proposed. A comparison was made between the correspondence of the obtained models and the experimental results when using different methods of activation. At a significance level of 5 % and degrees of freedom equal to 1 and 3, the values of the Fisher criterion  $F_{1,3}(0.05)=0.198$  were calculated. Let's check the fulfillment of the condition  $F_{tabl} > F_{1,3}(0.05)$ ,  $10.1 > 0.198$  – so that the constructed mathematical models are considered adequate with a probability of 95 %.

**5. 3. Study of the structural characteristics of ferritization sediments**

As a result of ferritization in both methods of activating the reaction mixture, a black dispersed suspension is formed, which further crystallizes with the formation, in particular, of dense ferrite structures. The study of the quantitative and qualitative composition of sediments was carried out for samples with both thermal and electromagnetic pulse activation of the process at aeration rates of 0.5 dm<sup>3</sup>/min (Fig. 3) and 2.0 dm<sup>3</sup>/min (Fig. 4) per 1 dm<sup>3</sup> of reaction mixtures.

The formed precipitates have a high crystallinity of the structure. The identification of the phases of the samples under study showed that they contain ferrite compounds with ferromagnetic properties, in particular, zinc ferrite. Unlike hydroxides, they do not dissolve in dilute solutions of powerful mineral acids and alkalis at ordinary temperatures. This is due to the special structure of their crystal lattice of the spinel type [17]. In addition, diffraction maxima related to the phase of ferrum oxyhydroxide FeO(OH) and sodium sulfate Na<sub>2</sub>SO<sub>4</sub> with a crystal lattice parameter  $a=2.96$  and  $a=5.84$ , respectively, are noted on the X-ray diffraction patterns. In the studied samples, the phases of zinc ferrite and magnetite from ferritization with thermal activation were identified.

Table 3

Results of wastewater treatment from heavy metals by ferritization with electromagnetic pulse activation

Sample no.	Air mixture flow rate Q, [dm <sup>3</sup> /min per 1 dm <sup>3</sup> g.f.]	Residual concentration C, [mg/dm <sup>3</sup> ]		Purification degree α, [%]		Normative MPC for galvanic needs, mg/dm <sup>3</sup>					
		Zn <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Fe <sup>2+</sup>	I cat.		II cat.		III cat.	
						Zn <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Fe <sup>2+</sup>
2.1	0.5	1.97	1.24	99.937	99.992	5.0	0.3	1.5	0.1	0.2	0.05
2.2	1.5	0.95	0.65	99.969	99.995						
2.3	2	0.24	0.19	99.992	99.998						
2.4	2.5	0.16	0.12	99.995	99.999						
2.5	3.5	0.25	0.08	99.992	99.999						

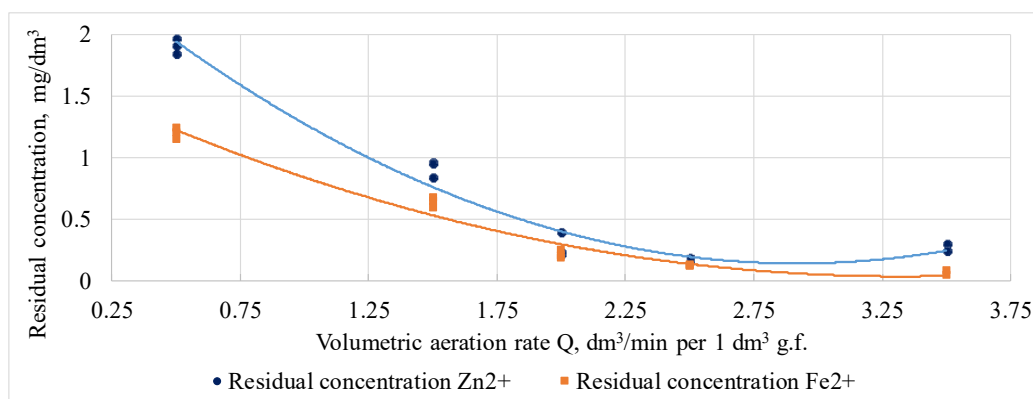


Fig. 2. Dependence of the residual concentrations of heavy metal ions on the volumetric aeration rate during the electromagnetic pulse activation of the solution

