CHEMICAL ENGINEERING TRANSACTIONS
VOL. 115, 2025
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Carlo Pirola, Antonio Espuña, Sabrina Copelli

**ISBN** 979-12-81206-16-8; **ISSN** 2283-9216
DOI: 10.3303/CET25115015

# Evaluation of the Coagulant *Opuntia Floccosa* in the Treatment of Silica Reduction in Industrial Wastewater

Steve D. Camargo*, Judith P. Curasi, Lizbet I. Tolentino

Universidad Continental. Faculty of Engineering, Professional Academic School of Environmental Engineering, Huancayo, Peru.
scamargo@continental.edu.pe

The availability of water is critical to the survival and viability of various organisms, including humans. This study used natural coagulants to improve water quality and mitigate resulting contamination, primarily from industrial operations. It is crucial to establish standards and treatment protocols to protect this invaluable natural resource and reduce the occurrence of diseases, such as silicosis, associated with the presence of silica in water.
The general objective of this study is to determine the efficacy of a natural coagulant obtained from the species Opuntia floccosa to reduce the amount of silica in the water. The experimental methodology was designed using the jug test to determine both the coagulation time and the optimal dose of the coagulant. Samples were obtained from effluent from non-metallic mining activities. Data were collected from six treatments, each replicated three times. The treatments consisted of varying the doses of coagulant applied to the samples, with the following variations in grams per liter: $P_0$ = 0 g/L, $P_1$= 1 g/L, $P_2$ = 2 g/L, $P_3$ = 3 g/L, $P_4$ = 4 g/L, and $P_5$ = 5 g/L.The results of the research show that the coagulant based on Opuntia floccosa had a significant effect on silica removal, with a removal efficiency of 86%. In addition, it was confirmed that the optimal amount of this coagulant was 2 g/L and that the best time for coagulation was 4 minutes. These findings highlight the potential of Opuntia floccosa as an effective and eco-friendly alternative to conventional chemical coagulants, paving the way for more sustainable water treatment solutions.

## 1. Introduction

Water pollution is a significant global concern, with the mining industry being a major contributor to this problem due to its mineral extraction and processing activities (Orellana Macías & Perles Roselló, 2022) . These activities introduce a variety of both soluble and insoluble substances into water systems, which pose challenges for treatment. Colloidal particles, due to their small size, present a considerable challenge for removal, leading to long-lasting environmental consequences. Among the contaminants generated by mining, silica is particularly concerning due to its ability to remain suspended in water, thus making it difficult to treat using conventional methods (Reece & Hulse, 2023).
Mining-related water pollution not only threatens aquatic ecosystems but also affects human health, agriculture, and industrial operations that rely on clean water. Heavy metals, suspended solids, and chemicals like silica can disrupt the natural balance of water bodies and decrease their utility for various uses. For example, suspended silica particles in rivers and lakes can obstruct light penetration, affecting the photosynthesis process in aquatic plants and ultimately reducing oxygen levels in the water (Coronado-Vázquez & Gómez-Salgado, 2019).. This reduction in oxygen can lead to adverse effects on fish populations and other aquatic life, disrupting entire ecosystems. Furthermore, silica particles, when inhaled from dried sediments, can cause respiratory diseases like silicosis, particularly among workers and communities near mining sites. Effective treatment of mining effluents is crucial not only for environmental protection but also for public health, as contaminated water can have severe impacts on surrounding communities. According to a report by the National Water Authority, mining effluents constitute 25.4% of the total waste discharged into rivers, while industrial sources contribute 5.6%. The Mantaro River in Peru, for example, suffers from severe pollution due to untreated discharges, which affects nearby communities that rely on this water for agriculture, livestock, and even human consumption (Delgado, 2021). Silica, as one of the main pollutants, ranks fourth in industrial production, with a total annual

Paper Received: 29 May2024; Revised: 09 December 2024; Accepted: 8 March 2025
Please cite this article as: Camargo S.D., Curasi J.P., Tolentino L.I., 2025, Evaluation of the Coagulant Opuntia Floccosa in the Treatment of Silica Reduction in Industrial Wastewater, Chemical Engineering Transactions, 115, 85-90 DOI:10.3303/CET25115015

output of 142,161 tons. The accumulation of untreated mining effluents in water bodies leads to long-term ecological degradation, reducing the availability of clean water resources. In some regions, the scarcity of water resources exacerbates the problem, making water treatment a critical issue for both local governments and industries. Therefore, developing effective, low-cost, and sustainable solutions for wastewater treatment is a growing priority. Conventional chemical coagulants, such as aluminum sulfate and ferric chloride, are widely used for removing contaminants from industrial wastewater (Bobillo & Colombo, 2023). However, these chemicals can generate secondary pollutants, increase the sludge volume, and contribute to residual toxicity in treated water.

