

Combined Natural Coagulant Powder Peels Apricot and Chemical Coagulants MgCL2 for Synthetic Dairy Wastewater Treatment

Raheem Khalaf Azeez¹, Ali Jwied Jaeel¹, and Mohd Badruddin bin Mohd Yusof²

¹ Civil Engineering Department, Wasit University, Iraq

² Civil Engineering Department, UTM University, Malaysia

Corresponding Author Email: std2023203.R.K@uowasit.edu.iq

Received Apr.12, 2025

Revised Jun.28, 2025

Accepted Jun.29, 2025

Online Sept.1, 2025

ABSTRACT

Dairy wastewater is characterized by high concentrations of organic and inorganic pollutants, which pose a threat to environmental and public health if discharged without proper treatment. This study aims to investigate the effectiveness of using natural (apricot seed powder) and chemical (magnesium chloride) coagulants individually and in combination for the treatment of dairy. The study revealed that the application of natural and chemical coagulants in dairy wastewater treatment significantly enhances pollutant removal efficiency. In terms of turbidity, the natural coagulant at a concentration of 45 mg/L achieved a removal efficiency of 61.67%, while the chemical coagulant at the same concentration reached 85%. When combined at a concentration of chemical coagulant and natural coagulant Respectively 15+45 mg/l, the efficacy of removal was enhanced to 95.8%. Similarly, for total dissolved solids (TDS), the natural and chemical coagulants at 45 mg/L exhibited removal efficiencies of 75.91% and 85%, respectively, which improved to 95% when combined. Regarding total suspended solids (TSS), the natural coagulant removed 68%, and the chemical coagulant removed 88% at 45 mg/L, with a combined application yielding a 94% removal rate. For chemical oxygen demand (COD), the removal efficiencies were 68.80% and 83.20% for the natural and chemical coagulants, respectively, whereas their combination at 45+15 mg/L enhanced the removal to 96%. Likewise, biochemical oxygen demand (BOD) removal was 71.05% with the natural coagulant and 86.84% with the chemical coagulant, while their combination resulted in a removal efficiency of 94.7%. These findings demonstrate the substantial improvement in dairy wastewater treatment performance through the synergistic use of natural and chemical coagulants.

Keywords: COD removal, coagulation, dairy wastewater treatment, powder peels apricot, turbidity removal

1 Introduction

The study treated dairy wastewater using magnesium chloride and apricot seed powder, chosen for their availability and cost-effectiveness. Initial COD and BOD₅ levels were very high (1250 and 950 mg/L), posing environmental and health risks if untreated. The combined coagulants achieved up to 96.6% COD and 96% BOD₅ removal, showing eco-friendly treatment potential. Heavy metal contamination in rapidly industrializing areas poses a major threat to aquatic ecosystems and human health [1-4]. In addition to coliforms and various pollutants, both surface and groundwater sources are contaminated with harmful trace metals [5]. Given that many populations rely on groundwater, which often contains high arsenic levels, the health risks are significant [6-8]. Urbanization and industrialization have led to extensive natural resource exploitation worldwide [9]. Organic (carbohydrates, dyes, fertilizers, pesticides, oils, plastics, proteins, etc.) and inorganic (heavy metals) pollutants increasingly contaminate water sources, primarily from industrial, agricultural, and urban wastewater discharges [10]. Sewage effluents contain 99.9% water and 0.1% solids, including fats (10%), carbohydrates (25%), and proteins (65%) [12]. These effluents also introduce pathogens [13]. A conventional drinking water treatment plant includes units for coagulation, flocculation, sedimentation, filtration, and disinfection [14-15]. Because of their affordability and efficiency, common coagulants like Aluminium sulphate

