ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2576-6724 (Print)
ISSN: 2576-6732 (Online)
CODEN: ACMCCG

Acta Chemica Malaysia (ACMY)

DOI: http://doi.org/10.26480/acmy.01.2025.01.05

CrossMark

RESEARCH ARTICLE

DEVELOPMENT OF INORGANIC COAGULANT SLURRY TO TREAT TEXTILE INDUSTRIAL WASTES

Syed Abdurrahim Alsagoff, Ahmed H.A. Dabwan*

Faculty of Engineering, University College TATI, 24000 Kemaman, Terengganu.
****Corresponding Author E-mail: drahmedtati@gmail.com***

ARTICLE DETAILS

Article History:

Received 10 December 2024
Revised 27 January 2025
Accepted 31 January 2025
Available online 14 February 2025

ABSTRACT

This study aims to develop and optimize a slurry inorganic coagulant for the treatment of textile industrial wastewater. Moreover to investigates the efficiency and capability of the coagulant, focusing on the influence of key parameters, such as time, concentration, and coagulant dosage, on the coagulation and flocculation process. The initial development of the coagulant encountered challenges, leading to an iterative refinement process. Eventually, an optimized coagulant formulation comprising alum, calcium hydroxide, and fly ash in a ratio of 1:2:1/2 was identified. This coagulant demonstrated remarkable efficacy, achieving a 100% removal of total colour from the wastewater at the dosage of 0.75 g when methylene blue was used. The colour removal efficiency was significantly influenced by the coagulant dosage, as higher doses beyond 1.0 g exhibited decreased removal rates. Additionally, the study investigated the impact of time on the coagulation process, identifying the optimum time for slurry coagulant at the 12th hour. Beyond this time, the coagulant's efficiency reached equilibrium. Furthermore, the study examined the influence of concentration on the coagulant's performance, demonstrating that as the concentration of the sample increased, the colour removal efficiency decreased. The results of this study provide valuable insights into the kinetics of the coagulation process and its application in wastewater treatment. The optimized coagulant formulation offers a promising solution for efficient colour removal in textile industrial wastewater. The findings contribute to a deeper understanding of the coagulation process, aiding in the design of effective water treatment protocols.

KEYWORDS

Textile industry wastes; inorganic coagulant; coagulation and flocculation; methylene blue; slurry

1. Introduction

This procedure demonstrates a water purification method that encourages the aggregation of suspended particles into settleable flocs by Water makes up 65% of our bodies and covers 71% of the earth's surface. Everyone desires access to clean water for drinking, pleasure, and aesthetic enjoyment. When water is contaminated, it loses its aesthetic and economic worth to us and poses a risk to our health as well as the survival of the fish that live there and other animals that depends on it. One of the most serious environmental issues is the chemical contamination of rivers and streams (Sonune and Ghate, 2004). Wastewater from most home and industrial processes contains undesired harmful pollutants. Water resources in this situation need to be constantly protected. In order to remove insoluble particles and soluble contaminants from effluents, current wastewater treatment systems include physical, chemical, and biological processes (Crini and Lichtfouse, 2018).

Due to its efficiency, simplicity, and low energy consumption, the coagulation-flocculation process is typically recognized as one of the most significant methods for treating industrial wastewater and raw water. In the last few decades, the coagulation-flocculation process has seen widespread use in industry. Additionally, this method is frequently utilized as a pre-treatment for other integrated treatment methods such membrane filtering, biological treatment, and advanced oxidation methods (Yaser et al., 2017). The primary goals of the first stage of treatment are to remove suspended solids and colloidal impurities from wastewater using coagulation/flocculation techniques. Coagulation (rapid mix stage) and flocculation (slow mix stage) disrupt and aggregate small, stabilized colloidal imperfections into large particle units known as flocs, which are primarily removed in the subsequent solid-liquid separation stages of sedimentation and filtration (Mohamed and Alfalous, 2020).

