Vol. 11, No. 3, 2025

INTENSIFICATION OF THE WASTEWATER TREATMENT PROCESS IN THE PRODUCTION OF SANITARY WARE USING COAGULANTS AND FLOCCULANTS

Andrii Shkop, Sergii Kulinich, Oleksii Shestopalov, Alona Bosiuk ✉, Antonina Sakun, Nataliia Ponomarova

National Technical University "Kharkiv Polytechnic Institute",
2, Kyrpychova Str., Kharkiv, 61002, Ukraine
Alona.Bosiuk@mit.khpi.edu.ua

https://doi.org/10.23939/ep2025.03.226

Received: 04.07.2025

Abstract. This article discusses the issue of sludge water treatment generated in the production of ceramic sanitary ware. Experimental studies were conducted on the effectiveness of physical and chemical treatment methods, in particular the use of coagulants (aluminium sulphate) and flocculants of various types (anionic, non-ionic, cationic). The optimal parameters for water treatment have been determined, which allow for the maximum removal of suspended particles and minimise the formation of sediment. It has been established that the use of aluminium sulphate in a concentration that does not lower the pH of the medium below 6.0–6.5, in combination with flocculants, ensures effective water clarification. The best result was obtained with a flocculant dosage of 250 g/t in a ratio of anionic to non-ionic 1:1. The combined use of coagulants and flocculants made it possible to reduce the residual turbidity of water to <5 mg/dm³ and accelerate the precipitation of finely dispersed particles by 1.5–2.0 times compared to traditional methods. An improved technological scheme for purification has been proposed, which includes coagulation, flocculation, settling and centrifugation, with the possibility of further use of purified water in the production cycle. The results obtained can be used to modernise local treatment facilities of ceramic industry enterprises and introduce closed water use systems. The proposed reagent selection method is adaptable to wastewater of similar composition and reduces the environmental impact.

Keywords: wastewater treatment, coagulation, flocculation, sedimentation rate, water reuse, environmental safety.

1. Introduction

The production of ceramic sanitary ware is accompanied by the generation of significant amounts of wastewater containing fine suspended particles, residues of clay materials, mineral salts, and organic impurities. The discharge of organic compounds, heavy metals, and chemicals used in the ceramic industry leads to substantial water pollution. Therefore, wastewater must undergo thorough treatment (Shurygin et al., 2021). The low natural sedimentation rate of suspended particles complicates the purification process and necessitates the use of reagent-based methods, particularly coagulation and flocculation (Shkop et al., 2017 b).

The basic technology for treating wastewater in the production of ceramic sanitary ware involves several main stages. First, mechanical methods are used, including coarse cleaning with screens and grates, sand traps and sedimentation tanks to remove coarse impurities. The next stage is physical and chemical treatment, during which chemical reagents are usually used to precipitate impurities in the form of sludge. However, these methods are not effective enough for removing colloidal and fine particles that

For citation: Shkop, A., Kulinich, S., Shestopalov, O., Bosiuk, A., Sakun, A., Ponomarova, N. (2025). Intensification of the wastewater treatment process in the production of sanitary ware using coagulants and flocculants. *Journal Environmental Problems*, *10*(3), 226–236. DOI: https://doi.org/10.23939/ep2025.03.226

remain in the water after settling. As a result, the treated water remains highly turbid, and the sludge formed requires complex disposal. Biological treatment is not usually used due to the specific composition of the wastewater from this production. Thus, traditional technological solutions do not provide a high degree of treatment, which limits the possibilities for reusing water in production.

Known technological schemes for wastewater treatment at ceramic industry enterprises are generally similar but differ in scale and capacity. Their main drawback lies in the considerable volume of sludge generated and the insufficient efficiency of water clarification, which limits the possibility of its reuse in the production process.

The current challenge is to explore combined treatment methods that can improve process efficiency, reduce water clarification time, minimize sludge volume, and facilitate its further disposal. This study aims to assess the effectiveness of various reagents and develop an improved wastewater treatment scheme that allows for the reuse of treated water.

Wastewater generated during the production of ceramic sanitary ware contains a large amount of fine suspended solids, which significantly complicates its treatment. Traditional methods such as sedimentation are often insufficient due to the low settling rate of particles and high residual turbidity of the water. Moreover, the resulting sludge requires additional measures for dewatering and disposal, placing an additional burden on both production processes and the environment.

An important aspect of the problem is the limited availability of water resources, which necessitates the development of technologies that enable the reuse of treated water within the production cycle. This would contribute to reducing wastewater discharge volumes, decreasing the consumption of fresh water, and enhancing the environmental safety of ceramic industry enterprises.

Therefore, there is a need to improve existing wastewater treatment schemes through the combined use of coagulants and flocculants. This approach will accelerate the sedimentation process, improve the quality of treated water, and optimize sludge management.

The increasing demands for environmental safety and the rational use of water resources make the issue of effective treatment of ceramic industry wastewater relevant. In this production, two main and one secondary wastewater streams are generated. The first arises during the preparation of slip and the shaping of products and contains many suspended clay particles, glycerin, and surfactants. The second stream is associated with the preparation of ceramic paints and contains pigments based on metal oxides. The third, secondary, stream is domestic and fecal wastewater (Yaroshenko & Shabanov, 2011). The use of traditional methods does not provide the required level of purification, which complicates the reuse of water in production and increases the negative impact on the environment.