($\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$) are employed extensively [16-17]. However, these chemicals may alter water properties [18-19]. Natural polymer-based coagulants offer an eco-friendly and biodegradable alternative without negatively impacting water quality [20]. Studies highlight the effectiveness of plant-based coagulants: *Ocimum basilicum* with alum achieved 92% decolorization and 87% COD reduction [21], while psyllium husk removed 90% of color and 96% of TSS [21]. Alum and ferric chloride showed COD and heavy metal removal rates of 28% and 86%, respectively [22]. Chickpeas (*Cicer arietinum*) were also effective in palm oil mill effluent treatment, achieving 86% turbidity removal and 87% TSS removal [23-24]. This confirms chickpeas as a sustainable alternative to chemical coagulants. Wastewater treatment is essential for protecting environmental and public health, and it typically involves physical, chemical, and biological processes. Physical methods include screening and sedimentation; chemical methods involve coagulation, precipitation, and disinfection, while biological treatment uses microorganisms to degrade organic pollutants. These approaches are often combined to achieve optimal results depending on the wastewater type. Previous studies Castillo et al. (2023) studied the combined use of *Moringa oleifera* seed extract and alum for the treatment of dairy wastewater. A maximum turbidity removal of 96% and COD removal of 88% were achieved when a dosage of 1 g/L moringa combined with 50 mg/L alum was used. The optimum pH for coagulation was 6.5. The study showed that the synergy between natural and chemical coagulants improved pollutant removal efficiency significantly [25].

research gap Limited research has investigated the combined use of apricot peel powder and magnesium chloride for the treatment of dairy wastewater, despite the existence of numerous studies on chemical or natural coagulants. This study's main goal is to identify the ideal chemical and natural coagulant dosages for treating effluent from the dairy sector. Its specific objective is to assess apricot peel powder as a natural substitute for magnesium chloride as a chemical coagulant. Apricot peel was chosen because it is inexpensive, readily available locally, environmentally benign, and rich in natural substances like tannins and polyphenols that promote efficient coagulation. The effectiveness of mixing natural and artificial coagulants for improved pollution removal is also examined in this study.