Companies involved in silica production are frequently associated with adverse environmental impacts, particularly in terms of surface water contamination. This situation highlights the urgent need for the adoption of green technologies to manage industrial waste more effectively. Natural coagulants, such as those derived from plant species, are gaining attention as sustainable alternatives to synthetic chemicals. These coagulants have been shown to improve water quality while minimizing environmental impact. Among the natural coagulants, Opuntia floccosa, a cactus species native to the Andean region, stands out due to its high content of mucilage, a substance with strong coagulating properties.

Natural coagulants, such as Opuntia floccosa, offer several advantages over chemical coagulants. They are biodegradable, non-toxic, and more affordable, especially in regions where these plants are abundant. Their use also reduces the chemical load in treated water, minimizes sludge generation, and lessens the risk of harmful by-products. *Opuntia floccosa* has shown particular promise due to its high availability in Andean regions, ease of collection, and demonstrated efficacy in previous studies on water treatment.

The main objective of this study is to formulate a novel coagulant derived from the *Opuntia floccosa* species, with the specific purpose of effectively removing silica from liquid effluents. By reducing silica concentrations in industrial wastewater, this project seeks to contribute to the overall improvement of water quality. Additionally, this research aims to explore the potential of *Opuntia floccosa* as an environmentally friendly alternative to conventional chemical coagulants, offering a more sustainable approach to wastewater treatment in industries with high water consumption, such as mining and construction. The findings are expected to provide actionable insights for the development of more efficient and sustainable water treatment processes, as indicated by studies like those conducted by Maroneze et al., (2014).

## 2. Methodology

### 2.1 Study Area

This research was conducted using industrial wastewater from a non-metallic mining company dedicated to the extraction and commercialization of aggregates for civil construction. The samples were obtained from this company located in the town of Pachacayo, in the district of Canchayllo, province of Jauja, department of Junín, Peru. The collection point is situated at a latitude of 11°46'13.65"S and a longitude of 75°42'32.84"W, at an altitude of 3,540 meters above sea level. The geographical and environmental conditions of this area, particularly the elevation, were critical factors in the study as they influence the behavior of natural coagulants like *Opuntia floccosa* in wastewater treatment.

The choice of study area is significant due to the heavy industrial activity in this region, which produces large amounts of effluents that are often discharged into local water bodies. These effluents contain pollutants such as silica, which pose serious environmental and public health risks. By selecting this site, the study aims to address a real-world problem of water contamination in a region where effective wastewater treatment is urgently needed.

### 2.2 Sampling

In accordance with the National Protocol for the Monitoring of the Quality of Surface Water Resources (National & Water, n.d.), the necessary samples were taken at the discharge point, where the waters reach the nearest water sources. Six samples of the industrial wastewater effluent were collected directly from the discharge point at various time intervals to ensure a representative analysis. Samples were collected using sterile containers, following standard procedures for environmental sampling. Each container was labeled with the date, time, and specific location of collection to maintain proper documentation and traceability. Each sample consisted of 2 liters of water, labeled with the respective silica concentration parameter. The samples were stored at 4°C to preserve their integrity until analysis, without the need for additives for conservation, in accordance with the regulations of the Ministry of the Environment of Peru (MINAM). According to MINAM, a concentration of 3.3047 mg/L is considered moderate for each point initially chosen (National & Water, n.d.).


*Figure 1: Geographic map of the study area in Pachacayo, Canchayllo, Jauja, Junín, Peru, indicating the specific locations where the industrial wastewater samples from the non-metallic mining company were collected.*

### 2.3 Coagulant Preparation and Characterization

The *Opuntia floccosa* species, commonly found at altitudes between 3,000 and 4,500 meters above sea level in the Andean region, was chosen as the natural coagulant for this study. The collection of this species involved careful removal of the spines and glochids, which could interfere with the coagulation process. The harvested pads of *Opuntia floccosa* were thoroughly cleaned and washed to remove external impurities such as dust and organic material.The inner tissue of *Opuntia floccosa* was dehydrated in an oven at 60°C for 48 hours to preserve its coagulating properties. After dehydration, the tissue was ground using a mechanical grinder to produce a fine powder with a particle size of less than 0.5 mm, which passed through a No. 45 sieve. This preparation ensured that the coagulant was uniformly distributed in the water samples, maximizing its surface area for effective interaction with silica particles during the treatment process (Pauca Tanco, 2017).