Modern trends in water treatment are aimed at implementing combined methods of coagulation and flocculation (Onen & Gocer, 2018), which significantly improve the quality of treated water and reduce the treatment time. The study (Yaroshenko & Shabanov, 2010) analyzed the composition of wastewater from a ceramic plant, which confirmed the high variability of their physico-chemical characteristics and the need for an individual selection of treatment methods. However, the optimal parameters for reagent dosing and effective technological solutions for wastewater from sanitary ceramics production remain insufficiently studied.

This study is aimed at finding effective wastewater treatment methods that will increase the sedimentation rate of suspended particles, reduce the amount of generated sludge, and ensure the possibility of water reuse. The implementation of the obtained results will contribute to reducing the environmental burden of ceramic industry enterprises and increasing their environmental responsibility.

The physical and chemical composition of wastewater from ceramic production varies significantly depending on the technological stage and type of product. According to experimental data and literature sources (Sari Erkan, 2019; Martínez-García et al., 2012; Chong et al., 2009), typical indicators for such effluents are: suspended solids – 800–1200 mg/dm^3, COD – 250–400 mgO$_2$/dm^3, BOD$_5$ – 50–100 mgO$_2$/dm^3, surfactants – up to 15 mg/dm^3, pH – within 6.2–8.0. Heavy metal ions are also found in wastewater: Zn^{2+} – up to 1.0 mg/dm^3, Cr^{3+} – up to 0.2 mg/dm^3, Fe^{3+} – up to 2.0 mg/dm^3, Al^{3+} – up to 1.5 mg/dm^3. Specific pollutants include glycerine, clay particle residues, metal oxides, silica, calcium, magnesium and sodium salts. Such a v ariable composition significantly complicates wastewater treatment, necessitating the use of adaptive reagent methods.

The advantages of using ceramic membranes for the filtration of complex wastewater are widely covered in modern scientific research (Almecija et al., 2009; Barredo-Damas et al., 2010; Ebrahimi et al., 2015; Ebrahimi et al., 2014; Hua et al., 2007). However, contemporary studies provide almost no practical examples for the treatment of ceramic industry wastewater. In this work, the author investigates the removal of chemical oxygen demand (COD) from ceramic industry wastewater using chemical coagulation with alum and ferric chloride ($FeCl_3$) as coagulants. In addition, the research focuses on determining the capillary suction time (CST) of sludge samples, which is an important indicator of its dewatering potential (Sari Erkan, 2019).

The wastewater treatment schemes in ceramic tile and sanitary ceramics workshops described in the literature are similar, differing only in capacity. Wastewater is discharged into equalizing tanks, from where it is pumped by membrane pumps into special settling tanks, into which a coagulant (aluminum hydroxychloride) and a flocculant (polyacrylamide) are dosed. After treatment, part of the water is returned to the production cycle as technical water. The sludge retained in the settlers is dewatered using filter presses. The portion of the sludge, as well as residue on the screens (a mixture with foreign objects), which cannot be reused in production, is transported to a solid waste landfill.

The production of sanitary ceramic products has significantly contributed to the development of industrial water treatment technologies. In particular, efficient treatment and reuse of wastewater (Maura et al., 2023) helps reduce water consumption costs and minimize the negative environmental impact. However, ceramic production also generates significant volumes of wastewater containing heavy metals and other pollutants. Studies show that ceramic industry wastewater may contain up to 15 mg/L of boron and up to 2000 mg/L of suspended solids, which requires the implementation of effective treatment methods (Martínez-García et al., 2012; Chong et al., 2009). Boron is widely used in the production of sanitary ceramics to improve their mechanical strength. Overall, ceramic materials belong to the class of inorganic compounds that may contain organic impurities and non-metallic components (Khomenko et al., 2022; Budnyk et al., 2008). Furthermore, the production process results in products with varying clay content, which may be glazed or unglazed, porous or vitreous (Barros et al., 2007; Budnyk et al., 2008).

In their study (Elias et al., 2014), the authors investigate the treatment of ceramic industry wastewater using the method of rhizofiltration, applying a bioremediation system based on water hyacinth. This approach contributes to the effective removal of heavy metals and other pollutants from wastewater, enabling the minimization of their negative environmental impact and allowing for the reuse of treated water in the production process.

However, existing wastewater treatment schemes require further improvement to enhance the efficiency of pollutant removal and reduce environmental impact. In particular, the issues of optimizing the dosing of coagulants and flocculants to minimize excess sludge formation, as well as the possibilities for its further disposal or recycling, remain insufficiently studied. As noted by the author in their research (Onyshchuk, 2023), the effectiveness of flocculation and coagulation largely depends on the careful selection of reagents and technological parameters, which must be adapted to the specific type of wastewater. An unresolved issue is also the methodology for selecting different types of coagulants and flocculants using technological tests, which allow the obtained results to be used for adjusting the operation of treatment equipment.