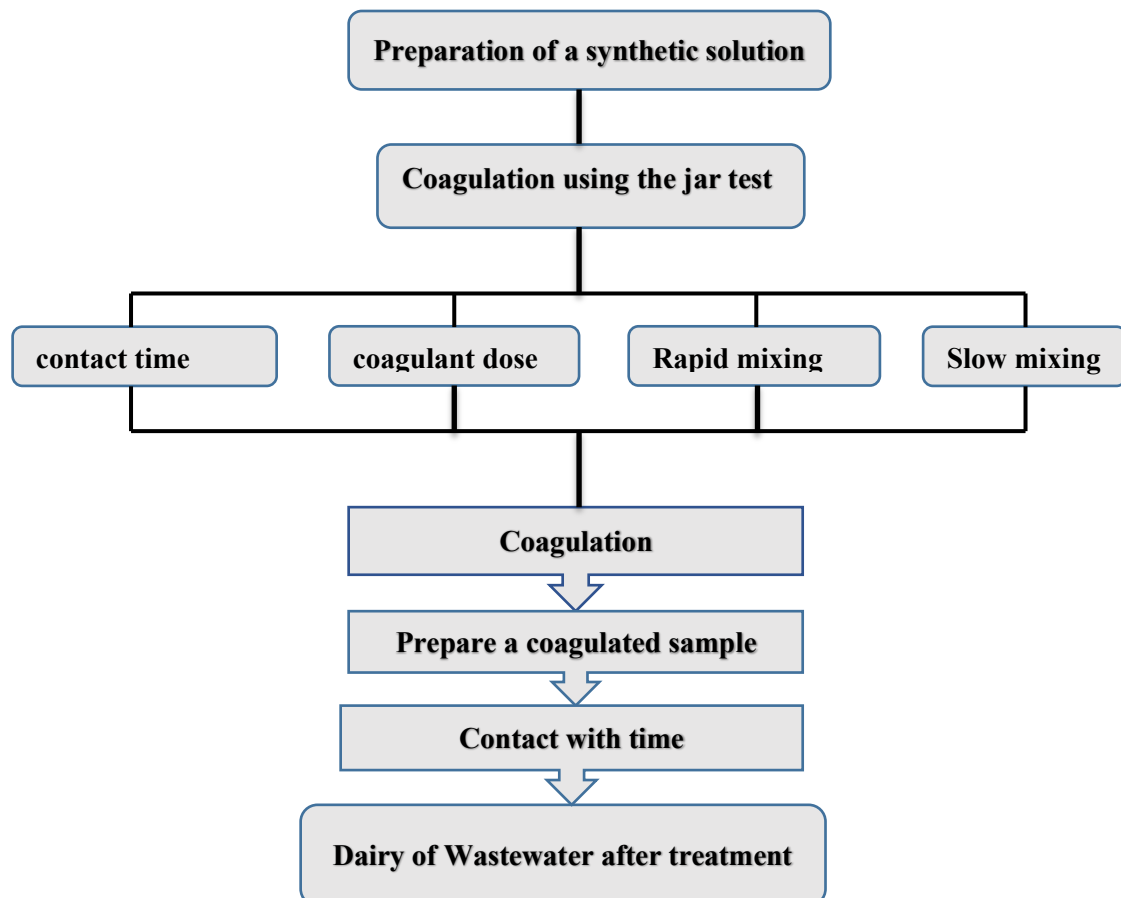


Figure1. Diagram Depicting the Treatment Process.

2 Material and methods

2.1 Synthetic Dairy wastewater

The wastewater of the dairy plant is collected and stored at a temperature of 10°C Silesian, and the characteristics of the wastewater of the dairy plant are presented in Table 1.

In order to replicate the normal makeup of real dairy sector effluents, the wastewater employed in this investigation was artificially generated in the lab in accordance with previously published literature source. According to the referenced source, its physical and chemical characteristics were assessed and confirmed to represent accurate pollutant concentrations.

Table 1. Synthetic Dairy Wastewater.

NO.	Chemical compound	Chemical symbol	Concentration mg/l	References
1	Milk powder	-----	1440	[25]
2	Ammonium chloride	NH ₄ CL	583.3	
3	Magnesium Sulphates	MgSo ₄ .7H ₂ o	50 mg/l	
4	Ferric chloride hexahydrate	Fecl ₃ .6H ₂ O	3 mg/l	
5	Calcium chloride monohydrate	CaCl ₂ .H ₂ O	0.4 mg/l	
6	Aluminum potassium sulphate	KAl (SO ₄) ₂ .12H ₂ o	60 mg/l	
7	Soudium dihydrogen Phosphate	NaH ₂ PO ₄	900mg/l	

Table 2. Characteristics of Dairy Wastewater.

Element	“Concentration*”	“Unit”
“BOD”	950	“mg/L”
“COD”	1250	“mg/L”
“Turbidity”	600	“NTU”
“pH”	(5,6,7,8)	-
“TDS”	1100	“mg/L”
“TSS”	750	“mg/L”

*Average of 3 values

2.2 Preparation of Magnesium Chloride Solution

As per the American Public Health Association (APHA) protocol for improving the coagulation process, magnesium chloride (MgCl₂) stock solutions were made by dissolving 100 grammes of MgCl₂ in one liter of distilled water, as per the APHA (1998) protocol for coagulation process improvement. This produced a stock solution with a concentration of 100 mg/L. Titration techniques were used to create four working concentrations (15, 30, 45, and 60 mg/L) from this stock. These concentrations were determined after conducting preliminary experiments to test the suitability of the substance in the required range, as the initial results showed that these ranges (15-60 mg/L) cover the effects to be measured without causing the deposition of large quantities, as well as for their effectiveness more than others.