Chemical coagulants like alum, ferric chloride, and polyelectrolyte have been used to separate suspended solids (colloids) from water effectively. destabilising the charged colloids and thereby negating the forces that keep them apart (Saritha et al., 2014). If the pH is adjusted to the ideal range and the coagulant dose is used, coagulation is the best approach for removing organic material. The best outcomes for the elimination of organic can be obtained by increasing the dose of the coagulant (alum). Two critical factors in the industrial wastewater treatment process are the alum dose and pH (Sahu and Chaudhari, 2014). Significant organic elimination is achievable using alum as the coagulant. The efficacy of coagulation for organic removal is significantly influenced by the pH of the wastewater during coagulation. A little acidic environment is significantly better for organic elimination. The ideal pH is somewhat pushed to slightly more acidic values for water with a higher organic content (Sahu, 2019). Significance of this work is utilizing inorganic coagulant made of alum, calcium hydroxide, and fly ash as slurry where can be used in real plant through pumping to higher level rather than carrying.

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Cite the Article: Syed Abdurrahim Alsagoff, Ahmed H.A. Dabwan (2025). Development of Inorganic Coagulant Slurry to Treat Textile Industrial Wastes. *Acta Chemica Malaysia, 9(1): 01-05.*

2. Preparation of Methylene Blue Sample

To prepare a methylene blue stock solution with a concentration of 100ppm in 1 Liter of distilled water, a precise measurement of 0.1g of methylene blue powder was obtained. The procedure was carried out under appropriate safety measures in a well-ventilated environment, considering the potential hazards associated with methylene blue. A clean container suitable for holding the stock solution was selected, and 1 Liter of distilled water was accurately dispensed into it. The previously measured 0.1g of methylene blue powder was meticulously added to the container containing the distilled water. The resulting solution was stirred gently using a glass rod or magnetic stir bar, ensuring thorough mixing until complete dissolution of the methylene blue powder was achieved. The successful preparation of a methylene blue stock solution with a concentration of 100ppm was confirmed upon complete dissolution of the powder. The container was appropriately labelled with the date, concentration, and other pertinent information for future reference.

To ensure the stability of the stock solution, it was stored in a cool and dark environment to minimize the influence of light. Proper handling procedures were followed, considering the potential hazards associated with methylene blue. Disposal of any waste was carried out in compliance with the applicable regulations governing hazardous substances. These steps were undertaken to generate a methylene blue stock solution with precise specifications, making it suitable for utilization for this research and experimental protocols, in accordance with the established protocols and safety guidelines.

3. Developing The Coagulant

The development of an effective coagulant involved combining three components: alum, calcium hydroxide, and fly ash. These components were carefully mixed to create a coagulant with enhanced coagulation properties. The selection of these specific components was based on their known coagulation capabilities and potential synergistic effects. During the mixing process, the charge of the coagulant components played a crucial role. The electrical charge of the particles had to be taken into consideration to ensure proper interaction and effective coagulation. By considering the charge of each component, the mixing process aimed to optimize the attraction and binding of particles in the water treatment process. The mixing conditions and parameters were adjusted to facilitate the desired chemical reactions and maximize the coagulation efficiency. The appropriate mixing intensity, duration, and sequence were determined to promote the formation of stable flocs and facilitate the removal of impurities.

3.1 Initial Coagulant Developed

At the outset of the project, it became evident that the initially formulated coagulant failed to yield the anticipated results. This inadequacy was notably manifested through an observed escalation in sample turbidity, accompanied by the incomplete precipitation of impurities. Subsequently, recognizing the need for a substantial improvement in coagulant efficacy, a methodical and iterative refinement process was set into motion with the primary objective of optimizing the coagulant formulation. This extensive refinement procedure was characterized by a deliberate and exhaustive series of trial and error experiments, diligently conducted in pursuit of achieving the utmost effectiveness in coagulation performance, a critical cornerstone of the entire project's success.

Figure 1: Initial developed coagulant failed to obtain the desired results.