In addition, the issue of reducing freshwater consumption in production processes through the maximum reuse of treated wastewater remains relevant. Promising research includes the implementation of additional treatment stages, particularly sorption and membrane technologies, to achieve the required quality of water returned to production.

2. Experimental part

The aim of this study is to improve the efficiency of wastewater treatment in ceramic tile and sanitary ware production by removing suspended solids through the selection of optimal doses and ratios of coagulants and flocculants.

This is necessary for the enhancement of technological treatment schemes, which will help reduce the negative environmental impact and increase water conservation within production processes.

To achieve this aim, the following objectives were set:

– to investigate physical and physicochemical methods for treating wastewater samples from ceramic tile and sanitary ware production and to determine their effectiveness;

– to assess the efficiency of various coagulants and flocculants, as well as their combinations;

– to develop a treatment technology for the removal of suspended solids from wastewater.

The study was conducted using real wastewater samples from an operating sanitary ware production facility, collected at different times and from various workshops: Sample No. 1 (solid phase concentration: 23 g/l); Sample No. 2 (solid phase concentration: 7.8 g/l).

The sludge waters from ceramic sanitary ware production contain solid particles of varying sizes, formed as a result of technological processes. The main parameters of the studied samples included volume, solid content, and pH value. The kinetics of particle sedimentation were examined by observing changes in water transparency over different time intervals. The study allowed for the determination of the optimal settling time required to achieve the highest degree of liquid clarification.

The research was carried out in several stages:

1. Sample preparation – wastewater samples with volumes of 5–20 liters collected from ceramic sanitary ware production were subjected to preliminary analysis to determine the concentration of solid residue using the evaporation method.

2. Gravitational settling – the initial samples were tested under still settling conditions for 4 to 24 hours, with changes in clarity and particle sedimentation rate recorded.

3. Centrifugation – a laboratory beaker centrifuge was used at separation factor values Fr = 990–2286 to evaluate the efficiency of mechanical phase separation.

4. Chemical treatment – various reagents were used for coagulation and flocculation of suspensions, including ferric chloride, aluminum oxychloride, and aluminum sulfate as coagulants, and cationic, anionic, nonionic flocculants, as well as their combinations. For each reagent, the sedimentation rate of the suspension after the addition of flocculants (V_1) and after intense mixing (V_2) was recorded according to the methodology described in more detail in publications (Shkop et al., 2017b; Shestopalov et al., 2019).

The diagram shown in Fig. 5 is a basic diagram and reflects the general sequence of treatment processes recommended for wastewater of a similar composition. Technological parameters, such as process duration, reagent dosage, sludge volume and moisture content, depend on specific production conditions and may vary. According to the methodology described in this study, the recommended coagulant consumption is 100 g/m³, flocculant consumption is 250 g/t (in two stages: 125 (non-ionic) + 125 (anionic) g/t), and the moisture content of the sludge after centrifugation is 45 ± 5 %. The studies were conducted in triplicate, the results were averaged, and the deviations did not exceed ±5 %, which confirms their reliability.

5. pH monitoring – changes in the pH of the medium after the addition of coagulants and flocculants were recorded, as this parameter affects sediment formation and aggregation efficiency.

6. Comparison of effectiveness – the effectiveness of different reagent combinations was compared, and optimal doses and conditions were identified to achieve the highest treatment efficiency.

3. Results and Discussion

As a result of gravitational settling of Sample No. 1, the following observations were made:

– after four hours of settling, clarification was minimal; the sample remained cloudy with approximately 50 % of the particles settling out;

– after 24 hours of settling, the sample remained turbid, indicating the presence of fine suspended particles (primarily clay particles such as kaolin clays).

To study the kinetics of gravitational sedimentation, a 500 ml sample of wastewater was placed in a transparent laboratory measuring flask (cylinder) with a diameter of 50 mm to observe the process of clarification and sediment formation. The kinetics of sediment growth in the sample during the settling process are shown in the graph in Fig. 1.

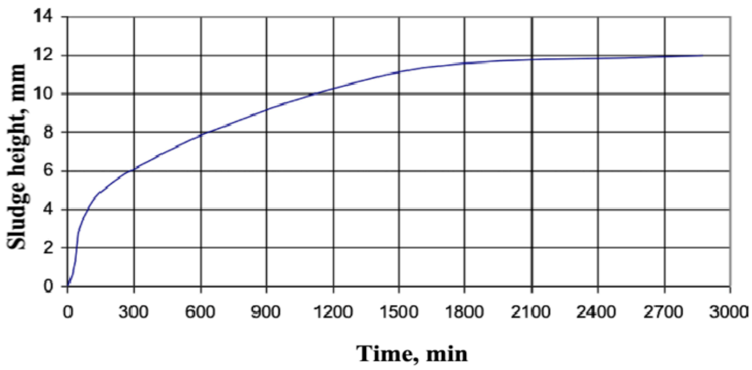

Fig. 1. Sedimentation kinetics during the settling process

An analysis of the sedimentation kinetics indicates that the wastewater sample contains finely dispersed particles forming a stable dispersion system, for which gravitational settling is largely ineffective (only coarse particles settle, while the majority remain suspended). However, preliminary settling allows for the removal of approximately 40–60 % of the solid phase (depending on the settling time) without the use of chemical reagents.

