Walisongo Journal of Chemistry Vol. 8 Issue 1 (2025), 38-44
ISSN: 2621-5985 (online); 2549-385X (print)
DOI: https://doi.org/10.21580/wjc.v8i1.23656

THE EFFECTIVENESS OF COAGULANTS AND FLOCCULANTS IN IMPROVING CLARIFIER WATER QUALITY: A CASE STUDY AT PT PERTA ARUN GAS, LHOKSEUMAWE

Maulidia Rahmah[1], Mahrizal[2], Anjar Purba Asmara[1]*

[1]Department of Chemistry, Faculty of Science and Technology, Universitas Islam Negeri Ar-Raniry, Banda Aceh, Indonesia
[2]PT Perta Arun Gas, Lhokseumawe, Aceh, Indonesia

*Corresponding author: anjarpa@ar-raniry.ac.id

Abstract

This study evaluated the effectiveness of coagulants and flocculants in improving clarifier water quality, with a focus on pH, iron (Fe) concentration, and turbidity levels. In accordance with Indonesia's Ministry of Health Regulation No. 32/2017 on environmental health standards for water, clarifier water samples were analyzed before and after treatment. The results show that the treated water complied with the specified standards, with pH levels ranging from 6.5 to 8.5, Fe concentrations below 1 mg/L, and turbidity under 25 NTU. The application of aluminum sulfate as a coagulant and polymer as a flocculant effectively reduced Fe concentrations and turbidity while adjusting the pH to acceptable levels. These findings confirm the critical role of coagulation and flocculation in industrial water treatment processes and demonstrate their potential for enhancing water quality in clarifier systems.

Keywords: *aluminum sulfate, clarifier water quality, coagulation, flocculation, water purification*

Introduction

Achieving clean and clear water is not an instantaneous process; it involves a sequence of treatment steps to ensure its safety for use. One effective method for water clarification involves the coagulation and flocculation processes within a clarifier system (Pillai & Thombre, 2024).

Established in 2015 in Lhokseumawe, Aceh, PT Perta Arun Gas focuses on regasification, liquefied natural gas (LNG) hub operations, and liquefied petroleum gas (LPG) terminal services. The company also demonstrates a commitment to clean water management within its operational area by employing clarifier technology to separate solid particles from water, thereby maintaining a contaminant-free supply. This dedication ensures that water quality meets stringent standards for industrial use. Through the use of clarifiers, PT Perta Arun Gas enhances its performance in the natural gas industry and contributes to environmental sustainability and the conservation of natural resources.

A clarifier tank plays a critical role in separating floc formed during the coagulation and flocculation processes (Ghangrekar, 2022). This equipment improves the clarity of turbid raw water by promoting sedimentation. Coagulants and flocculants are commonly added to enhance this process, facilitating the aggregation of suspended particles. However, the required dosage of coagulants for effective turbidity removal may increase significantly in the presence of elevated concentrations of natural organic matter (Dayarathne et al., 2021).

Colloidal particles, both inorganic and organic, as well as dissolved organic matter, vary significantly in particle size, leading to fundamentally different removal pathways (Aragaw & Bogale, 2023). Consequently, the optimal parameter set for turbidity removal may differ from that required for natural organic matter removal, thereby complicating the coagulation process. To achieve optimal water quality, it is essential to assess the effect of natural organic matter concentration on the removal efficiency of these impurities. This effect is contingent upon several factors, including the concentration of natural organic matter (Guillossou et al., 2020), the turbidity of the incoming water (Arcentales-Ríos et al., 2022), and the pH and alkalinity of the influent (Omar & Vilcáez, 2024). These variables affect the coagulation mechanism by altering the species formed by the added coagulants. To better understand the role of these variables, process modeling can be employed to bridge empirical observations with theoretical insights and vice versa (Wang & Lin, 2021).