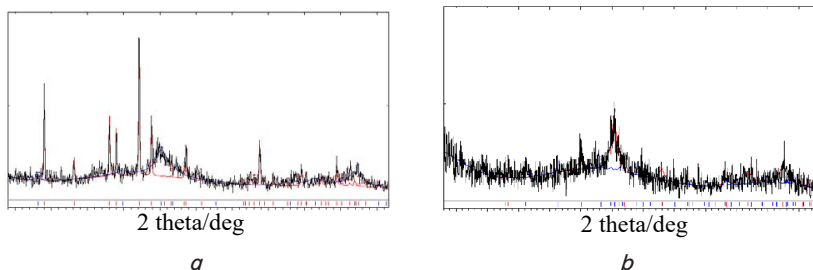


Fig. 3. Diffraction patterns of ferritization precipitates obtained at an aeration rate of 0.5 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture: *a* – thermal; *b* – electromagnetic pulse activation

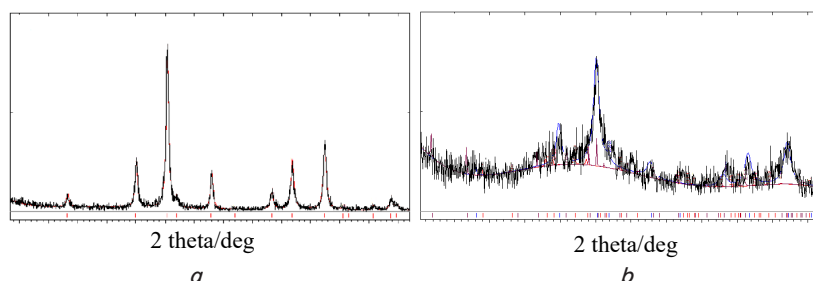


Fig. 4. Diffraction patterns of ferritization sediments obtained at aeration rate of 2.0 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture: *a* – thermal; *b* – electromagnetic pulse activation

Quantitative phase analysis was performed for all samples of the obtained sediments. Table 4 shows the ferromagnetic components contained in the composition of the sediments. The results of a quantitative analysis showed that an increase in the aeration rate leads to an increase in ferrite phases in sediments: with the thermal method of activation by 24 %, electromagnetic pulse – by 34 %. This, in turn, helps to reduce the amount of impurities, in particular, sodium sulfate Na<sub>2</sub>SO<sub>4</sub> by 6 % and 10 %, respectively.

obtained substances have micropores formed in the process of obtaining ferrites [17].

### 6. Discussion of the results of processing zinc-containing wastewater by ferritization

The results of the study indicate that the volumetric aeration rate and, accordingly, the amount of oxidant in the reaction mixture significantly affect the efficiency of extraction of zinc and ferrum ions by the ferritization method with various methods of activating the process. It has been experimentally established (Fig. 1) that the residual concentrations of zinc ions extracted from the electrolyte solution during thermal activation practically do not change when aeration is applied in the range of 0.5–2.0 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture. At an air flow rate of 2.0 dm<sup>3</sup>/min or more, the zinc extraction efficiency is somewhat reduced. At the same time, the residual concentrations of ferrum ions decrease with an increase in the aeration rate of 2.5–3.5 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture and have a value in the range of 0.08–0.12 mg/dm<sup>3</sup>.

Obviously, this is due to the fact that with an increase in the amount of the oxidant leads to an intensification of the crystallization process of dispersed compounds of heavy metals [22]. The research results shown in Fig. 2 show that when using electromagnetic pulse activation, the ferritization process provides a high degree of extraction of ions of both zinc and ferrum. It reaches values of 99.995 % and 99.999 % for ferrum and zinc ions, respectively, when using a volumetric aeration rate of 2.0 dm<sup>3</sup>/min per 1 dm<sup>3</sup> of the reaction mixture. Residual concentrations of heavy metal ions decrease to 0.08 and 0.16 mg/dm<sup>3</sup> for ferrum and zinc ions, respectively. This quality of wastewater treatment allows it to be reused in the electroplating industry. However, it complies with the current standards for the content of these heavy metal ions only for the needs of category 1 and does not meet the technological needs of production in categories 2 and 3.