Centrifugation of the initial sample without chemical enhancement was performed using a laboratory beaker centrifuge at separation factors of Fr = 990, Fr = 1500, and Fr = 1940 (Table 1).

Table 1

Results of Centrifugation of Sample №1 in the laboratory Centrifuge

Separation Factor, Fr	Volume/Weight of Initial Sample	Weight of clarified sample, g	Note
990	250 ml /256.4 g	247.1	The sample is turbid, after 17 hours of settling, sediment is visible at the bottom.
1500	250 ml /257.1 g	247.15	
1940	250 ml /255.95 g	247.1	

Fig. 2 shows the appearance of clarified water after centrifugation in a laboratory beaker centrifuge at separation factors of Fr = 990, Fr = 1500, and Fr = 1940.

An analysis of the results indicates that centrifugation does not yield fully transparent water but does partially reduce the concentration of suspended particles. Complete clarification and the production of clear water can only be achieved through the use of chemical coagulants and flocculants, which destabilize the dispersion system formed by fine solid-phase fractions.

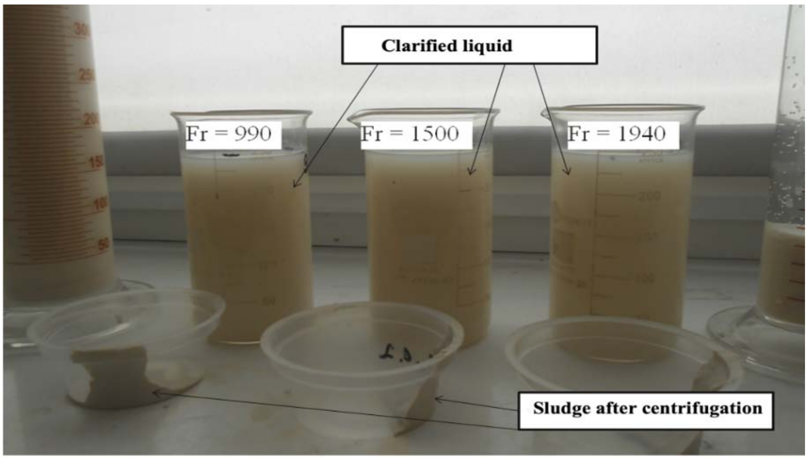

Fig. 2. Appearance of clarified water after centrifugation

At the next stage, chemical treatment of the sample was carried out using various reagents.

1. When the initial 250 mL sample was treated with 0.5 mL of 10 % ferric chloride, clear clarified water with slight whiteness was obtained. The sedimentation rate V_1 at 50 % of the sample volume was 0.6 mm/s. After centrifugation in a beaker centrifuge at Fr = 990, clear clarified water and a yellowish precipitate were obtained.

2. When the initial 250 mL sample was treated with 0.1 mL of aluminum oxychloride, clear clarified water with slight whiteness was obtained. The sedimentation rate V_1 at 50 % of the sample volume was 0.3 mm/s. After centrifugation in a beaker centrifuge at Fr = 990, clear clarified water was obtained.

3. When the 250 mL sample was treated with flocculants (50 % cationic + 50 % anionic) at a 0.05 % concentration (180 g/t), white clarified water was obtained. The sedimentation rate was V_1 = 6.1 mm/s and V_2 = 2.9 mm/s. After centrifugation in a beaker centrifuge at Fr = 990, white but non-transparent clarified water was obtained.

4. When the 250 ml sample was treated with 0.6 ml of 10% aluminum sulfate, whitish clarified water was obtained (see Fig. 3, a). The sedimentation rate V_1 at 50 % of the sample volume was 0.36 mm/s.

After centrifugation in a beaker centrifuge at Fr = 990, clear clarified water with a small amount of white sludge was obtained.

5. When the 250 mL sample was treated with a nonionic flocculant at a 0.05 % concentration (180 g/t), white clarified water was obtained. The sedimentation rate was V_1= 5.4 mm/s and V_2= 2.8 mm/s.

6. When the 250 mL sample was treated with 0.5 ml of 10 % aluminum sulfate followed by the addition of a nonionic flocculant at a dosage of 90 g/t, clear clarified water was obtained (Fig. 3, b). The sedimentation rate was V_1= 6.7 mm/s and V_2= 5.2 mm/s. After centrifugation in a beaker centrifuge at Fr = 990, clear clarified water and sludge with a moisture content of 51 % were obtained.

a *b*

Fig. 3. Appearance of samples after treatment:
a – with aluminum sulfate; *b* – with aluminum sulfate followed by enhancement with a nonionic flocculant

An analysis of the clarification results for Sample No. 1 indicates that the best performance for this type of wastewater was achieved using aluminum sulfate and a nonionic flocculant. The introduction of these reagents resulted in clear water. The highest efficiency was demonstrated by the combination of this coagulant with the nonionic flocculant, as their joint action led to the formation of large, fast-settling aggregates (V_1= 6.7 mm/s), which were minimally affected by mixing (V_2= 5.2 mm/s).

