

UDC 628.316:663.8

REAGENT PRETREATMENT OF WASTEWATER FROM SOFT DRINK PRODUCTION TO IMPROVE ANAEROBIC BIOREACTOR PERFORMANCE**Nasirova Nilufarkhon Kabildjanovna**Candidate of Chemical Sciences, Associate Professor,
Tashkent State Agrarian University, Republic of Uzbekistan, Tashkent
E-mail: mukhamedovanilufarkhon@gmail.com**Mukhamedov Kabildjan Gafurovich**Doctor of Technical Sciences, Professor,
Islam Karimov Tashkent State Technical University,
Republic of Uzbekistan, Tashkent**Abstract.**

The article presents a scientific justification for reagent pretreatment of wastewater generated during the production of soft drinks and fruit beverages containing pulp. Such wastewater is characterized by a high content of dissolved organic compounds, finely dispersed suspended solids, pectin substances, sugars, organic acids and washing residues. The introduction of pulp-containing juice lines sharply increases chemical oxygen demand and the concentration of suspended solids, which may destabilize anaerobic biological treatment. The study substantiates the use of coagulation and flocculation as a preliminary physicochemical stage before anaerobic treatment. Aluminum oxychloride-based coagulants and anionic polymer flocculants promote destabilization of colloidal particles, formation of large flocs, rapid phase separation and reduction of the load on the anaerobic bioreactor. The proposed approach improves the operational stability of wastewater treatment facilities and reduces risks associated with floating layers, biomass washout and excessive sludge formation.

Keywords:

soft drink production, wastewater, coagulation, flocculation, suspended solids, turbidity, anaerobic reactor, reagent pretreatment, sludge dewatering.

INTRODUCTION

The beverage industry is one of the dynamically developing sectors of the food industry. The expansion of product lines, including carbonated drinks, fruit juices, syrups, nectars, pulp-containing beverages and functional drinks, directly affects both the quantity and quality of industrial wastewater. Compared with wastewater from the production of conventional carbonated drinks, wastewater from fruit juice and pulp-containing beverage production has a more complex composition and a higher content of finely dispersed organic particles.

In soft drink plants, wastewater is formed mainly during equipment washing, bottle and container rinsing, syrup preparation, raw material losses, product changeover and cleaning-in-place operations. In the case of pulp-containing beverages, fruit fibers, pectin substances, natural pigments, carbohydrates, organic acids and colloidal particles enter the wastewater. These components increase the chemical oxygen demand (COD), turbidity and suspended solids concentration, and they may remain dispersed in water for a long time without spontaneous sedimentation.

Direct feeding of such wastewater to biological treatment units is not always technologically justified. Finely dispersed particles may accumulate on the surface of anaerobic

biomass granules, reduce mass transfer, form floating layers and create stagnant zones inside the reactor. Therefore, preliminary physicochemical treatment is required to reduce the mechanical and colloidal load before biological degradation. Coagulation and flocculation are considered effective methods for destabilizing colloids, aggregating suspended particles and removing them by settling or flotation.

SCIENTIFIC PROBLEM AND RESEARCH OBJECTIVE

The scientific problem addressed in this article is the destabilization of anaerobic treatment caused by a high concentration of suspended and colloidal organic particles in wastewater from soft drink production. The problem becomes especially relevant when a plant introduces a pulp-containing juice line, because even a small amount of pulp residues can sharply increase turbidity and COD.

The objective of this article is to substantiate the use of coagulation-flocculation pretreatment for soft drink wastewater in order to improve the stability of anaerobic bioreactor operation. To achieve this objective, the following tasks were considered: analysis of wastewater composition; explanation of the physicochemical mechanisms of coagulation and flocculation; justification of pH control; evaluation of coagulant and flocculant selection; and assessment of the expected influence on anaerobic treatment and sludge management.

COMPOSITION OF WASTEWATER FROM SOFT DRINK PRODUCTION

Wastewater from soft drink production is a multicomponent dispersed system. It contains dissolved organic substances, colloidal particles, coarse and fine suspended solids, residues of sugars and syrups, fruit pulp, pectin compounds and cleaning agents. The ratio between these components changes depending on the product type, technological regime, washing frequency and losses of raw materials during production.