3.2 The Developed Coagulant

After numerous attempts, the desired coagulant formulation was successfully developed, consisting of alum, calcium hydroxide, and fly ash in a ratio of 1:2:1/2, respectively. This optimized composition demonstrated significantly improved coagulation efficacy and successfully addressed the initial shortcomings. To achieve the desired results consistently, a coagulant-alum combination was adopted. For each sample requiring testing, the coagulant was added first, followed by the addition of alum in a 1:1 ratio. This combination proved to be critical in enhancing the coagulation process and ensuring the efficient removal of impurities. The iterative nature of the coagulant development process allowed for the identification of the most effective formulation, leading to the successful achievement of the project's objectives. By utilizing alum, calcium hydroxide, and fly ash in specific proportions and implementing the coagulant-alum combination, the optimized coagulant demonstrated superior performance, offering a promising solution for industrial wastewater treatment.

Figure 2: The developed coagulant successfully removed the colour from the sample.

4. Study of The Coagulant

4.1 Effect Of Coagulant Dose

In the extensive investigation aimed at enhancing the coagulation and flocculation process for water treatment, a systematic examination of varying coagulant dosages spanning the range from 0.25 to 1.0 grams was meticulously carried out. This comprehensive study sought to comprehensively evaluate the profound impact of these coagulant dosages specifically on the removal of color from water samples. Throughout these experiments, all other pertinent parameters, such as pH, temperature, and water source, were rigorously maintained at consistent levels to ensure that the observed effects were solely attributed to changes in coagulant dosage. The elucidation of the results, as presented in Figure 4.5, unveiled a rather intriguing and informative trend in the context of color removal efficiency. Notably, it was found that the coagulant dosage of 0.75 grams exhibited the most remarkable performance, achieving a truly impressive 100% removal of total color content from the water under scrutiny. This outcome not only demonstrates the efficacy of the coagulation-flocculation process but also underscores its pivotal role in enhancing water clarity, thereby rendering it suitable for a variety of applications.

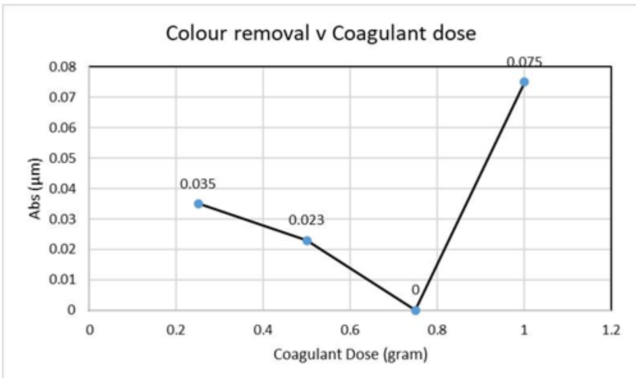

Figure 3: Effect of coagulant dose

Furthermore, the analysis of the data revealed a noteworthy pattern in the relationship between coagulant dosage and color removal. As expected, there was a direct proportionality between these two factors, with increasing coagulant dosages leading to heightened color removal rates. However, the most intriguing observation emerged when the coagulant dosage reached the upper limit of 1.0 gram, at which point the color removal efficiency exhibited an abrupt and unexpected decline. This peculiar phenomenon serves as a critical point of interest in the study, as it suggests the presence of an optimal coagulant dosage threshold. This abrupt decrease in color removal at the highest dosage level can be attributed to the possibility of exceeding the optimal charge-neutralization capacity and introducing excessive precipitates, leading to the unintended coverage of additional surface areas or active sites, which, in turn, hampers the overall color removal process.

Consequently, these findings underscore the undeniable significance of coagulant dosage in dictating the efficacy of the coagulation process in water treatment applications. The proficient removal of color and impurities from water is evidently contingent on the precise quantity of coagulant employed, emphasizing the critical need for a meticulous and data-driven optimization of coagulant dosages in order to consistently attain the desired water treatment objectives with maximum effectiveness and efficiency. This research not only contributes to the fundamental understanding of coagulation-flocculation processes but also provides practical insights that can be applied in various water treatment scenarios to ensure the provision of clean and clear water for diverse purposes.

