BG Pulse Journal USA
ISSN:1947-2536 http://www.bgpulseusa.com/index.php/bg
BG PULSE JOURNAL

UDC 663.4:628.3:66.067.1

INTEGRATED PRETREATMENT STRATEGIES FOR BREWERY WASTEWATER: COAGULATION-FLOCCULATION, ELECTROCOAGULATION AND RESOURCE-RECOVERY PERSPECTIVES

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
Mukhamedov Jamoliddin Kabildjanovich
Candidate of Chemical Science, PhD Tashkent Institute of Chemical Technology

Tashkent, Republic of Uzbekistan

Doi: https://doi.org/10.5281/zenodo.23193923

Abstract. Brewery wastewater is characterized by strong fluctuations in organic load, suspended solids, nutrients, pH and temperature, which complicates the direct application of a single treatment method. This review evaluates integrated pretreatment strategies with emphasis on coagulation-flocculation, electrocoagulation and hybrid treatment concepts. Recent literature demonstrates that conventional coagulation-flocculation is particularly effective for suspended-solids and phosphorus removal, while its effect on dissolved organic matter is often more limited. In contrast, full-scale treatment systems that combine physicochemical and biological stages can achieve very high overall COD and BOD removal. Emerging hybrid approaches, including electrocoagulation coupled with bio-coagulants or adsorbents, can further improve nutrient, color and particulate removal, whereas circular-economy concepts increasingly consider brewery wastewater as a carbon source or a feedstock for biomass recovery. On this basis, a process-integration framework is proposed in which pretreatment selection is linked to the dominant pollutant fraction, downstream treatment requirements, sludge generation and resource-recovery potential. The analysis shows that brewery wastewater pretreatment should be designed as a functional barrier and load-equalization step rather than as an isolated end-of-pipe treatment. This approach provides a more rational basis for selecting treatment trains under variable brewery operating conditions.

Keywords: brewery wastewater, pretreatment, coagulation-flocculation, electrocoagulation, COD, BOD, suspended solids, nutrients, resource recovery.

Introduction

Breweries are water-intensive food-processing facilities in which water is used for mashing, wort preparation, fermentation, filtration, cleaning-in-place operations, equipment washing and packaging. The resulting wastewater is therefore not a uniform stream but a combination of process losses, yeast residues, soluble carbohydrates, proteins, cleaning chemicals and suspended materials. Its composition may vary substantially during the working day and between production campaigns.

The principal challenge is the simultaneous presence of readily biodegradable organic matter, colloidal particles, suspended solids, phosphorus- and nitrogen-containing compounds, detergents and intermittent pH shocks. These characteristics make brewery wastewater suitable for biological treatment, but they also create risks of hydraulic and organic overloading, foaming, poor settling and unstable reactor performance when highly variable wastewater is introduced directly into a biological unit.

For this reason, pretreatment is increasingly considered not merely as a preliminary clarification step but as a process-control tool. Mechanical separation and flow equalization reduce short-term load fluctuations, pH adjustment protects subsequent unit operations, and coagulation-flocculation or electrocoagulation can remove particles and selected dissolved or colloidal constituents before the wastewater reaches the main treatment stage.

Recent studies illustrate the importance of this integrated view. Industrial-scale coagulation-flocculation has shown strong removal of suspended solids and phosphorus but only moderate removal of COD and BOD, whereas complete treatment plants combining several unit processes can achieve overall organic-matter removal above 95%. These differences indicate that the efficiency of an individual pretreatment stage should be evaluated according to its functional role within the whole treatment train rather than by final-discharge criteria alone.

The aim of this article is to compare current brewery-wastewater pretreatment strategies and to formulate a practical process-integration framework for selecting treatment steps according to pollutant characteristics, downstream requirements and resource-recovery objectives. Unlike a single-process evaluation, the present analysis focuses on the relationship between pretreatment performance and the function of subsequent treatment stages.

Materials and Methods

The study was designed as a structured analytical review of brewery-wastewater treatment literature. Publications describing physicochemical characterization, coagulation-flocculation, electrocoagulation, biological treatment, hybrid processes and resource-recovery approaches were compared. Particular attention was given to studies published between 2024 and 2025, while established earlier sources were used to provide technological background.

The comparison was based on five groups of criteria: (1) target pollutant fraction; (2) reported removal of COD, BOD, total suspended solids (TSS), nitrogen or phosphorus when numerical data were available; (3) operational sensitivity to pH and influent variability; (4) compatibility with downstream biological or polishing treatment; and (5) potential disadvantages such as chemical consumption, sludge production or process complexity.