2.3 Preparation of natural coagulant solutions (Powder peels Apricot)

Because of its high concentration of bioactive substances such proteins, polyphenols, and tannins, which aid in charge neutralization and bridging to destabilize suspended particles, apricot peel functions as a natural coagulant. It is a viable substitute for chemical coagulants in wastewater treatment because of its many benefits, which include being easily available, affordable, biodegradable, and environmentally benign. For the purpose

of this investigation, the seeds were extracted from Iraqi apricots that were gathered from apricot trees in the area. Following that, the seeds were washed with tap water and dried in an oven at a temperature of fifty degrees Celsius for a period of five hours. The seeds were then removed from the pulp, and just the outer shell was used for the purposes of this process. All of the pulp is left out. A flour mill machine is then used to smash the seeds, and the resulting powder is then filtered through a sieve with a 600-micron opening. To improve the coagulation process, solutions of stocks of this natural coagulant (seed Apricot coagulant) have been created by dissolving one liter of distilled water with one hundred grammes of Seed Powder. This was done in order to enhance the coagulation process. As a consequence of this, a seed coagulation solution with a concentration of one hundred milligrams per liter can be produced from one milliliter of this stock. This solution was filtered using filter paper with a micron size of one in order to guarantee that it was free of any particles that were still present. This was followed by the preparation of 10 different concentrations of coagulant seeds through the use of titration techniques. The concentrations ranged from 15, 30, 45, and 60 mg/l. A Memmert UN110 oven (made in Germany) with a temperature range of +30°C to +300°C and an accuracy of $\pm 1^\circ\text{C}$ was used for the drying process. In compliance with ASTM D2216-19, the samples were dried for 5 hours at 50°C to guarantee consistent weight accomplishment. For even heat distribution ($\pm 2^\circ\text{C}$), the oven has forced air circulation. As in Figure 1 below.



Figure 2. Preparation of Apricot Seed Powder with a Sieve of 600 Microns.

2.4 Experimental Procedure

The four beakers in the jar test equipment used in this investigation have a capacity of each one 1000 milliliters. Comparative examination of various coagulants in water and wastewater treatment studies is made possible by this equipment, which simulates coagulation and flocculation processes under regulated mixing circumstances. The pH level directly affects the solubility of coagulants and the surface charge of particles, making it a crucial factor in the coagulation-flocculation process. pH values of 5, 6, 7, and 8 were examined in this study to see how well they removed contaminants from dairy effluent. According to the results, pH 6 is the ideal environment for optimizing coagulant performance, especially for both chemical and natural coagulants utilized in the treatment process. It consistently offered the maximum removal efficiency across the majority of parameters.

The characteristics of each coagulant that contribute to coagulation, as well as the ideal dosage for each coagulant (magnesium chloride and powder peels apricot), were determined through the sedimentation test and the container. One flask was employed as a control, while the other was placed in cups. The quantities of each coagulant were varied, ranging from 15 to 60 mg/l. The samples were then subjected to rapid mixing at 120 rpm for 2 minutes, followed by 25 minutes of slow mixing at (15) RPM. After it had been completely mixed, the flux was given permission to settle (ASTM, 1995). For a period of 45 minutes. The residual turbidity was determined by withdrawing samples from each beaker at a depth of 4 cm below the surface using a pipette. The removal effectiveness of each coagulant in lowering turbidity, TDS, TSS, BOD, and COD was used to calculate the optimal dosage. The optimal dosage was defined as the one that produced the best removal percentages across all of these metrics. After determining which is the best dose of magnesium chloride, the optimal combination percentage of these two coagulants (MgCL₂ and powder peels apricot) is

determined by combining a fixed $MgCl_2$ dose (optimal dose) with varying natural coagulation ranges from 15 mg/L to 60 mg/L. In order to determine the optimal combining ratio of these two coagulants (Magnesium chloride and powdered peels apricot), the optimal dose was investigated with a range of normal coagulability from 15 mg/L to 60 mg/L. The application's removal of turbidity, TDS, TSS, BOD, and chemical oxygenation was investigated in relation to the optimal mixing dose ratios of chemical and natural coagulation formulations. The processes of fast and slow mixing and addition of chemical and natural coagulants are carried out in the jar test device as shown in Figure No. 2 below.