As a result of gravitational settling of Sample No. 2, the following was observed:

– no clarification was observed after 12 hours; the sample remained whitish and turbid, with a sediment layer at the bottom of the measuring cylinder approximately 0.5 to 1 mm thick;

– after 24 hours of settling, the sample remained whitish and turbid, indicating the presence of fine suspended particles, with the sediment layer increasing to about 1.5 to 2 mm.

– During centrifugation of the sample in a laboratory beaker centrifuge without chemical enhancement at separation factors of Fr = 990 and Fr = 1500, no significant differences were observed in the degree of clarification or the amount of solid sludge obtained; in both cases, the sludge volume was minimal (Table 2).

Table 2

Results of Centrifugation of Sample No. 2

No.	Separation factor value, g	Exposure time, s	Suspension separation results			
			Volume, ml	Volume of liquid, ml	Volume of sludge, ml	Description of clarified liquid and sludge
1	900…990 (800…990)	26	250	248/248.65	~1	White, turbid clarified liquid; a small amount of sludge present; sludge is moist
2	1500…1580	36	250	250/247	~1	Whitish, turbid clarified liquid; a small amount of sludge present; sludge is moist

When treating Sample No. 2 (500 ml) with 1 ml of 10 % aluminum oxychloride, followed by the addition of a combination of nonionic flocculant (250 g/t) and anionic flocculant (250 g/t), clear clarified water was obtained. The sedimentation rate was V_1= 9.5 mm/s and V_2= 2.9 mm/s. After compaction, the sludge volume amounted to 1/10 (50 ml) of the sample volume, corresponding to a concentration of 78 g/l.

However, this total flocculant dosage of 500 g/t is not optimal, which prompted further chemical testing of Sample No. 2 with various reagents, yielding the following results.

Stage 1. The dosage of the coagulant solution (aluminum sulfate, which had shown high effectiveness in previous tests on Sample No. 1) and the amount of flocculants remained constant, while the types and combinations of flocculants were varied.

When the 250 ml sample was treated with 0.5 mL of 10 % aluminum sulfate, the formation of small aggregates (flocs) was observed. Then, a flocculant with a 0.05 % concentration was added at a dosage of 257 g/t, and the sedimentation rate of the flocs was measured, as well as their residual sedimentation rate after 40 seconds of mechanical stirring with a laboratory mixer. The results of the study are presented in Table 3.

Table 3

Results of selecting the type and combination of flocculants

Type of flocculant added after coagulant	Sedimentation rate of flocs after formation (V_1), mm/s	Sedimentation rate of flocs after intense mixing (V_2), mm/s	Characteristics of clarified liquid
Anionic flocculant	11.67	3.8	Fine suspension
Cationic flocculant	4.2	1.46	Fine suspension
Nonionic flocculant	18.17	5.58	Clarified white suspension
Flocculant mixture (50 % nonionic + 50 % cationic)	5.21	2.05	Clarified white suspension
Flocculant mixture (50 % nonionic + 50 % anionic)	13.75	9.82	Clear water

An analysis of Table 3 indicates that the nonionic flocculant demonstrated higher overall effectiveness. However, the most mechanically stable flocs were formed when using a combination of nonionic and anionic flocculants. This may indicate the presence in the water of either solid particles with varying charges or the formation of secondary structures when combining flocculants – where one flocculant adsorbs more effectively onto particle surfaces, and the other forms bridges and promotes floc growth. These results are consistent with previous studies; for example, in coal sludge treatment, the highest efficiency was achieved using a combination of nonionic and anionic flocculants (Shkop et al., 2017 a), while for foundry dust sludge, a combination of anionic and cationic flocculants proved most effective (Bosiuk et al., 2024).

Stage 2. The optimal amount of coagulant and its effect on the flocculation process were investigated. Increasing the coagulant dosage in wastewater may be economically disadvantageous and negatively affect flocculation.

At this stage, the dosage and types of flocculants were kept constant, while the coagulant dosage was varied and changes in the pH of the medium were recorded.

When treating Sample No. 3 (250 ml; initial pH = 8.39) with 10 % aluminum sulfate in volumes ranging from 0.5 to 3 ml, the pH of the sample changed from 6.98 to 4.87. After the formation of small aggregates (flocs) over ~10 minutes, flocculants (50 % nonionic + 50 % anionic) at a 0.05 % concentration and dosage of 257 g/t were added. The sample was then mixed, and sedimentation rates were measured as in the previous experiments. The results are presented in Fig. 4.