Experimental data from the source study show that after the introduction of a juice line containing pulp, the wastewater parameters changed sharply. COD increased from 428 to 13,850 mg O₂/dm³, while suspended solids increased from 105 to 7,400 mg/dm³. This confirms that pulp-containing production substantially increases the load on wastewater treatment facilities and requires a pretreatment stage before anaerobic digestion.

Table 1

Change in wastewater composition after the launch of a pulp-containing juice line

Parameter	Before pulp-containing juice line	After pulp-containing juice line
COD, mg O ₂ /dm ³	428	13,850
Suspended solids, mg/dm ³	105	7,400

PHYSICOCHEMICAL BASIS OF COAGULATION

Coagulation is a physicochemical process aimed at destabilizing colloidal and finely dispersed particles in water. Such particles usually possess a surface charge and are surrounded by an electrical double layer. Due to electrostatic repulsion, they remain stable in the dispersed state and do not settle rapidly. When a coagulant is introduced, the electrical double layer is compressed, the zeta potential decreases and particles begin to aggregate.

Coagulants based on aluminum and iron salts hydrolyze in water and form aluminum or iron hydroxides. These hydroxides have a high adsorption capacity and can capture colloidal organic substances, fine suspended particles and partly dissolved impurities. However, the formation and stability of hydroxide flocs strongly depend on pH. In an acidic medium, hydroxide precipitation is incomplete; in a neutral or slightly alkaline medium, floc formation is usually more intensive and phase separation improves.

Aluminum oxychloride-based coagulants are of particular interest because they contain pre-hydrolyzed polymeric aluminum species. These species may form effective coagulation nuclei at relatively low doses and cause less acidification than ferric chloride. In contrast, ferric chloride

can decrease pH more strongly, which requires additional neutralization before efficient hydroxide floc formation.

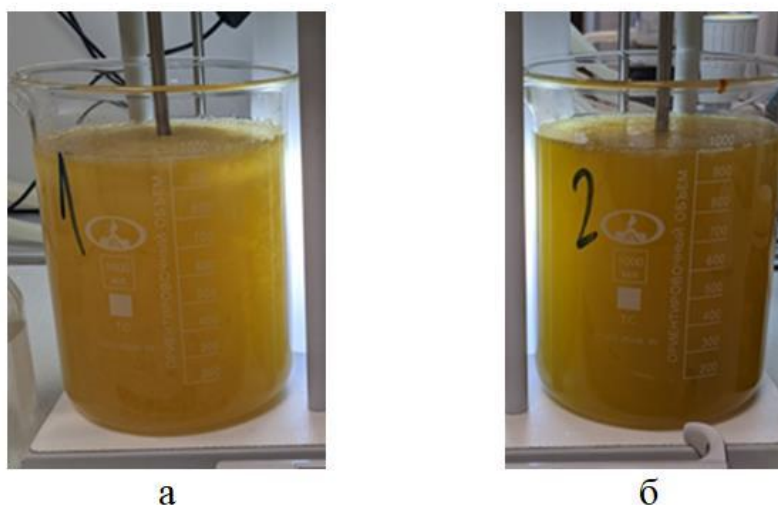


Figure 1. Model wastewater after coagulant addition: a - aluminum oxychloride-based coagulant; b - ferric chloride-based coagulant. Adapted from the experimental source.

The experimental photographs show that after adding coagulants, finely dispersed and poorly separable flocs are formed. This indicates that coagulation alone is not sufficient for stable clarification of pulp-containing wastewater. pH adjustment and subsequent flocculation are required to enlarge the formed aggregates and improve their settling behavior.