Methodology

Materials

The materials utilized in this study included inlet and outlet clarifier water samples, distilled water, and ferrozine iron reagent. The instruments used for testing included cuvettes, a magnetic stirrer, beakers, measuring cylinders, volumetric pipettes, rubber bulbs, a 2100AN turbidimeter, a pH module, a conductivity module, and a UV-Vis spectrophotometer (model DR-5000).

Procedures

pH Determination of Inlet and Outlet Clarifier Water Samples

The pH measurement followed the procedure outlined in the company manual. An 80 mL portion of the raw water sample was transferred into a 100 mL beaker equipped with a magnetic stir bar. The pH electrode was immersed in the sample, and the “Measure pH” function was selected on the MetrOhm 867 pH Module. The measurement was initiated by pressing “Start” and allowed to run to completion.

Determination of Iron (Fe) Concentration in Inlet and Outlet Clarifier Water Samples

Iron concentration was determined using a UV-Visible spectrophotometric method. A blank was prepared by adding 25 mL of distilled water to a cuvette. For the sample analysis, 25 mL of the water sample was transferred into a separate cuvette, followed by the addition of 1 mL of ferrozine iron reagent. The mixture was thoroughly shaken until fully dissolved, allowed to stand for five minutes, and then analyzed using a DR-5000 UV-Vis spectrophotometer.

Determination of Turbidity in Inlet and Outlet Clarifier Water Samples

A clean cell bottle for the HACH turbidimeter was prepared. The water sample was thoroughly stirred and then poured into the cell bottle up to the designated fill line. The cell bottle was gently shaken to ensure homogeneity before analysis. Subsequently, it was inserted into the turbidimeter, and the “Enter” button was pressed to initiate the turbidity measurement.

Results and Discussion

The inlet and outlet water samples from the clarifier exhibited significant differences, primarily due to the treatment processes occurring within the clarifier tank, including the addition of coagulants and flocculants. The use of aluminum sulfate as a coagulant and a polymer as a flocculant resulted in pH levels (see **Figure 1**) that generally complied with the environmental health standards for hygiene and sanitation water, as stipulated in Indonesia's Ministry of Health Regulation No. 32/2017, which specifies a pH range of 6.5–8.5 (Roza, 2023). Following treatment with alum and polymer, the pH values remained within the acceptable range. However, a slight decrease from an initial pH of 7.5 to approximately 6.3 was observed, attributed to excess coagulant dosage.

Alum is widely utilized in water treatment due to its cost-effectiveness, the stability of the formed flocs (Zwane et al., 2024), and its operational simplicity (Zaman et al., 2021). After mixing with water, alum releases positively charged ions interacting with the negatively charged colloidal particles in the water. This electrostatic interaction promotes aggregation, forming larger, denser particles that settle more readily. The reduction in pH associated with the application of aluminum sulfate is illustrated in the following reaction:

$$Al_2(SO_4)_3 + 6H_2O \rightarrow Al(OH)_3 + 6H^+ + 3SO4^{2-}$$

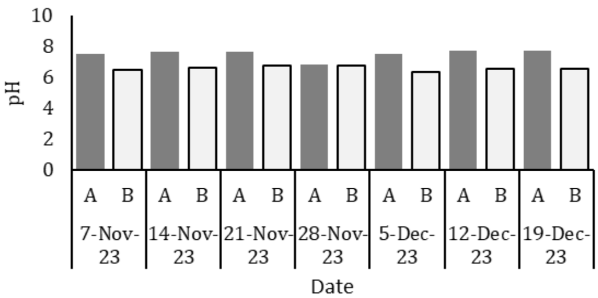

Figure 1. Measured pH of water samples A (inlet) and B (outlet) from the clarifier.

The hydrolysis of aluminum sulfate produces ions critical to the water purification process (Krupinska, 2020). The resulting aluminum hydroxide complex, characterized by a high charge density, effectively adsorbs suspended impurities such as clay, silt, and organic matter, forming larger aggregates that enhance sedimentation.