### 2.4 Jar Testing

Jar testing is a laboratory method widely used to determine the optimal dosage of a coagulant and to observe the reactions between the coagulant and other factors present in the water. In this study, the jar test was employed to evaluate the coagulation, sedimentation, and flocculation processes, which are crucial for determining the effectiveness of Opuntia floccosa in silica removal.A total of 1 liter of water was taken from the collected samples, which was then divided into five containers, each containing 200 milliliters. Each container was treated with a specific dosage of the coagulant, denoted as $P_0$ = 0 g/L, $P_1$= 1 g/L, $P_2$ = 2 g/L, $P_3$ = 3 g/L, $P_4$ = 4 g/L, and $P_5$ = 5 g/L. The P0, container, which did not contain any coagulant, served as a control to compare the effectiveness of the treated samples.The laboratory equipment, equipped with paddles, was programmed to rotate at a constant speed of 100 revolutions per minute (rpm) for specific time intervals of 2 and 4 minutes. The controlled agitation simulated the mixing process that would occur in a full-scale treatment plant, allowing the coagulant to interact with the silica particles in the water, causing them to coagulate and settle.

## 3. Results

### 3.1 Silica Concentration (0 minutes)

The initial silica concentration in all collected samples was measured at 3.3047 mg/L, a value classified as moderate according to the Ministry of the Environment of Peru (MINAM). This baseline concentration was consistent across all samples, ensuring the comparability of subsequent treatments. The uniformity of the initial readings was crucial for assessing the effectiveness of Opuntia floccosa as a natural coagulant under varying dosages and coagulation times, see Table 1.

*Table 1: Initial Silica Concentration*

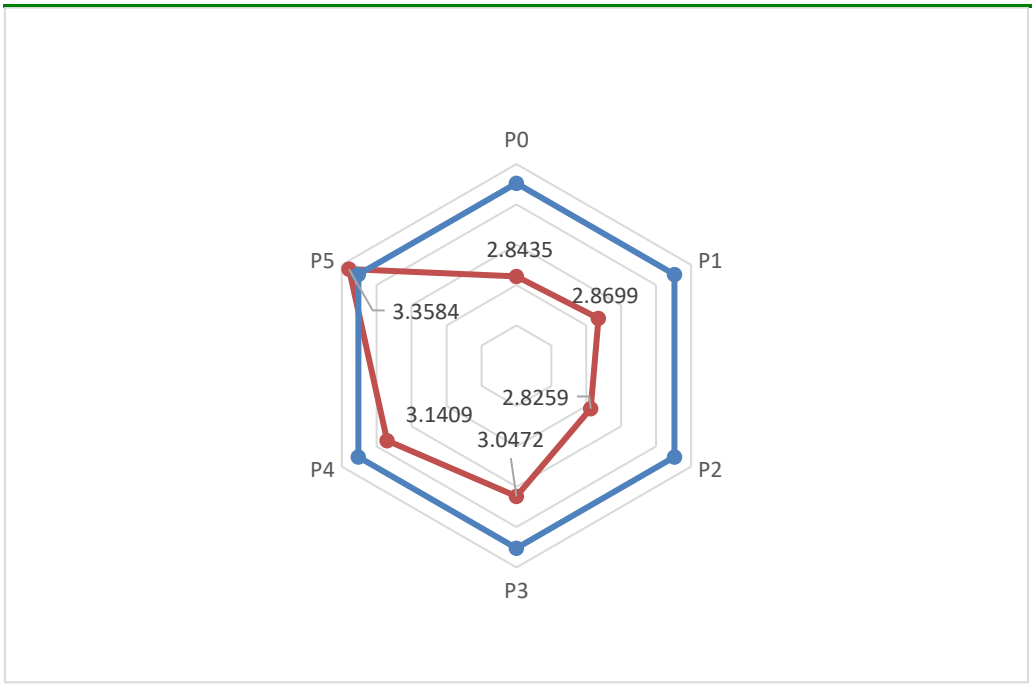
| Time | $P_0$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ |
|---|---|---|---|---|---|---|
| 0 minutes | 3.3047 | 3.3047 | 3.3047 | 3.3047 | 3.3047 | 3.3047 |

### 3.2 Silica Concentration (2 minutes)

The results of the silica concentration in the case of the $P_5$ treatment are presented, a value of 3.35837 mg/L was obtained, which resulted in a lower silica reduction. On the other hand, P2 achieved the greatest silica reduction, with a value of 2.82590 mg/L. See Table 2.