No new experimental measurements are reported in this article. Numerical values cited in the comparative analysis are taken from the referenced studies and are used to identify technological patterns rather than to claim new treatment efficiencies.

Results and Discussion

1. Variability of brewery wastewater as a design factor

Brewery wastewater may contain high concentrations of biodegradable organic compounds originating from wort, beer losses, sugars, soluble starch, alcohols and yeast-associated material. At the same time, cleaning-in-place operations introduce alkaline or acidic streams and can cause rapid changes in pH and conductivity. The practical consequence is that equalization and pH control should be considered core pretreatment operations even when advanced treatment technologies are available.

A 2025 industrial study of real brewery wastewater reported influent pH variations from 5.6 to 10.2. Such variability can strongly affect coagulation chemistry and biological-process stability.

The same study emphasized that stabilization of pH within a narrower operating interval improves the conditions for chemical precipitation and floc formation. Therefore, treatment performance depends not only on reagent type but also on upstream hydraulic and chemical homogenization.

2. Coagulation-flocculation as a solids and nutrient control barrier

Coagulation-flocculation is well suited to pollutants present as suspended, colloidal or precipitable fractions. In a recent industrial-scale investigation using polyaluminium chloride and an anionic flocculant, TSS removal reached 86.8%, while total phosphorus and orthophosphate removal reached 95.5% and 99.6%, respectively. In the same process, BOD5 and COD removals were markedly lower, at 34.3% and 26.5%. This contrast is technologically important because it shows that coagulation-flocculation should not be expected to remove the entire dissolved organic load. Previous work by Nasirova and co-authors has also demonstrated the applicability of reagent-based treatment and modified polyacrylamide flocculants for intensifying clarification of industrial wastewater, supporting the broader technological basis for polymer-assisted coagulation-flocculation [4,5].

The principal advantage of this stage is therefore load conditioning. By removing settleable and colloidal material, coagulation-flocculation can reduce solids carryover, improve clarification and limit the amount of particulate matter entering biological reactors or membrane units. Its performance is particularly relevant when phosphorus removal is required or when wastewater contains a high proportion of dispersed organic solids. In a previous brewery-wastewater study by Nasirova and Mukhamedov, preliminary physicochemical treatment achieved substantial reductions in COD, BOD, and suspended solids, further confirming the role of coagulation-flocculation as a pretreatment step rather than a stand-alone final treatment [3].

The main limitations are reagent demand and chemical-sludge generation. For this reason, optimization should include not only percentage removal but also chemical dosage, sludge yield and the downstream management of separated solids.

3. Electrocoagulation and hybrid physicochemical processes

Electrocoagulation offers an alternative means of generating coagulant species in situ. It can be combined with natural coagulants, adsorbents or subsequent biological stages. A 2024 study applying an indigenous bio-coagulant-assisted electrocoagulation process to brewery wastewater used response-surface methodology to optimize the operating conditions, demonstrating the growing role of multi-factor optimization in physicochemical treatment design.

A 2025 study combining electrocoagulation with activated carbon produced from pumpkin seed reported removals of 97.73% for nitrate, 96.55% for phosphate and 98.61% for color. These values show the potential of hybrid physicochemical processes for targeted contaminant removal, particularly where nutrients or color become limiting parameters. However, such systems also introduce electrical-energy demand, electrode management and additional operational variables.

Accordingly, electrocoagulation is most attractive when conventional coagulation is insufficient for the target contaminants, when chemical storage is undesirable, or when a hybrid polishing function justifies the added complexity.

4. Why high overall COD removal requires a treatment train

The difference between pretreatment efficiency and total-plant efficiency is evident in full-scale performance studies. A 2024 evaluation of a brewery wastewater treatment plant in Addis Ababa reported approximately 97.2% removal of both COD and BOD5 and 95.7% removal of TSS. These high values reflect the combined action of multiple treatment stages rather than the performance of a single physicochemical step.

This observation supports a staged treatment philosophy. A pretreatment stage can remove suspended solids, stabilize the influent and reduce shock loads; biological treatment can then remove the major biodegradable dissolved fraction; polishing stages can address residual nutrients, suspended matter or dissolved salts. Judging a pretreatment technology solely by final-discharge limits can therefore lead to incorrect conclusions about its usefulness.

5. Resource recovery and circular-economy options

Recent research increasingly evaluates brewery wastewater as a secondary resource rather than only as a waste stream. One 2025 full-scale assessment considered brewery wastewater as an external carbon source for municipal denitrification and reported both economic and greenhouse-gas benefits under the studied conditions. Other recent work has explored brewery wastewater as a cultivation medium for photosynthetic biomass, linking treatment with recovery of value-added products.