However, the sulfuric acid generated during hydrolysis contributes to increased acidity, necessitating pH adjustment to maintain optimal coagulation and flocculation conditions. When alkalinity is low, buffering agents such as sodium bicarbonate ($NaHCO_3$) may be added to restore chemical balance (Yu et al., 2025).

This reaction is central to the coagulation-flocculation mechanism, where coagulation destabilizes colloidal particles, and flocculation facilitates their aggregation into larger flocs, both essential for effectively removing contaminants and improving water clarity.

The chemical process known as flocculation facilitates the formation of larger macro-flocs. During this stage, water-soluble polymers, or flocculants, bond the previously coagulated particles into longer, larger chains. As these floc chains grew, the flocs became heavier and visible to the naked eye. The flocculants generate particles with a high mass-to-pull ratio, enhancing efficient sedimentation (Salaghi et al., 2023). In aquatic environments, excess iron is highly undesirable, as it can cause rust stains on industrial equipment. One effective method for removing excess iron involves the addition of aluminum sulfate as a coagulant and polymers as flocculants. Iron in water typically exists in Fe^{2+} and Fe^{3+} forms (Li et al., 2024), which react with oxygen, hydrogen, and sulfur as organic compounds. Coagulants and flocculants bind Fe atoms, precipitating them and thereby reducing or eliminating iron content in the water (Yang et al., 2023).

The iron concentration in Sample A fluctuated over time, ranging from 0.165 mg/L on November 28, 2023, to a peak of 0.496 mg/L on November 14, 2023. There was no consistent trend in the concentration levels, as they varied, possibly indicating fluctuations in influent water quality or adjustments to coagulant dosages. In contrast, the iron concentration in Sample B remained consistently low, ranging from 0.002 mg/L to 0.026 mg/L across the observed dates, significantly lower than that in Sample A. These low levels suggest that the coagulant, in conjunction with the clarifier, effectively reduced the iron concentration, even as the influent iron concentration (Sample A) fluctuated.

The data indicate that the coagulation process effectively reduced iron concentrations, as the output sample (B) consistently showed much lower iron levels than the input sample (A). This consistent reduction demonstrates that the coagulant performed as intended, successfully removing iron from the water, even as input levels varied. The clarifier system appeared effective at maintaining low iron concentrations in the treated water, further supporting the coagulant's role in effectively removing iron over time.

The coagulation process facilitates the precipitation of iron, particularly ferric iron, as iron hydroxide settles along with other flocculated particles. Previous studies have reported that iron removal was most effective when the pH was slightly acidic (Ali et al., 2021; Esfandiar et al., 2022), which aligns with the pH reduction observed in the present study data. In petroleum wastewater, iron often exists in both soluble and particulate forms, and aluminum sulfate has been noted for its effectiveness in targeting both forms through coagulation and precipitation.

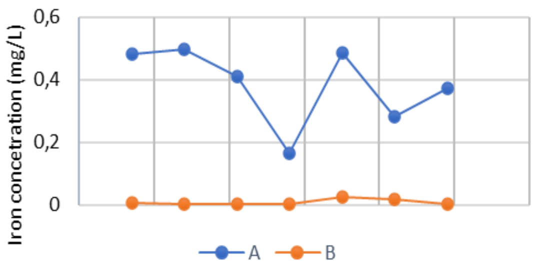

Figure 2. Measured iron (Fe) concentration in the observed water samples of A (inlet) and B (outlet) from November 7, 2023, to December 19, 2024.

Figure 2 illustrates the reduction in iron concentration before and after the addition of coagulants and flocculants. The post-treatment clarifier water demonstrated iron levels complying with the environmental health standards for sanitation and hygiene water, as per the Indonesian Ministry of Health Regulation No. 32/2017, which stipulates a maximum allowable iron concentration of 1 mg/L. The resulting iron concentrations, ranging from 0.002 to 0.026 mg/L, were well within these established standards.