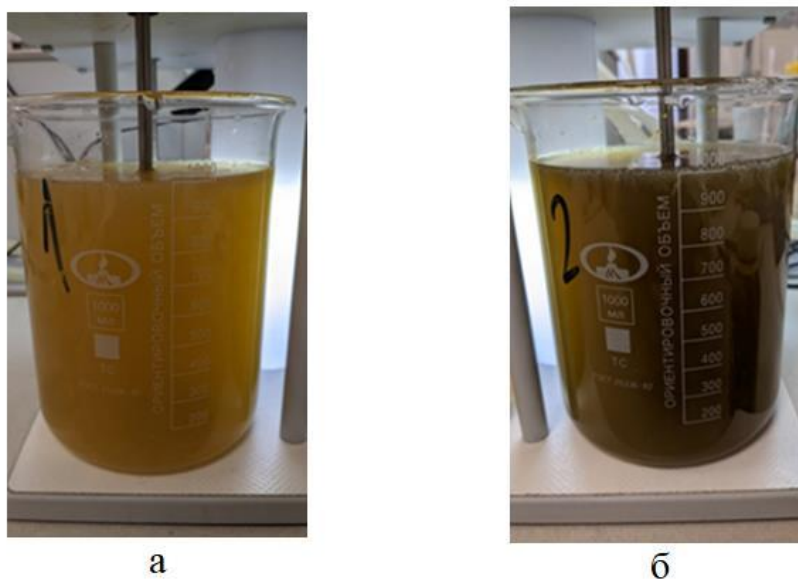


Figure 2. Model wastewater after coagulation and pH neutralization to approximately 6.7: a - aluminum-based coagulant; b - iron-based coagulant. Adapted from the experimental source.

SCIENTIFIC BASIS OF FLOCCULATION

Flocculation is the next stage after coagulation. It is based on the use of high-molecular-weight polymeric reagents capable of forming bridges between destabilized particles. The polymer chains adsorb on several particles at the same time and combine them into larger, stronger and faster-settling flocs. This mechanism is especially important for wastewater containing fruit pulp and pectin colloids, because the particles may remain stable even after partial coagulation.

The efficiency of flocculation depends on the ionic type of the polymer, molecular weight, charge density, dose, mixing regime and the properties of the particles after coagulation. Anionic,

cationic and nonionic flocculants may behave differently in the same wastewater. For the studied model wastewater, the anionic flocculant promoted the formation of larger and more stable flocs than the cationic flocculant.

The relevance of polymer flocculants for dispersions is also supported by the study of Nasirova, Mukhamedov and co-authors, where modified polyacrylamide-based polyelectrolytes were evaluated as effective agents for particle aggregation and clarification [7].



Figure 3. Model wastewater after coagulation, neutralization and flocculation: enlargement of flocs and separation of the sediment phase. Adapted from the experimental source.

OPTIMIZATION OF REAGENT DOSES

The selection of reagent dose is a key technological factor in coagulation-flocculation treatment. A low coagulant dose may be insufficient to destabilize colloidal particles, while an excessive dose may cause restabilization, non-uniform floc structure or destruction of aggregates. Therefore, optimal doses should be determined by laboratory jar tests for each specific wastewater.

In the experimental study, aluminum oxychloride-based coagulant doses of 0.2, 0.4, 0.5, 0.9 and 1.0 mg/dm³ were examined. The best clarification result was obtained at 0.4 mg/dm³ in the presence of an anionic flocculant. Increasing the coagulant dose did not lead to further improvement; on the contrary, the floc structure became less uniform and the tendency toward aggregate destruction increased.