These approaches change the purpose of pretreatment. If the wastewater is intended for carbon-source recovery, excessive removal of readily biodegradable COD may be undesirable. If it is intended for membrane treatment or biomass cultivation, removal of suspended solids and toxic cleaning residues may become more important. Thus, the optimal pretreatment train depends on the intended downstream use of the wastewater.

Table 1. Comparative role of selected brewery-wastewater treatment strategies

Treatment approach	Main target	Reported performance example	Main advantage	Main limitation
Coagulation-flocculation	TSS, colloids, phosphorus	TSS 86.8%; TP 95.5%; orthophosphate 99.6% in a 2025 industrial study	Rapid clarification and strong particulate/nutrient removal	Chemical consumption and sludge generation; limited dissolved-COD removal
Full treatment train	COD, BOD, TSS and broader effluent quality	COD 97.2%; BOD5 97.2%; TSS 95.7% in a 2024 full-scale plant evaluation	High overall treatment efficiency	Higher infrastructure and process-control requirements
Bio-coagulant-assisted electrocoagulation	Mixed suspended and dissolved contaminants	Optimized by response-surface methodology in a 2024 brewery-wastewater study	Reduced dependence on conventional chemical coagulants; flexible optimization	Electricity demand, electrode management and process complexity
Electrocoagulation + activated carbon	Nutrients and color	Nitrate 97.73%; phosphate 96.55%; color 98.61% in a 2025 study	Strong targeted removal and adsorption synergy	Added adsorbent handling and energy demand

Resource-recovery integration	Carbon utilization and circularity	Brewery wastewater evaluated as an external carbon source in a 2025 full-scale assessment	Potential economic and environmental benefits	Requires strict quality control and compatibility with receiving process

Table 1 demonstrates that the highest percentage removal is not necessarily associated with the most appropriate pretreatment choice. A technology should be selected according to the pollutant fraction that must be controlled before the next process step. For example, a coagulation-flocculation stage that removes most TSS but only a limited fraction of COD can still be highly effective when its purpose is to protect a downstream biological reactor from solids overload.

6. Proposed process-selection framework

A practical treatment decision can be organized around three questions. First, what fraction of the pollution is dominant: suspended/colloidal, biodegradable dissolved, nutrient-related, or mineral/dissolved? Second, what is the purpose of the next treatment stage? Third, is the objective discharge compliance, water reuse, energy recovery or material recovery?

When suspended solids and colloids dominate, screening, equalization and coagulation-flocculation are logical first choices. When dissolved biodegradable COD dominates, biological treatment should remain the principal removal stage, while pretreatment should focus on pH, hydraulic stabilization and removal of inhibitory or particulate components. When phosphorus or color is limiting, physicochemical treatment may be intensified. When reuse is the final objective, membrane, adsorption or advanced polishing steps may be required after the main organic-load removal stage.

The proposed framework therefore shifts the design criterion from 'maximum removal in one step' to 'maximum functional compatibility between consecutive steps'. This reduces unnecessary reagent use and helps prevent the common error of using a strong pretreatment process to remove compounds that would be more efficiently treated biologically or recovered as a resource.

Table 2. Decision matrix for selecting brewery-wastewater pretreatment

Dominant problem	**Preferred pretreatment function**	**Suitable options**	**Downstream objective**
Large solids / yeast / colloids	Remove particulate load	Screening + coagulation-flocculation + sedimentation	Stable biological treatment or filtration
Strong pH and flow fluctuations	Equalize hydraulic and chemical load	Equalization + pH control	Protect all downstream stages
High biodegradable dissolved COD	Preserve biodegradability while preventing shocks	Equalization with limited physicochemical removal	Biological COD/BOD removal
High phosphorus / nutrient load	Target nutrient removal	Coagulation-flocculation or electrocoagulation	Discharge compliance or polishing

Reuse or high-quality effluent	Remove residual dissolved and fine contaminants	Filtration, adsorption, membranes or ion exchange	Water reuse
Resource-recovery objective	Retain useful carbon or nutrients selectively	Selective pretreatment	Carbon source, biomass or other recovery route

Conclusion

1. Brewery wastewater should be treated as a variable multi-component stream in which pretreatment serves primarily to stabilize and condition the influent for subsequent treatment.

2. Coagulation-flocculation is especially effective for suspended solids and phosphorus, but recent industrial data show that its removal of dissolved organic matter can be comparatively limited. It is therefore most rational as a targeted pretreatment rather than a universal final-treatment method.

3. Very high overall COD, BOD and TSS removal is achievable when physicochemical operations are integrated with biological and polishing stages. This confirms the importance of treatment-train design.