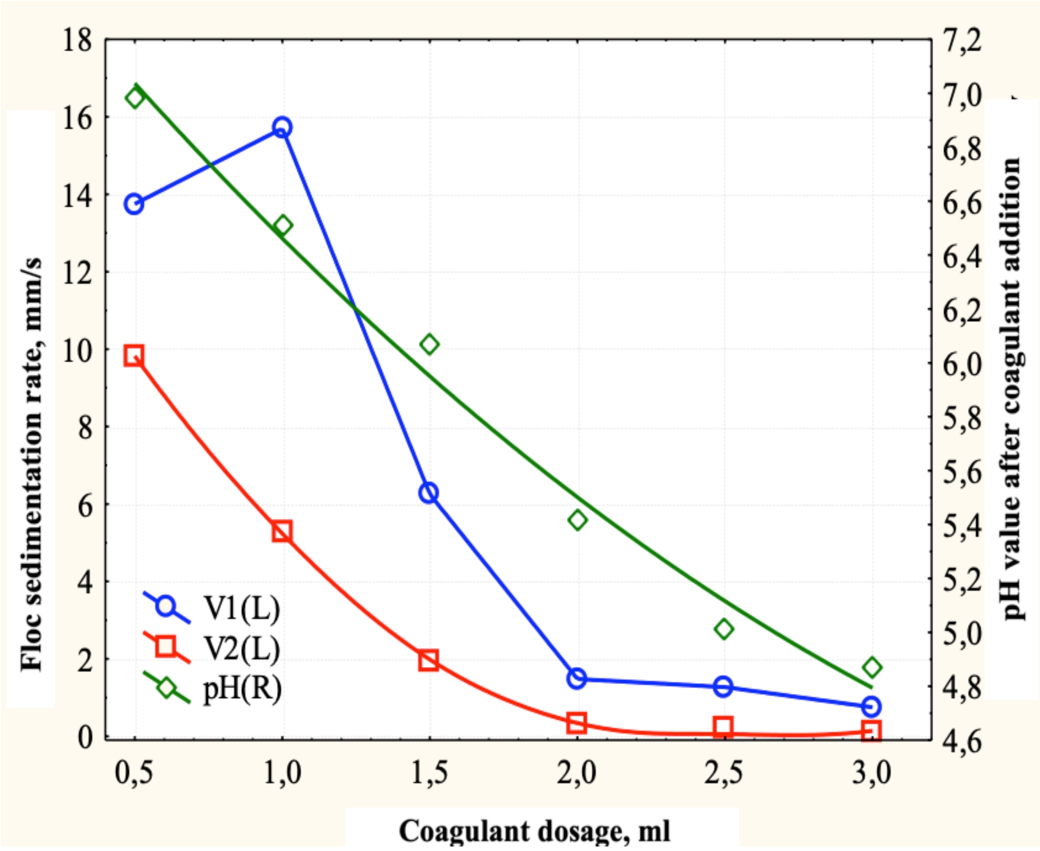

Fig. 4. Dependence of floc sedimentation rates on coagulant dosage and pH changes of the medium

An analysis of the results shown in Fig. 4 indicates that increasing the coagulant dosage while maintaining a constant flocculant rate leads to a reduction in both the size and strength of the flocs. This may be attributed to changes in the pH of the medium due to the accumulation of sulfate ions in the liquid.

Changes in ceramic sanitary ware production technology, particularly in the composition of raw materials or the parameters of individual operations, can significantly affect the chemical composition of wastewater and, accordingly, the effectiveness of coagulants and flocculants. Therefore, it is advisable to use an adaptive approach that involves regular analysis of the composition of wastewater and selection of optimal reagents based on the results of laboratory tests.

Thus, the analysis of the conducted research allows for the following general conclusions:

In most samples, clarification of the liquid phase occurred slowly, indicating high suspension stability. After 24 hours of sedimentation, many turbid suspended clay particles (kaolin) remained in the samples, confirming the need for additional treatment. Centrifugation without chemical reagents also failed to produce clear water but did allow for the rapid separation of coarse particles. The use of a laboratory centrifuge at different separation factors did not significantly improve the removal of fine particles of dispersed clay.

For maximum removal of suspended solids in less concentrated samples (C = 7.8–16 g/L), it is advisable to use coagulants in combination with flocculants. Among the coagulants, aluminum sulfate showed the highest efficiency in promoting aggregation and destabilizing the dispersed suspension. The use of aluminum sulfate combined with various flocculants led to complete clarification of the liquid, free of suspended particles. The most effective combinations included 50 % nonionic and 50 % anionic flocculants. It was found that the coagulant dosage should not be excessive and should not reduce the pH of the medium below 6.5.

Therefore, to achieve the best water clarification results, it is advisable to apply a combined use of coagulants and flocculants, while also maintaining an optimal pH level in the medium.

Based on the summarized findings above, the following treatment scheme can be proposed for sanitary ware manufacturing enterprises (Fig. 5).