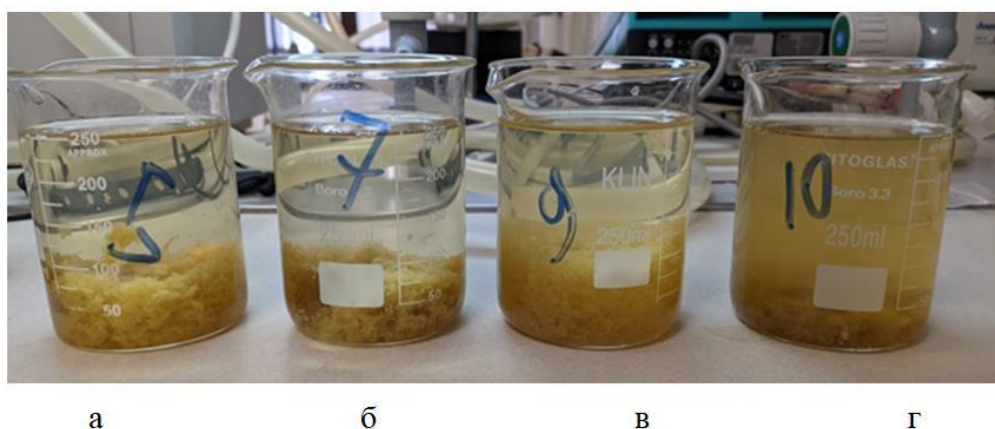


Figure 4. Floc formation at different coagulant doses: 0.2, 0.4, 0.5 and 0.9 mg/dm³. Adapted from the experimental source.

Table 2

Effect of coagulant dose on turbidity after flocculation

Indicator	0.2	0.4	0.5	0.9	1.0
pH after coagulant addition	3.70	3.63	3.71	3.80	3.81
Anionic flocculant dose, mg/dm ³	4.6	4.6	4.6	4.6	4.6
Turbidity, NTU	94.9	41.1	45.6	62.0	79.1

The comparison of anionic and cationic flocculants also confirmed the importance of polymer charge. The anionic flocculant formed larger and more stable flocs, whereas the cationic flocculant left considerably higher turbidity. This result can be explained by the interaction between the charge of the polymer chain, the surface properties of the destabilized particles and the hydroxide aggregates formed during coagulation.

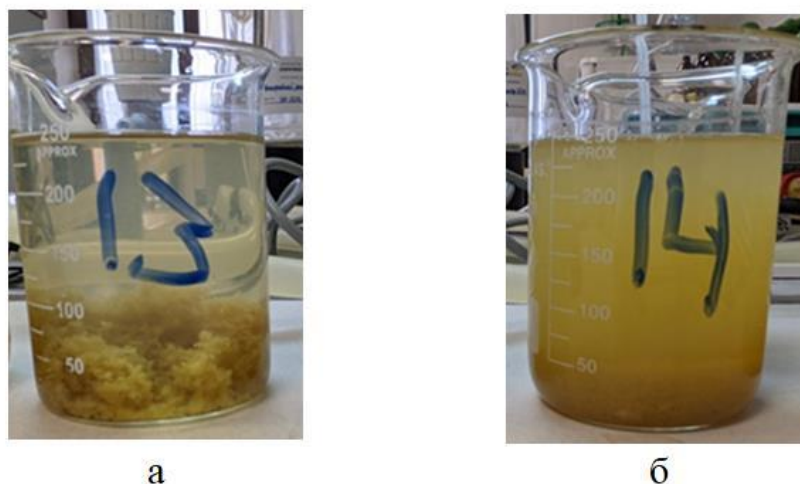


Figure 5. Comparison of anionic and cationic flocculants: the anionic polymer forms larger and more stable flocs. Adapted from the experimental source.

TREATMENT EFFICIENCY AND EFFECT ON ANAEROBIC BIOREACTOR OPERATION

The most important technological result of reagent pretreatment is the removal of suspended solids. In the model wastewater, the concentration of suspended solids was 3,951.81 mg/dm³; after reagent treatment it decreased to 35.40 mg/dm³. The removal efficiency is therefore approximately 99%. Such a reduction significantly decreases the mechanical load on the anaerobic reactor and reduces the probability of biomass washout and floating crust formation.

Table 3

Decrease in suspended solids concentration after reagent treatment

Sample type	Suspended solids, mg/dm ³
Initial industrial wastewater	51.78
Model wastewater	3,951.81
Water after reagent treatment	35.40

Anaerobic reactors are effective for treating wastewater with high organic load, but their stable operation depends on the hydraulic and particulate composition of the influent. Excessive suspended and colloidal matter can cover the surface of anaerobic granules, slow down substrate diffusion and reduce the activity of methanogenic microorganisms. It can also create stagnant zones and floating layers, which decrease the useful volume of the reactor.