4.2 Effect of Concentration

The exploration of concentration levels emerged as a pivotal and illuminating facet in the meticulous evaluation of the efficiency and effectiveness of the coagulation process. A nuanced investigation was carried out to dissect the intricate relationship between concentration and the coagulant's performance, with particular emphasis on its profound impact on color removal. As the concentration of the water sample under scrutiny increased, a striking phenomenon began to unravel—the color intensity exhibited a notable escalation, prompting an in-depth analysis of how this parameter influenced the coagulant's effectiveness.

The experimental framework was meticulously designed to systematically scrutinize the influence of concentration, spanning a range from 20 to 50 parts per million (ppm), while judiciously employing the previously determined optimal coagulant dosage. This precision in experimental design ensured that the outcomes would provide a comprehensive understanding of the coagulation process across a spectrum of concentrations that are typically encountered in real-world scenarios.

The findings stemming from this comprehensive analysis revealed a compelling narrative of concentration-dependent coagulation behavior. Beyond the concentration threshold of 25 ppm, a diminishing trend in the coagulant's efficiency became conspicuous, signifying a departure from the ideal conditions for complete color removal. Specifically, at the concentration of 40 ppm, the color removal rate reached a commendable 83.8%, showcasing the coagulant's capacity to deliver significant improvements in water quality. Even at the higher end of the concentration spectrum, at 50 ppm, a substantial color removal rate of 78% was attained. While total color removal remained elusive at these concentrations, the results underscore the coagulant's ability to achieve remarkably high removal rates, rendering the treated water samples notably clear in terms of color.

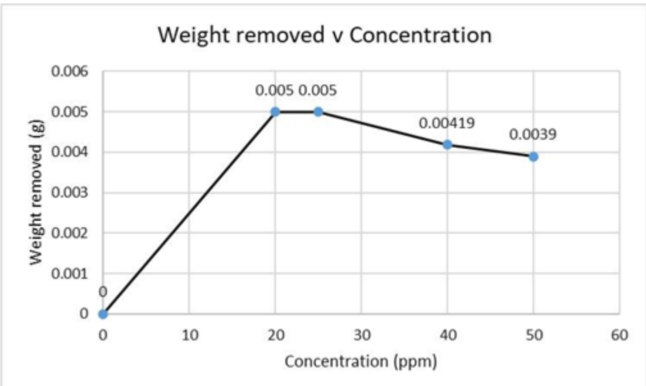

Figure 4: Effect of concentration

These intriguing findings serve as a testament to the paramount importance of considering the concentration of the water sample as a critical variable in the coagulation process. By shedding light on the nuanced interplay between concentration and coagulant efficiency, this study not only enriches our understanding of the coagulation- flocculation process but also offers valuable insights into the coagulant's adaptability and efficacy, even in scenarios where higher concentrations of impurities are encountered. Such knowledge is of paramount importance, especially in industries like textile manufacturing, where the treatment of wastewater laden with colorants and contaminants is a recurrent challenge. This research thus stands as a valuable contribution to the realm of water treatment optimization, offering practical guidance for addressing the complex and dynamic nature of industrial wastewater treatment processes.

Figure 5: methylene blue before and after coagulation

4.3 Effect Of Time For Slurry

The meticulous assessment of the slurry coagulant's reaction time emerged as a pivotal aspect of our research endeavors, aimed at unraveling the temporal intricacies that govern the optimal efficiency of wastewater treatment. Time, as a variable, wielded substantial influence over the performance of the slurry coagulant, thereby profoundly affecting its ability to remove impurities from the aqueous medium.

The empirical journey embarked upon in this investigation involved an exhaustive exploration of how varying duration of treatment impacted the coagulation process. The goal was to pinpoint the precise time frame that would yield the highest removal efficiency for impurities, particularly focusing on color removal. This quest for temporal optimization was conducted through a series of systematically designed experiments, marked by meticulous control of other variables to ensure that the observed effects were solely attributable to variations in the reaction time.

Our findings unveiled an intriguing and dynamic narrative of the interplay between time and coagulant performance. It was evident that the maximum rate of color removal was achieved when the reaction time extended to the 24th hour, highlighting the incremental improvements in treatment efficiency as the process continued. However, what emerged as a critical observation was the diminishing efficiency after the 12th hour. This noticeable decline in removal rate indicated a gradual deceleration in the coagulation process, suggesting that the optimal conditions for impurity removal had been surpassed.