*Table 2: Silica concentration (2 minutes)*

| Time | $P_0$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ |
|---|---|---|---|---|---|---|
| 2 minutes | 2.8435 | 2.8699 | 2.8259 | 3.0472 | 3.1409 | 3.3584 |

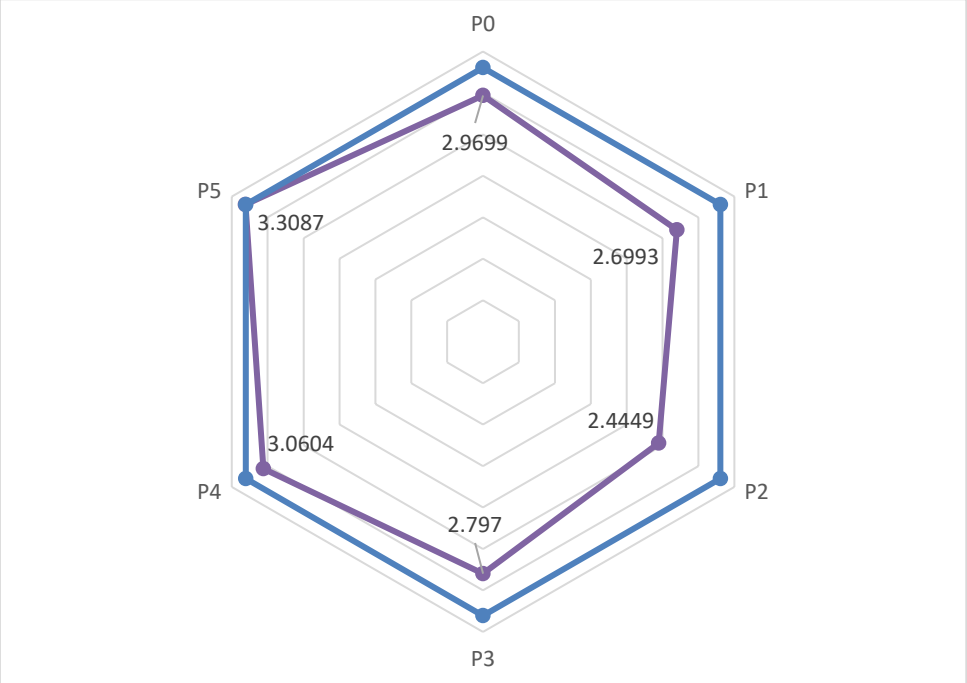



### 3.3 Silica Concentration (4 minutes)

The results of the silica concentration in the case of the $P_5$ treatment obtained a value of 3.3087 mg/L, which resulted in a lower silica reduction. On the other hand, $P_2$ achieved the greatest silica reduction with a value of 2.4449 mg/L. See Table No. 3.

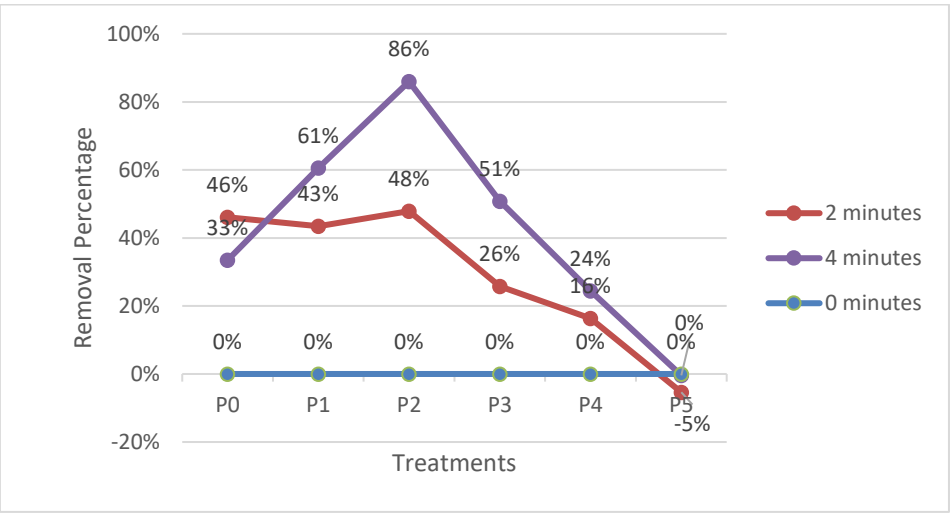
*Table 3. Silica Concentration (4 minutes)*

| Time | $P_0$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ |
|---|---|---|---|---|---|---|
| 4 minutes | 2.9699 | 2.6993 | 2.4449 | 2.797 | 3.0604 | 3.3087 |