Preliminary coagulation-flocculation treatment reduces these risks by removing the major part of the suspended organic particles before the wastewater enters the anaerobic stage. As a result, the biological process becomes more stable, mass transfer conditions improve, and the reactor is less exposed to shock loads caused by product changeover or accidental pulp discharge.

SLUDGE FORMATION AND DEWATERING

The reagent treatment of wastewater inevitably produces sludge containing organic matter, fruit fibers, hydroxide precipitates and adsorbed colloids. Therefore, the dewatering properties of the sludge are important for the overall efficiency of the treatment system. A correctly selected flocculant not only clarifies water but also forms a denser sediment that can be more easily processed by filters, centrifuges or presses.

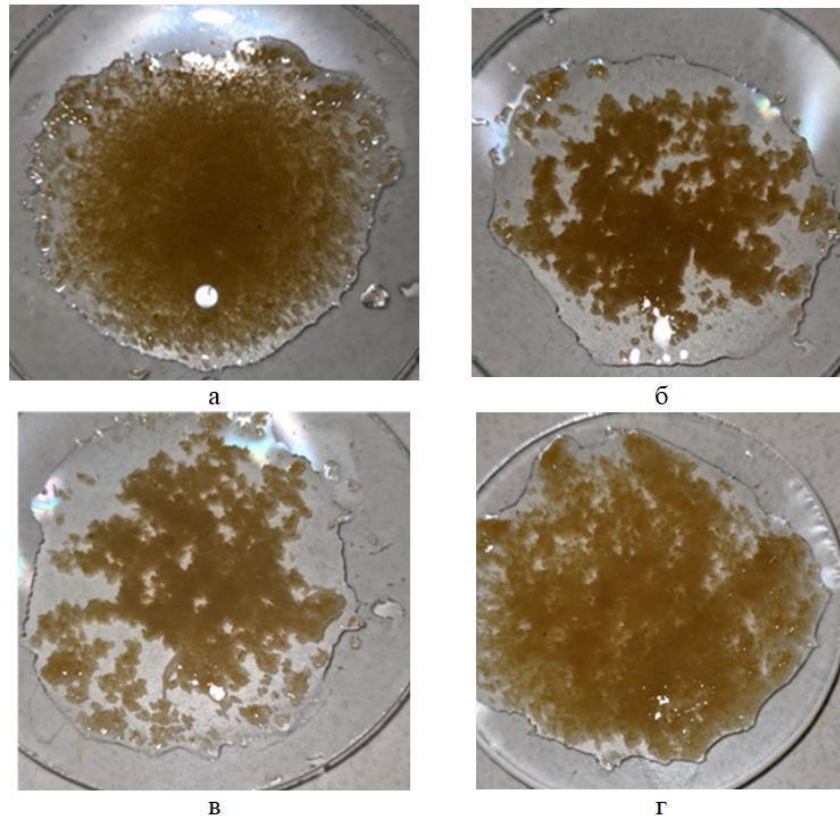


Figure 6. Sludge structure after the addition of different flocculants: differences in floc size and sediment density. Adapted from the experimental source.

The tested flocculants showed different effects on sludge structure. Some reagents promoted the formation of large flocs and a compact sediment, while others did not significantly change the sludge properties or increased its viscosity. For industrial application, the selected flocculant should provide both good clarification of the supernatant water and improved dewaterability of the sludge.