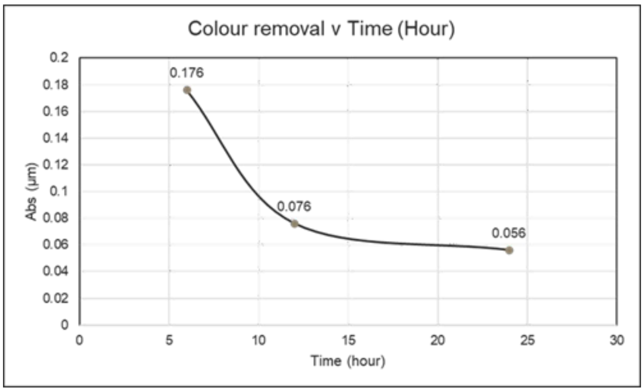

Figure 6: Effect of time for slurry

Subsequently, after the 24th hour, an intriguing phenomenon came to light: no further discernible changes in the removal rate were observed. This phenomenon signified that the system had reached a state of equilibrium, where the coagulation process had effectively stabilized, and the removal efficiency remained constant. Based on the wealth of empirical evidence garnered from our experiments, it was unequivocally established that the pinnacle of efficiency for the slurry coagulant occurred at the 12th hour. At this critical juncture, an impressive removal efficiency of 93.2% was achieved, representing the zenith of impurity removal potential. Beyond this temporal threshold, the efficiency plateaued, indicating that the coagulation process had reached a state of equilibrium where the rate of impurity removal remained steady. These findings not only provide critical insights into the temporal dynamics of the coagulation process but also offer practical guidance for optimizing the treatment of wastewater laden with impurities. Understanding the interplay between time and coagulant efficiency is pivotal for industries where water treatment is a recurring challenge, as it empowers them to make informed decisions about the duration of treatment processes to attain the desired water quality standards with maximum efficacy and efficiency.

5. Conclusion

In conclusion, this study aims is to develop and optimize a slurry inorganic coagulant for the treatment of textile industrial wastewater represented by methylene blue. Throughout the course of this study, significant progress has been made in understanding the coagulation process and its application in wastewater treatment. The initial development of the coagulant encountered challenges, with inefficiencies observed in achieving the desired results. However, through a systematic iterative refinement process, a successful coagulant formulation was identified, comprising alum, calcium hydroxide, and fly ash in a specific ratio of 1:2:1/2. This optimized coagulant demonstrated commendable efficacy in treating the textile industrial wastewater, leading to substantial colour removal and improved water quality.

Furthermore, the project investigated the influence of time on the coagulation process and identified the optimum time for slurry coagulant at the 12th hour. Beyond this point, the removal rate reached an equilibrium state, providing crucial insights into the kinetics of the coagulation process and contributing to the efficient design of wastewater treatment protocols. Additionally, the study explored the impact of concentration on the coagulant's performance. It was observed that as the concentration of the sample increased, the coagulant efficiency decreased, with complete colour removal becoming more challenging. Nevertheless, even at higher concentrations, the coagulant exhibited remarkable colour removal rates, signifying its potential for effective treatment of textile industrial wastewater.

Overall, this project has advanced our knowledge of coagulation techniques and their practical application in industrial wastewater treatment. The optimized slurry inorganic coagulant, incorporating alum, calcium hydroxide, and fly ash, demonstrates promising results in terms of colour removal and impurity reduction. These findings hold great significance for sustainable water treatment practices in the textile industry.