Figure 3. Jar Testing Apparatus.

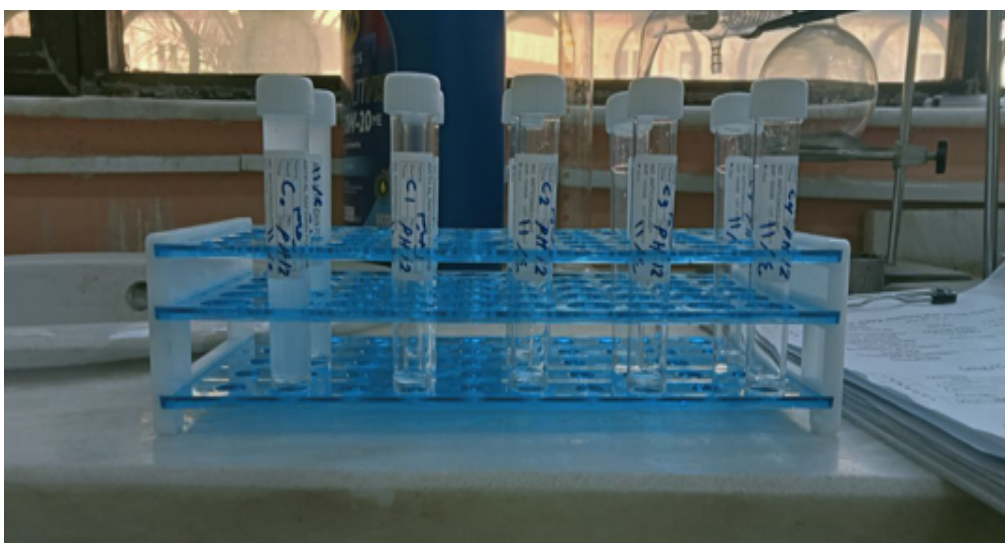


Figure 4. Preparation of Samples for the Required Laboratory Examination.

3 Results and discussion

3.1 Identifying the Optimal Doses of Coagulants for the Removal of Turbidity, Total Dissolved Solids, BOD, and COD

Using a jar tester, a series of experiments were completed in order to ascertain the ideal dose for every coagulant (magnesium chloride and powder peels apricot) in terms of turbidity, total dissolved solids, total soluble solids, chemical oxygen demand (COD), and elimination of COD. It was necessary to employ a range of concentrations for each coagulant, ranging from 15 mg/L to 60 mg/L individually. According to the findings of the study, the most effective doses for removing turbidity with $MgCl_2$ and powder peels were from apricots. The effect of doses and the type of coagulants, whether chemical, natural or combined, is also shown in the detailed diagram in the figures below(4,5,6,7,8).

Table 3. Efficiency Removal of Contaminants Using the Chemical Coagulant MgCl₂

Pollutants	Concentration of chemical coagulant MgCl ₂	Removal ratio
turbidity	45 Mg/L	85%
TDS	45 Mg/L	85%
TSS	45 Mg/L	88%
BOD	45 Mg/L	86.84%
COD	45 Mg/L	83.20%

Table 4. Efficiency Removal of Contaminants Using Natural Coagulant (Powder Peels Apricot).

Pollutants	Concentration of Natural Coagulant (powder peels apricot)	Removal ratio
turbidity	45 Mg/L	61.67%
TDS	45 Mg/L	75.91%
TSS	45 Mg/L	68%
BOD	45 Mg/L	71.05%
COD	45 Mg/L	68.80%