The results of this study are consistent with previous research demonstrating the effectiveness of aluminum sulfate and polymer-based flocculants in water treatment. For instance, Zwane et al. (2024) emphasized the stability of flocs formed during alum-based coagulation, while Zaman et al. (2021) highlighted its superior performance compared to eco-friendly alternatives in industrial applications. The consistent reduction in iron concentration observed in this study aligns with the findings of Ali et al. (2021) and Yang et al. (2023), who detailed the mechanisms by which aluminum sulfate precipitated iron in both ferric and ferrous forms. Furthermore, the observed dependence of coagulation efficiency on pH and alkalinity is consistent with Esfandiar et al. (2022), which underscored the role of slightly acidic conditions in optimizing the removal of heavy metals.

Table 1. Observed turbidity in water samples A (inlet) and B (outlet)

No	Date	Sample	Turbidity (NTU)
1	November 7, 2023	A	75.2
		B	1.32
2	November 14, 2023	A	69.6
		B	0.916
3	November 21, 2023	A	70.5
		B	1.54
4	November 28, 2023	A	22.4
		B	1.09
5	December 5, 2023	A	79.5
		B	1.47
6	December 12, 2023	A	54.3
		B	2.9
7	December 19, 2023	A	71.4
		B	1.955

Adding aluminum sulfate as a coagulant and a polymer as a flocculant to clarifier water resulted in turbidity levels that generally met the physical parameter standards outlined by environmental health regulations for sanitation and hygiene water (Indonesian Ministry of Health Regulation

No. 32/2017). Turbidity serves as a critical parameter for evaluating the effectiveness of coagulation and flocculation processes (Matos et al., 2024). As shown in **Table 1**, turbidity in clarifier water fluctuated, primarily due to varying conditions in the source river water, which was significantly affected by climatic and weather changes (Pešić et al., 2020).

The turbidity of Sample A fluctuated throughout the sampling period, ranging from a low of 22.4 NTU on November 28, 2023, to a high of 79.5 NTU on December 5, 2023. These variations suggest changes in the initial water quality or in the composition of the influent water entering the clarifier.

In contrast, the turbidity of Sample B remained consistently low, ranging from 0.916 NTU to 2.9 NTU. Although minor fluctuations occurred, the turbidity levels were consistently lower than those observed in Sample A, indicating the clarifier's effectiveness in reducing turbidity. The overall trend suggests that the clarifier efficiently lowered turbidity, as the turbidity of Sample B (outlet) remained significantly lower than that of Sample A (inlet) throughout the entire sampling period.

Aluminum sulfate destabilizes colloidal particles, facilitating their aggregation and subsequent settling from the solution. Previous research indicates that optimal turbidity reduction occurs when the pH is slightly acidic to neutral (Saxena & Brighu, 2020; Tabash et al., 2024), which aligns with the observed pH reduction in Sample B. Additionally, studies suggest that petroleum wastewater typically contains fine particulate matter (Sun et al., 2021; Varjani et al., 2020), and aluminum sulfate is particularly effective in removing these particles due to its high charge density (de Jesus et al., 2024), thereby forming larger, easily removable flocs.

The significant reduction in turbidity supports previous findings by Matos et al. (2024) and Saxena and Brighu (2020), who emphasized the efficiency of aluminum-based coagulants in reducing particulate matter across different conditions. The variability in raw water turbidity, likely affected by seasonal and climatic factors, is consistent with the findings of Pešić et al. (2020), who documented similar fluctuations in untreated water quality due to environmental changes. This study thus contributes to the broader understanding of industrial water treatment processes, validating the effective application of aluminum sulfate and polymers in ensuring compliance with regulatory standards.