Recommendation

For future studies, it is recommended to explore the coagulant's effectiveness with different types of wastewater sources, extending beyond textile industrial wastewater. This will provide valuable insights into its versatility and potential applications in diverse water treatment scenarios. Additionally, investigating the coagulant's behaviour under varying operating conditions, such as temperature, pH, and coagulant dosages, will help optimize treatment protocols for enhanced efficiency. To promote sustainable practices, it is essential to assess the stability and reusability of the coagulant, considering its shelf life during storage and potential for recycling or regeneration. Comparative studies between the developed slurry inorganic coagulant and conventional coagulants should be conducted to understand its performance and cost- effectiveness in wastewater treatment applications. Furthermore, examining the coagulant's efficacy in removing other water quality parameters, such as turbidity, chemical oxygen demand (COD), and heavy metals, will provide a more comprehensive evaluation of its treatment capabilities. To validate its real-world effectiveness, long-term field trials in wastewater treatment plants or industrial facilities are recommended. Considering environmental implications, toxicity tests on aquatic organisms and assessments of the coagulant's potential environmental impact are crucial for safe and sustainable usage. Lastly, a cost-benefit analysis should be conducted to evaluate the economic viability and competitiveness of the coagulant system in comparison to other treatment methods.

Acknowledgements

A deeply gratitude to the funding and support from University College TATI under (UCTATI/STG/9001-2401). The views, findings, recommendation or conclusion presented in this paper are those of the authors and may not reflect the point of view of the supporting agency.

References

Abdelbasir, S.M., and Shalan, A.E., 2019. An overview of nanomaterials for industrial wastewater treatment. Korean Journal of Chemical Engineering, 36 (8), Pp. 1209–1225.

Aguilar, M.I., Llor, M., Soler, O., and Ortu, J.F., 2002. Destabilization Of Model Wastewater In The Chemical Coagulation Process. Water Resources, 36 (11), Pp. 2910–2919.

Ahmed, M.B., Zhou, J.L., Ngo, H.H., Guo, W., Thomaidis, N.S., and Xu, J., 2017. Progress in the biological and chemical treatment technologies for emerging contaminant removal from wastewater: A critical review. Journal of Hazardous Materials, 323, Pp. 274–298.

Buyukkamaci, N., and Koken, E., 2010. Economic evaluation of alternative wastewater treatment plant options for pulp and paper industry. Science of the Total Environment, 408, Pp. 6070–6078.

Chowdhury, M., Mostafa, M.G., Biswas, T.K., and Saha, A.K., 2013. Treatment of leather industrial effluents by filtration and coagulation processes. Water Resources and Industry, 3, Pp. 11–22.

Crini, G., and Lichtfouse, E., 2018. Advantages and disadvantages of techniques used for wastewater treatment. Environmental Chemistry Letters. https://doi.org/10.1007/s10311-018-0785-9

Duan, J., Gregory, J., 2003. Coagulation by hydrolysing metal salts. Advances in Colloid and Interface Science, Pp. 100–102: 475-502bv

Dutta, S., Gupta, B., Srivastava, S.K., and Gupta, A.K., 2021. Recent advances on the removal of dyes from wastewater using various adsorbents: A critical review. Materials Advances.

Gunatilake, S.K., 2015. Methods of removing heavy metals from industrial wastewater. Methods, 1 (1), Pp. 14.

Irfan, M., Butt, T., Imtiaz, N., Abbas, N., and Shafique, R., 2017. The removal of COD, TSS and colour of black liquor by coagulation– flocculation process at optimized pH, settling and dosing rate. Arabian Journal of Chemistry, 10 (2), Pp. 2307–2318.

Khan, A.H., Khan, N.A., Ahmed, S., Dhingra, A., Singh, C.P., Khan, S.U., Mohammadi, A.A., Changani, F., Yousefi, M., Alam, S., 2020. Application of advanced oxidation processes followed by different treatment technologies for hospital wastewater treatment. J. Clean Prod., 269, Pp. 122411.

Lapointe, M., Barbeau, B., 2020. Understanding the roles and characterizing the intrinsic properties of synthetic vs. natural polymers to improve clarification through interparticle Bridging: A review. Sep. Purif. Technol., Pp. 231.

Malakoutian, M., and Fatehizadeh, A., 2010. Color removal from water by coagulation/caustic soda and lime.