### 3.4 Silica removal percentage

The final results show an amount of coagulant with the $P_2$ treatment = 2 g/l. of coagulant over a period of 2 minutes achieving a reduction of 48%. On the other hand, with the same amount of coagulant $P_2$ = 2 g/l. but extending the time to 4 minutes, a reduction of 86% is achieved. These results suggest that, in general, increasing the coagulation time and reducing the amount of coagulant will result in a higher percentage of silica removal.




## 4. Conclusions

This study has demonstrated the high efficacy of the natural coagulant derived from *Opuntia floccosa* in the removal of silica from industrial wastewater, achieving a maximum removal efficiency of 86% with an optimal coagulation time of 4 minutes. The use of this coagulant not only provides an effective alternative to conventional chemical coagulants but also offers significant environmental advantages, given its natural abundance in Andean regions and its reduced ecological impact. By using *Opuntia floccosa*, industries can decrease their reliance on synthetic chemicals that can cause further environmental harm, promoting a more sustainable approach to wastewater treatment. The results of this research align with previous studies on natural coagulants, though the effectiveness of *Opuntia floccosa* at relatively low concentrations in removing silica sets it apart as

a particularly promising solution for addressing industrial effluent contamination. Its potential application extends beyond mining, to other sectors with high water usage, where eco-friendly treatment processes are essential. Future studies should focus on optimizing dosage levels for different types of wastewater and contaminants, as well as conducting field-scale trials to better assess the practical implementation of *Opuntia floccosa* in diverse industrial settings, ultimately contributing to more sustainable water management practices.

**References**

Bobillo, F. M., & Colombo, M. (2023). Typological and experimental approaches in the study of quarry lithic technology: cases from northwestern and central eastern of Argentina. Journal of the Museum of Anthropology, 16(1), 229–244. https://doi.org/10.31048/1852.4826.v16.n1.38771

Coronado-Vázquez, V., & Gómez-Salgado, J. (2019). Teaching ethics in the distribution of resources and the protection of health for equitable and safe care. Educ Med, 20(S2), 163–167. https://doi.org/10.1016/j.edumed.2018.01.002

Delgado, A., Fernandez, A., Chirinos, B., Barboza, G., & Huamaní, E. L. (n.d.). Impact of the Mining Activity on the Water Quality in Peru Applying the Fuzzy Logic with the Grey Clustering Method. In IJACSA) International Journal of Advanced Computer Science and Applications (Vol. 12, Issue 1). www.ijacsa.thesai.org

Jiménez Cisneros, B. E. (2001). Environmental Pollution in Mexico: Causes, Effects and Appropriate Technology (ISBN: 968-18-6042-X). Editorial Limusa, SA de CV.

Macías, J. M. O., & Roselló, M. J. P. (2022). Mapping assessment of social vulnerability to groundwater pollution at the Gallocanta Groundwater Body (Aragón, Spain). Cuadernos Geográficos, 61(1), 311–328. https://doi.org/10.30827/cuadgeo.v61i1.21776

Maroneze, M. M., Zepka, L. Q., Vieira, J. G., Queiroz, M. I., & Jacob-Lopes, E. (2014). A tecnologia de remoção de fósforo: Gerenciamento do elemento em residuos industriais. Revista Ambiente e Agua, 9(3), 445–458. https://doi.org/10.4136/1980-993X

Nacional, A., & Agua, D. (n.d.). !\ANA National Protocol for the Monitoring of the Quality of Surface Water Resources.

Pauca Tanco, A. (2017). Catalogue of the cacti of the department of Arequipa, Peru. Arnaldoa, 24(2), 447–496. https://doi.org/10.22497/arnaldoa.242.24204

Reece, A. S., & Hulse, G. K. (2023). Geospatiotemporal and Causal Inferential Study of European Epidemiological Patterns of Cannabis- and Substance-Related Congenital Orofacial Anomalies. Journal of Xenobiotics, 13(1), 42–74. https://doi.org/10.3390/jox13010006

Torres, Á. C. P. (2023). Illegal mining as a mechanism of violation to environmental rights in Latin America during times of pandemic. Justice and Law Journal, 6(2). https://doi.org/10.32457/rjyd.v6i2.2139