Table 4

Composition of ferritization sediments at different aeration rates and activation methods

Sample no.	Air mixture flow rate <i>Q</i> , [dm <sup>3</sup> /min per 1 dm <sup>3</sup> g.f.]	Quantitative phase composition of sediment samples		
		Identified phase	Formula	Mass fraction of the main phase, %
1.1	0,5	Zinc ferrite	Zn(Fe <sub>2</sub> O <sub>2</sub> ) <sub>2</sub>	64
1.2	1,5			70
1.3	2			72
1.4	2,5			76
1.5	3,5			84
2.1	0,5	Zinc ferrite	Zn(Fe <sub>2</sub> O <sub>2</sub> ) <sub>2</sub>	64
2.2	1,5			55
2.3	2			85
2.4	2,5			89
2.5	3,5			84
2.1	0,5	Magnetite	Fe <sub>3</sub> O <sub>4</sub>	24
2.2	1,5			29

The data of structural analysis of sediment samples correlate well with the results of electron microscopy of ferrite sediment samples [21]. They showed the presence of crystals of irregular spherical shape in the pore space. In addition, the

has magnetic properties. In addition, the diffraction patterns revealed an insignificant amount of sodium sulfate Na<sub>2</sub>SO<sub>4</sub>. Also, according to the results of the study, it was revealed that an increase in the intensity of aeration of the reaction

mixture leads to an increase in the ferrite phase of  $Zn_2Fe_2O_4$  in the structure of precipitates and a decrease in the number of accompanying phases: ferrum oxyhydroxide  $FeO(OH)$  and sodium sulfate  $Na_2SO_4$ . Comparison of the quantitative phase composition of ferrite precipitates (Table 4) indicates that with both activation methods and aeration rate of 2.5–3.5  $dm^3/min$  per 1  $dm^3$  of the reaction mixture, the content of the metal ferrite phase is >76 %. The resulting precipitates have a high sorption capacity for ions of heavy metals and organic substances, given their porous structure.

Thus, the influence of one of the main technological factors of the process of ferritization treatment of highly concentrated zinc-containing wastewater from galvanic industries (the volumetric aeration rate on the efficiency of extraction of zinc ions and ferrum) has been confirmed. Its influence on the quantitative and qualitative composition of ferritization sediments suitable for further utilization has also been proved.

It should be emphasized that the use of an electromagnetic pulse method for activating the ferritization process, as opposed to a thermal one, is more energy efficient. It makes it possible to reduce the energy consumption during the processing of the reaction mixture by more than 40 %, and the determination of the optimal aeration rate of the reaction mixture – by 10 %, respectively. At the same time, its use improves the degree of extraction of heavy metal ions from the reaction mixture and promotes the formation of stable highly crystalline precipitates. It should also be noted that the regulation of the previously determined best values of the process parameters in conjunction with the optimal aeration intensity improves the degree of extraction of heavy metal ions, as well as the structure of the formed sediments.

The resulting sludge as a result of ferritization treatment of zinc wastewater after dehydration can be used as a valuable ferrite powder in the form of raw materials for the production of building materials. It can also be used in the production of environmentally friendly and stable chemically alkaline concretes [26].

It should be noted that the use of the proposed energy-saving EMP method for activating the ferritization process is advisable to use for the processing of highly concentrated technological solutions: spent electrolytes, pickling solutions, regeneration eluates of ion-exchange structures. It is relevant in the future to determine the optimal technolog-

ical parameters of EMP activation using the rational values of the aeration rate proposed in this work.

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## 7. Conclusions

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1. As a result of experimental studies, it has been shown that the best indicators of water purification from zinc and ferrum ions with traditional thermal activation of ferritization are achieved with aeration from 2.0 to 2.5  $dm^3/min$ . Residual concentrations of these ions in purified water are 0.14–0.17 and 0.14–0.18  $mg/dm^3$ , respectively, and the degree of purification ranges from 99.95 %. The water thus purified is suitable for reuse in the electroplating industry in accordance with the maximum permissible concentrations of heavy metal ions.

2. It was found that with an increase in the aeration rate from 0.5 to 2.5  $dm^3/min$ , the residual concentrations of heavy metal ions during EMP activation decrease to values of 0.08–0.16  $mg/dm^3$ . Comparisons of the experimental data obtained with thermal and EMP activation indicate the advisability of using low aeration rates, both with thermal and EMP activation of the reaction mixture. The introduction of energy-efficient solutions using optimal aeration rates and the simultaneous use of innovative EMP ferritization can significantly reduce energy consumption in industrial production.

3. The structure of ferritization precipitates with different activation methods was investigated, in which the phases of zinc ferrite  $Zn_2Fe_2O_4$ , ferrum oxyhydroxide  $FeO(OH)$  and sodium sulfate  $Na_2SO_4$  were found. An increase in the intensity of aeration of the reaction mixture leads to an increase in the content of ferrite phases. It was found that at an aeration rate of 2.0  $dm^3/min$ , phases with a maximum ferrite content of more than 85 % were found in the sediments. Resistant ferritic deposits are recommended for use in building materials.

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