Conclusion

This study concludes that the pH, iron concentration, and turbidity levels in the inlet and outlet clarifier water samples met the environmental health quality standards for water media as outlined in Indonesia's Ministry of Health Regulation No. 32/2017. These parameters were within the specified limits, with pH ranging from 6.5 to 8.5, iron (Fe) concentration below the maximum allowable limit of 1 mg/L, and turbidity under the maximum threshold of 25 NTU. The analysis further demonstrates that the use of coagulants and flocculants positively affected these parameters. Their application effectively lowered pH, reduced iron concentration, and decreased turbidity in the clarifier water, highlighting the efficacy of coagulants and flocculants in enhancing water quality. Future research should optimize coagulant and flocculant dosages for varying water conditions, explore sustainable alternatives, and integrate advanced treatment technologies. Pilot-scale studies and real-world applications might further validate and enhance the efficiency of these methods, contributing to more sustainable industrial water treatment practices.

Acknowledgments

The authors express their gratitude to PT Perta Arun Gas for facilitating this Field Practice Study in collaboration with the Chemistry Department of the Faculty of Science and Technology at UIN Ar-Raniry, Banda Aceh, Indonesia.

References

Ali, I., Babkin, A. V., Burakova, I. V., Burakov, A. E., Neskoromnaya, E. A., Tkachev, A. G., Panglisch, S., AlMasoud, N., & Alomar, T. S. (2021). Fast removal of samarium ions in water on highly efficient nanocomposite based graphene oxide modified with polyhydroquinone: Isotherms, kinetics, thermodynamics and desorption. Journal of Molecular Liquids, 329, 115584.

Aragaw, T. A., & Bogale, F. M. (2023). Role of coagulation/flocculation as a pretreatment option to reduce colloidal/bio-colloidal fouling in tertiary filtration of textile wastewater: A review and future outlooks. Frontiers in Environmental Science, 11, 1142227.

Arcentales-Ríos, R., Carrión-Méndez, A., Cipriani-Ávila, I., Acosta, S., Capparelli, M., Moulatlet, G., & Pinos-Vélez, V. (2022). Assessment of metals, emerging contaminants, and physicochemical characteristics in the drinking water and wastewater of Cuenca, Ecuador. Journal of Trace Elements and Minerals, 2, 100030.

Dayarathne, H., Angove, M. J., Aryal, R., Abuel-Naga, H., & Mainali, B. (2021). Removal of natural organic matter from source water: Review on coagulants, dual coagulation, alternative coagulants, and mechanisms. Journal of Water Process Engineering, 40, 101820.

de Jesus, J. O. N., Medeiros, D. L., Esquerre, K. P. O., Sahin, O., & de Araujo, W. C. (2024). Water treatment with aluminum sulfate and tanin-based biocoagulant in an oil refinery: the technical, environmental, and economic performance. Sustainability, 16(3), 1191.

Esfandiar, N., Suri, R., & McKenzie, E. R. (2022). Competitive sorption of Cd, Cr, Cu, Ni, Pb and Zn from stormwater runoff by five low-cost sorbents; Effects of co-contaminants, humic acid, salinity and pH. Journal of Hazardous Materials, 423, 126938.

Ghangrekar, M. M. (2022). Unit Operations and Chemical Unit Processes. In Wastewater to Water: Principles, Technologies and Engineering Design (pp. 225-342). Springer.

Guillossou, R., Le Roux, J., Mailler, R., Pereira-Derome, C. S., Varrault, G., Bressy, A., Vulliet, E., Morlay, C., Nauleau, F., & Rocher, V. (2020). Influence of dissolved organic matter on the removal of 12 organic micropollutants from wastewater effluent by powdered activated carbon adsorption. Water research, 172, 115487.

Krupinska, I. (2020). The effect of the type of hydrolysis of aluminum coagulants on the effectiveness of organic substances removal from water. Desalination and Water Treatment, 186, 171-180.