Manda, I.K.M., Chidya, R.C.G., Saka, J.D.K., and Biswick, T.T., 2016. Comparative assessment of water treatment using polymeric and inorganic coagulants. Physics and Chemistry of the Earth, Parts A/B/C, 93, Pp. 119–129.

Mohamed, F.M., and Alfalous, K.A., 2020. The effectiveness of activated silica derived from rice husk in coagulation process compared with inorganic coagulants for wastewater treatment. The Egyptian Journal of Aquatic Research, 46 (2), Pp. 131–136. https://doi.org/10.1016/j.ejar.2020.03.004

Muruganandam, L., Saravana, K.M.P., Jena, A., Gulla, S., and Godhwani, B., 2017. Treatment of waste water by coagulation and flocculation using biomaterials. IOP Conference Series: Materials Science and Engineering, 263, Pp. 032006.

Nassar, M.Y., Ali, E.I., Zakaria, E.S., 2017. Tunable auto-combustion preparation of TiO2 nanostructures as efficient adsorbents for the removal of an anionic textile dye. RSC Adv., 7, Pp. 8034–8050

Prakash, N.B., Sockan, V., and Jayakaran, P., 2014. Waste water treatment by coagulation and flocculation. International Journal of Engineering Science and Innovative Technology, 3 (2), Pp. 479-484.

Ratnaweera, H., 2004. Overview of coagulant dosing control. In: Chemical Water and Wastewater Treatment VII, Vol. VII (H. H. Hahn, E. Hoffman & H. Ødegaard eds.). IWA Publishing, London, pp. 3–13. ISBN: 1 84339 009 4.

Sahu, O., 2019. Electro-oxidation and chemical oxidation treatment of sugar industry wastewater with ferrous material: An investigation of physicochemical characteristic of sludge. South African Journal of Chemical Engineering, 28, Pp. 26–38.

Sahu, O.P., and Chaudhari, P.K., 2014. Physicochemical Treatment of Sugar Industry Wastewater: Coagulation Processes. Environmental Quality Management, 23 (4), Pp. 49–69.

Saritha, V., Srinivas, N., and Srikanth Vuppala, N.V., 2015. Analysis and optimization of coagulation and flocculation process. Applied Water Science, 7 (1), Pp. 451–460.

Sonune, A., and Ghate, R., 2004. Developments in wastewater treatment methods. Desalination, 167, Pp. 55-63. https://doi.org/10.1016/j.desal.2004.06.113

Syam Babu, D., Anantha Singh, T.S., Nidheesh, P.V., and Suresh, K.M., 2019. Industrial wastewater treatment by electrocoagulation process. Separation Science and Technology, Pp. 1– 33.

Thakur, S.S., and Choubey, S., 2014. Use of Tannin based natural coagulants for water treatment: An alternative to inorganic chemicals. International Journal of ChemTech Research, 6 (7), Pp. 3628-3634.

Varjani, S., Joshi, R., Srivastava, V.K., Ngo, H.H., and Guo, W., 2019. Treatment of wastewater from petroleum industry: current practices and perspectives. Environmental Science and Pollution Research, 27 (22), Pp. 27172–27180.

Yahya, N., Aziz, F., Jamaludin, N., Mutalib, M., Ismail, A., Salleh, W., Jaafar, J., Yusof, N., Ludin, N., 2018. A review of integrated photocatalyst adsorbents for wastewater treatment. J. Environ. Chem. Eng., 6, Pp. 7411– 7425.

Yaser, A.Z., and Pogaku, R., 2017. Recent trends for the removal of colored particles in industrial wastewaters. Environmental Science and Pollution Research, 24 (19), Pp. 15861–15862. https://doi.org/10.1007/s11356-017-9555-7

Zhao, C., Zhou, J., Yan, Y., 2020. Application of coagulation/ flocculation in oily wastewater treatment: A review, Science of the Total Environment.

Zhao, X., Yang, T., Liu, L., Zhang, X., Fan, L., Huang, Y., 2016. Effect of aluminum speciation on silica removal during coagulation of heavy-oil wastewater using polyaluminum chloride. Desalin. Water Treat., 57, Pp. 11789-11799.