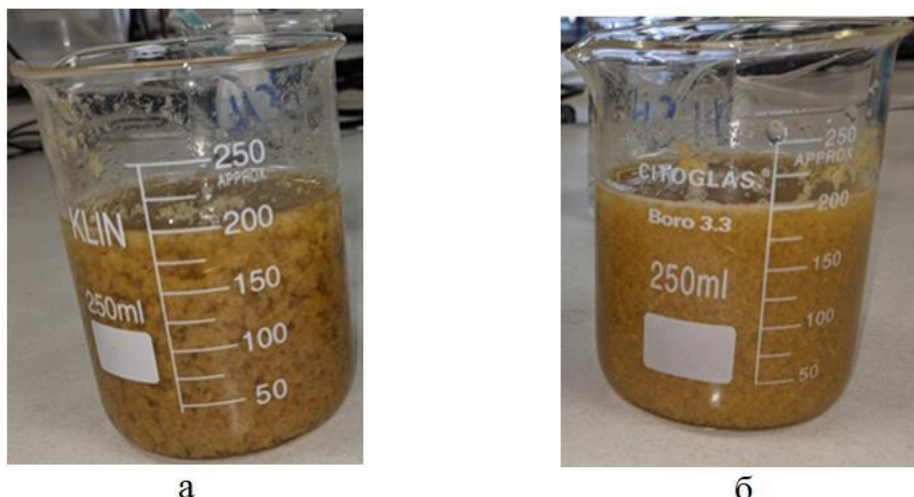


Figure 7. Effect of flocculants on sludge aggregation: comparison of Envifloc 4134X and Envifloc 4219X. Adapted from the experimental source.

RECOMMENDED TECHNOLOGICAL SCHEME

For industrial wastewater from soft drink and pulp-containing juice production, the following technological sequence can be recommended: equalization of wastewater composition; mechanical screening of coarse impurities; pH measurement and neutralization if necessary; addition of coagulant with intensive short-term mixing; addition of flocculant with gentle mixing; separation of formed flocs by settling or flotation; transfer of clarified wastewater to the anaerobic reactor; thickening and dewatering of the generated sludge.

This sequence is flexible and can be adapted to the composition of wastewater at a specific plant. If the concentration of suspended solids varies strongly during the day, an equalization tank is especially important. It reduces fluctuations in pH, COD and turbidity and allows stable reagent dosing. The final selection of reagents should be based on jar-test experiments, taking into account not only turbidity and suspended solids removal but also reagent cost, pH correction demand, sludge volume and dewatering properties.

CONCLUSION

Wastewater from soft drink production, especially from pulp-containing beverage lines, is characterized by high concentrations of suspended solids, colloidal organic particles and dissolved organic matter. Such wastewater may negatively affect anaerobic biological treatment by promoting biomass washout, floating layer formation, mass transfer limitations and unstable methane fermentation. Therefore, reagent pretreatment based on coagulation and flocculation is scientifically and technologically justified.

Aluminum oxychloride-based coagulants and anionic polymer flocculants provide effective destabilization and aggregation of finely dispersed impurities. Under optimized pH and dosing conditions, these reagents form large, stable flocs that are easily removed by settling or flotation. The decrease in suspended solids from 3,951.81 to 35.40 mg/dm³ confirms the high potential of this approach for reducing the load on the anaerobic bioreactor.

Thus, the integration of coagulation-flocculation pretreatment into wastewater treatment schemes for soft drink plants improves operational reliability, enhances the stability of anaerobic digestion, facilitates sludge dewatering and contributes to more environmentally safe wastewater management in the beverage industry.

REFERENCES

1. Musikhin E.K., Melnik T.A. Substantiation of optimal conditions for wastewater treatment in the production of non-alcoholic beverages. Scientific article, Ural State Forest Engineering University, 2023.

2. Getmantsev S.V., Nechaev I.A., Gandurina L.V. Treatment of industrial wastewater with coagulants and flocculants. Moscow: ASV Publishing House, 2008.
3. Weiser T., Karyakin M.A. From aerobic wastewater treatment to energy recovery. Beer and Beverages, 2006, No. 4, pp. 18-20.
4. Yurchenko V.V., Sviridov A.V., Sviridov V.V., Kargina A.V. Water softening using highly dispersed modified aluminosilicates. Forests of Russia and Forestry, 2013, No. 1, pp. 149-151.
5. Metcalf & Eddy. Wastewater Engineering: Treatment and Resource Recovery. 5th ed. McGraw-Hill Education, 2014.
6. Tchobanoglous G., Burton F.L., Stensel H.D. Wastewater Engineering: Treatment and Reuse. McGraw-Hill, 2003.
7. Nasirova N.K., Mukhamedov K.G., Mutalov Sh.A., Mukhamedov J.K. Study of flocculation properties of modified polyacrylamide. AIP Conference Proceedings, 2023, Vol. 2789, No. 1, 020013. <https://doi.org/10.1063/5.0145723>.