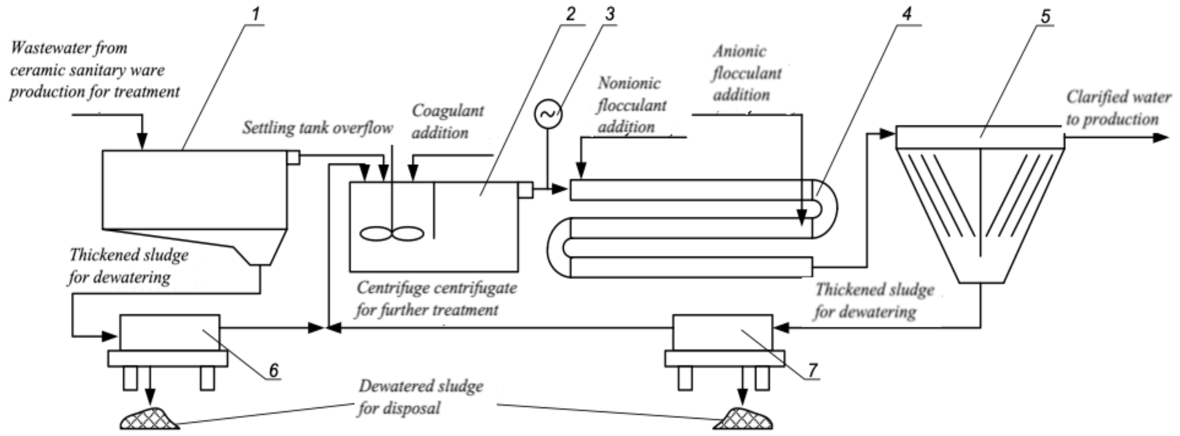

Fig. 5. Proposed wastewater treatment scheme for sanitary ware production: 1 – settling tank; 2 – tank with stirrer and floc formation chamber; 3 – pH sensor; 4 – tubular flocculator; 5 – lamella (inclined plate) settler; 6, 7 – centrifuges

Wastewater from different sections of sanitary ware production is directed to a settling tank, where large sand-sized particles (>80 μm) settle out and are sent for dewatering in centrifuge 6. The overflow from the settling tank, containing fine-dispersed particles, flows into tank 2, which serves as both a storage and floc formation chamber, where it is mixed with a coagulant. The coagulant destabilizes the dispersed suspension and is then directed to the flocculator 4, where nonionic flocculant is first added, followed by anionic flocculant. Prior to the flocculator, the pH of the medium is monitored using a pH sensor 3.

The formed flocs settle in the lamella settler 5, and the clarified water is returned to the production process for technological use. Sludge from settler 5 is dewatered in centrifuge 7. Centrifugates from centrifuges 6 and 7 may contain residual particles and are therefore returned to tank 2 for further treatment. The sludge from the centrifuges is returned to production for disposal.

Thus, the proposed scheme enables the removal of suspended solids from wastewater with minimal reagent consumption, allowing both the solid phase and treated water to be reused in production. The doses, types, and order of addition of coagulants and flocculants should be determined and selected based on laboratory tests, the methodology and examples of which are described in this article.

4. Conclusions

The study analyzed the effectiveness of various physical and physicochemical methods for treating sludge waters from ceramic sanitary ware production. The obtained results allowed for the identification of optimal technological solutions for each stage of water treatment, aimed at improving efficiency and minimizing environmental impact.

To achieve maximum removal of suspended solids, it is recommended to use aluminum sulfate as a coagulant at a concentration that does not reduce the pH of the medium below 6.0–6.5, in combination with flocculants. As flocculants, a 1:1 ratio of nonionic and anionic flocculants is recommended at a dosage of 250 g/t.

These results and the proposed methodology can be applied to the treatment of wastewater with similar composition; however, for each specific production type, the selection of reagent types and concentrations should be determined through technological testing following the methodology described in this article.

Based on the summarized results, a technological wastewater treatment scheme has been proposed that enables the removal of both coarse and fine dispersed particles using a minimal amount of reagents.

References

Almecija, M. C., Martinez-Ferez, A., Guadix, A., Paez, M. P., & Guadix, E. M. (2009). Influence of the cleaning temperature on the permeability of ceramic membranes. *Desalination*, *245*(1–3), 708–713. doi: https://doi.org/10.1016/j.desal.2009.02.041

Barredo-Damas, S., Alcaina-Miranda, M. I., Bes-Piá, A., Iborra-Clar, M. I., Iborra-Clar, A., & Mendoza-Roca, J. A. (2010). Ceramic membrane behavior in textile wastewater ultrafiltration. *Desalination*, *250*(2), 623–628. doi: https://doi.org/10.1016/j.desal.2009.09.037

Barros, M., Bello, P., Roca, E., & Casares, J. (2007). Integrated pollution prevention and control for heavy ceramic industry in Galicia (NW Spain). *Journal of Hazardous Materials*, *141*(3), 680–692. doi: https://doi.org/10.1016/j.jhazmat.2006.07.037

Bosiuk, A., Shkop, A., Kulinich, S., Samoilenko, D., Shestopalov, O., & Tykhomyrova, T. (2024). Multi-component wastewater from finely dispersed impurities treatment intensification. *Ecological Questions*, *35*(4), 1–18. doi: https://doi.org/10.12775/eq.2024.055

Budnyk, A. F., Yuskaiev, V. B., & Budnyk, O. A. (2008). *Nemetalevi materialy v s uchasnomu suspilstvi*: Navchalnyy posibnyk. Sumy: SumDU. (in Ukranian)

Chong, M. F., Lee, K. P., Chieng, H. J., & Syazwani Binti Ramli, I. I. (2009). Removal of boron from ceramic industry wastewater by adsorption–flocculation mechanism using palm oil mill boiler (POMB) bottom ash and polymer. *Water Research*, *43*(13), 3326–3334. doi: https://doi.org/10.1016/j.watres.2009.04.044