4. Electrocoagulation and hybrid processes can strengthen nutrient, color and particulate removal, but their energy demand, electrode management and operational complexity must be justified by the treatment objective.

5. Emerging circular-economy strategies create a new design requirement: useful organic carbon and nutrients should not always be removed as early as possible. Pretreatment should instead be selective and compatible with the intended recovery pathway.

6. A functional process-selection framework based on pollutant fraction, downstream compatibility and final water-management objective provides a more sustainable basis for brewery-wastewater treatment than selection based solely on the maximum removal percentage of a single stage.

References

1. Simate G. S., Cluett J., Iyuke S. E., Musapatika E. T., Ndlovu S., Walubita L. F., Alvarez A. E. The treatment of brewery wastewater for reuse: State of the art. Desalination. 2011;273(2-3):235-247. doi:10.1016/j.desal.2011.02.035.
2. APHA. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, DC: American Public Health Association; 2017.
3. Nasirova N. K., Mukhamedov K. G. Results of Reducing COD, BOD, Suspended Solids, Turbidity and Dry Residue in Brewery Wastewater. BG Pulse Journal USA. 2026;2(6):909-915.
4. Mukhamedov K. G., Nasirova N. K., Mukhamedov Zh. K., Abdurakhmanov O. Kh. Treatment of wastewater from electroplating industries by reagent method. Universum: Technical Sciences. 2023;7-3(112):51-56. [In Russian].
5. Nasirova N. K., Mukhamedov K. G., Mutalov Sh. A., Mukhamedov J. K. Study of floculation properties of modified polyacrylamide. AIP Conference Proceedings. 2023;2789(1):020013. doi:10.1063/5.0145723.
6. Khumalo S. M., Bakare B. F., Rathilal S., Tetteh E. K. Characterization of South African Brewery Wastewater: Oxidation-Reduction Potential Variation. Water. 2022;14(10):1604. doi:10.3390/w14101604.

7. Carnevale Miino M., Torretta V., Repkova M., Hlavinek P., Telek J. Treatment of a Real Brewery Wastewater with Coagulation and Flocculation: Impact on Organic Substance and Nutrient Concentrations. Applied Sciences. 2025;15(6):2999. doi:10.3390/app15062999.
8. Shumbe T., et al. Performance Evaluation of a Brewery Wastewater Treatment Plant: A Case of Heineken Brewery, Addis Ababa, Ethiopia. Heliyon. 2024;10(23):e40719. doi:10.1016/j.heliyon.2024.e40719.
9. Alayu E., Leta S. Post treatment of anaerobically treated brewery effluent using pilot scale horizontal subsurface flow constructed wetland system. Bioresources and Bioprocessing. 2020;7:77. doi:10.1186/s40643-020-00356-0.
10. Choi H. J. Parametric study of brewery wastewater effluent treatment using Chlorella vulgaris microalgae. Environmental Engineering Research. 2016;21(4):401-408. doi:10.4491/eer.2016.024.
11. Bidira F., Al-Senani G. M., Bekele E. A., Garomsa F. S., Vigneshwaran S., Al-Qahtani S. D., Asaithambi P. Synergistic pollutant removal from brewery wastewater using electrocoagulation-assisted pumpkin seed-activated carbon. Process Safety and Environmental Protection. 2025;200:107429. doi:10.1016/j.psep.2025.107429.
12. Indigenous bio-coagulant assisted electrocoagulation process for the removal of contaminants from brewery wastewater: Performance evaluation and response surface methodology optimization. Heliyon. 2024;10(22):e40394. doi:10.1016/j.heliyon.2024.e40394.
13. Li J., Xiao Z., Gu J., Yang Z., Dong W., Liu Y., Xu Z., Zhu W. Brewery wastewater as an alternative external carbon source for full-scale municipal wastewater treatment plants: A performance, cost, and environmental assessment. Journal of Water Process Engineering. 2025;72:107483. doi:10.1016/j.jwpe.2025.107483.
14. Barati B., Li Y., Gusev S., Rousseau D. P. L., Van Hulle S. W. H. Unlocking the potential of brewery wastewater: Sustainable cultivation of Arthrospira platensis for biomass and phycocyanin production. Journal of Water Process Engineering. 2025;70:107107. doi:10.1016/j.jwpe.2025.107107.
15. Zapata-Martinez O., Villa-Gomez D., Tapia-Tussell R., Dominguez-Maldonado J., Hernandez-Zarate G., Espana-Gamboa E., Valdez-Ojeda R., Alzate-Gaviria L. Craft Brewery Wastewater Treatment in a Scalable Microbial Fuel Cell Stack. Beverages. 2024;10(1):20. doi:10.3390/beverages10010020.