Li, H., Wang, Y., He, L., Wang, Y., Liu, M., Gu, L., Liu, S., Li, J., Yang, Y., & Wang, R. (2024). Enhance Fe (III) reduction in sludge fermentation for vivianite formation using exogenous H2 assisted by activated carbon. Water research, 122708.

Matos, T., Martins, M., Henriques, R., & Goncalves, L. (2024). A review of methods and instruments to monitor turbidity and suspended sediment concentration. Journal of Water Process Engineering, 64, 105624.

Omar, K., & Vilcáez, J. (2024). The role of alkalinity on metals removal from petroleum produced water by dolomite. Applied Geochemistry, 161, 105879.

Pešić, M., Milić, S., Nujkić, M., & Marić, M. (2020). The impact of climatic parameters on the turbidity and natural organic matter content in drinking water in the City of Bor (Eastern Serbia). Environmental Earth Sciences, 79(11), 267.

Pillai, S. B., & Thombre, N. V. (2024). Coagulation, flocculation, and precipitation in water and used water purification. In Handbook of water and used water purification (pp. 3-27).

Springer.
Roza, M. (2023). Implementation Analysis of the Pariaman City Regional Regulation No. 9 of 2015 concerning the Drinking Water Depot Business Permit. Journal of Indonesian Health Policy and Administration, 8(2), 9.
Salaghi, A., Diaz-Baca, J. A., & Fatehi, P. (2023). Enhanced flocculation of aluminum oxide particles by lignin-based flocculants in dual polymer systems. Journal of Environmental Management, 328, 116999.
Saxena, K., & Brighu, U. (2020). Optimized coagulation of humic acid and mineral turbidity at alkaline pH using high basicity PACl. Water Supply, 20(6), 2324-2338.
Sun, Y., Liu, Y., Chen, J., Huang, Y., Lu, H., Yuan, W., Yang, Q., Hu, J., Yu, B., & Wang, D. (2021). Physical pretreatment of petroleum refinery wastewater instead of chemicals addition for collaborative removal of oil and suspended solids. Journal of Cleaner Production, 278, 123821.
Tabash, I., Elnakar, H., & Khan, M. F. (2024). Optimization of iron electrocoagulation parameters for enhanced turbidity and chemical oxygen demand removal from laundry greywater. Scientific Reports, 14(1), 16468.
Varjani, S., Joshi, R., Srivastava, V. K., Ngo, H. H., & Guo, W. (2020). Treatment of wastewater from petroleum industry: current practices and perspectives. Environmental Science and Pollution Research, 27(22), 27172-27180.
Wang, R., & Lin, S. (2021). Pore model for nanofiltration: History, theoretical framework, key predictions, limitations, and prospects. Journal of Membrane Science, 620, 118809.
Yang, B., Graham, N., Liu, P., Liu, M., Gregory, J., & Yu, W. (2023). Atomic-level structural differences between Fe (III) coprecipitates generated by the addition of Fe (III) coagulants and by the oxidation of Fe (II) coagulants determine their coagulation behavior in phosphate and DOM removal. Environmental Science & Technology, 57(33), 12489-12500.
Yu, Q., Zhang, F., Li, R., Li, E., Qin, J., Chen, L., & Wang, X. (2025). Growth performance, antioxidant capacity, intestinal microbiota, and metabolomics analysis of Nile tilapia (Oreochromis niloticus) under carbonate alkalinity stress. Aquaculture, 595, 741675.
Zaman, N. K., Rohani, R., Yusoff, I. I., Kamsol, M. A., Basiron, S. A., & Rashid, A. I. A. (2021). Eco-friendly coagulant versus industrially used coagulants: identification of their coagulation performance, mechanism and optimization in water treatment process. International Journal of Environmental Research and Public Health, 18(17).
Zwane, Q., Tshangana, C., Mahlangu, O., Snyman, L., Msagati, T., & Muleja, A. (2024). Hierarchical Approach to the Management of Drinking Water Sludge Generated from Alum-Based Treatment Processes. Processes, 12(9), 1863.