Ebrahimi, M., Kerker, S., Daume, S., Geile, M., Ehlen, F., Unger, I., Schütz, S., & Czermak, P. (2014). Innovative ceramic hollow fiber membranes for recycling/reuse of oilfield produced water. *Desalination and Water Treatment*, *55*(13), 3554–3567. doi: https://doi.org/10.1080/19443994.2014.947780

Ebrahimi, M., Busse, N., Kerker, S., Schmitz, O., Hilpert, M., & Czermak, P. (2015). Treatment of the Bleaching Effluent from Sulfite Pulp Production by Ceramic Membrane Filtration. *Membranes*, *6*(1), 7. doi: https://doi.org/10.3390/membranes6010007

Elias, S. H., Mohamed, M., Nor-Anuar, A., Muda, K., Hassan, M. A. H. M., Nor Othman, M., & Chelliapan, S. (2014). Ceramic industry wastewater treatment by rhizofiltration system – Application of water hyacinth bioremediation. *IIOAB-India Journal*, *5*(1), 6–14.

Hua, F. L., Tsang, Y. F., Wang, Y. J., Chan, S. Y., Chua, H., & Sin, S. N. (2007). Performance study of ceramic microfiltration membrane for oily wastewater treatment. *Chemical Engineering Journal*, *128*(2–3), 169–175. doi: https://doi.org/10.1016/j.cej.2006.10.017

Khomenko, O. S., Datsenko, B. M., & Fomenko, G. V. (2022). Determination of approaches to the development of ceramic compositions for the manufacture of facial bricks. *Voprosy Khimii i Khimicheskoi Tekhnologii*, *6*, 98–107. doi: https://doi.org/10.32434/0321-4095-2022-145-6-98-107

Martínez-García, C., Eliche-Quesada, D., Pérez-Villarejo, L., Iglesias-Godino, F. J., & Corpas-Iglesias, F. A. (2012). Sludge valorization from wastewater treatment plant to its application on the ceramic industry. *Journal of Environmental Management*, *95*, 343–348. doi: https://doi.org/10.1016/j.jenvman.2011.06.016

Maura, J., Atreya, S., & Arshi, A. (2023). The Treatment of Wastewater, Recycling and Reuse - Past, Present, and in the Future. *International Journal of Science and Research (IJSR)*, *12*(11), 210–222. doi: https://doi.org/10.21275/sr231013064713

Onen, V., & Gocer, M. (2018). The effect of single and combined coagulation/flocculation methods on the sedimentation behavior and conductivity of bentonite suspensions with different swelling potentials. Particulate Science and Technology, *37*(7), 827–834. doi: https://doi.org/10.1080/02726351.2018.1454993

Onyshchuk, O. (2023). To the study of the flocculation and coagulation process in the purification of water for industrial application. *Herald of Khmelnytskyi National University. Technical Sciences*, *317*(1), 151–154. doi: https://doi.org/10.31891/2307-5732-2023-317-1-151-154

Sari Erkan, H. (2019). Ceramic Industry Wastewater Treatment By Chemical Coagulation Process: A Statistical Optimization of Operating Parameters. *Sakarya University Journal of Science*, *23*(2), 233–243. doi: https://doi.org/10.16984/saufenbilder.385584

Shestopalov, O., Briankin, O., Tseitlin, M., Raiko, V., & Hetta, O. (2019). Studying patterns in the flocculation of sludges from wet gas treatment in metallurgical production. *Eastern-European Journal of Enterprise Technologies*, *5*(10(101)), 6–13. doi: https://doi.org/10.15587/1729-4061.2019.181300

Shkop, A., Tseitlin, M., Shestopalov, O., & Raiko, V. (2017 a). Study of the strength of flocculated structures of polydispersed coal suspensions. *Eastern-European Journal of Enterprise Technologies*, *1*(10(85)), 20–26. doi: https://doi.org/10.15587/1729-4061.2017.91031

Shkop, A., Tseitlin, M., Shestopalov, O., & Raiko, V. (2017 b). A study of the flocculs strength of polydisperse coal suspensions to mechanical influences. *Eureka: Physics and Engineering*, *1*, 13–20. doi: https://doi.org/10.21303/2461-4262.2017.00268

Shurygin, M., Guenther, C., Fuchs, S., & Prehn, V. (2021). Effective treatment of the wastewater from ceramic industry using ceramic membranes. *Water Science and Technology*, *83*(5), 1055–1071. doi: https://doi.org/10.2166/wst.2021.039

Yaroshenko, K. K., & Shabanov, M. V. (2010). Analiz stokiv keramičnoho kombinatu ta rozrobka tekhnolohiy yikh ochyshchennya: *XIII Mizhnarodna naukovo-praktychna konferentsiya, Ekolohiya. Lyudyna. Suspilstvo*, 2010, Kyiv: NTUU “KPI”.

Yaroshenko, K. K., & Shabanov, M. V. (2011). Efektyvnist koahulyatsiynoho ochyshchennya vodnykh stokiv keramichnoho vyrobnytstva: *Zbirnyk naukovykh prats Instytutu heokhimiyi navkolyshnoho seredovyshcha*, 19, 96–100.