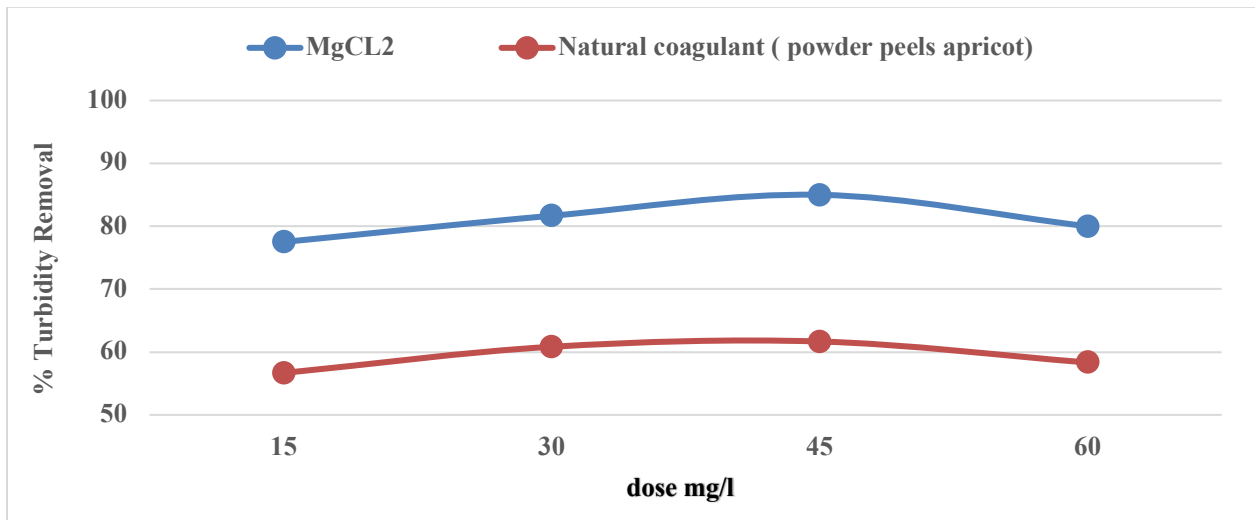


Figure 5. Comparison of Turbidity Removal Efficiency Using MgCl₂ and Natural Coagulant (Apricot Peels Powder) at Different Dosages

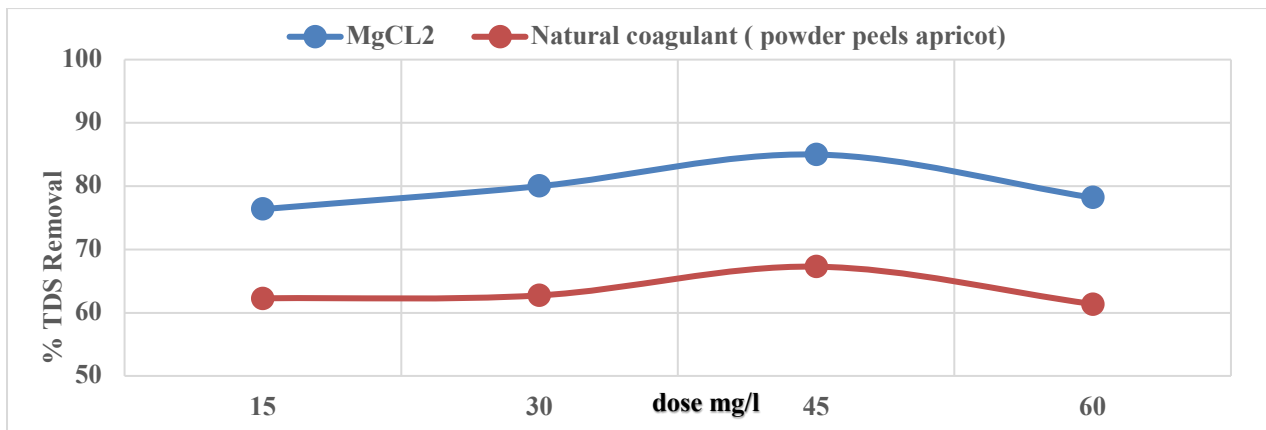


Figure 6. Comparison of TDS Removal Efficiency Using MgCl₂ and Natural Coagulant (Apricot Peels Powder) at Different Dosages.

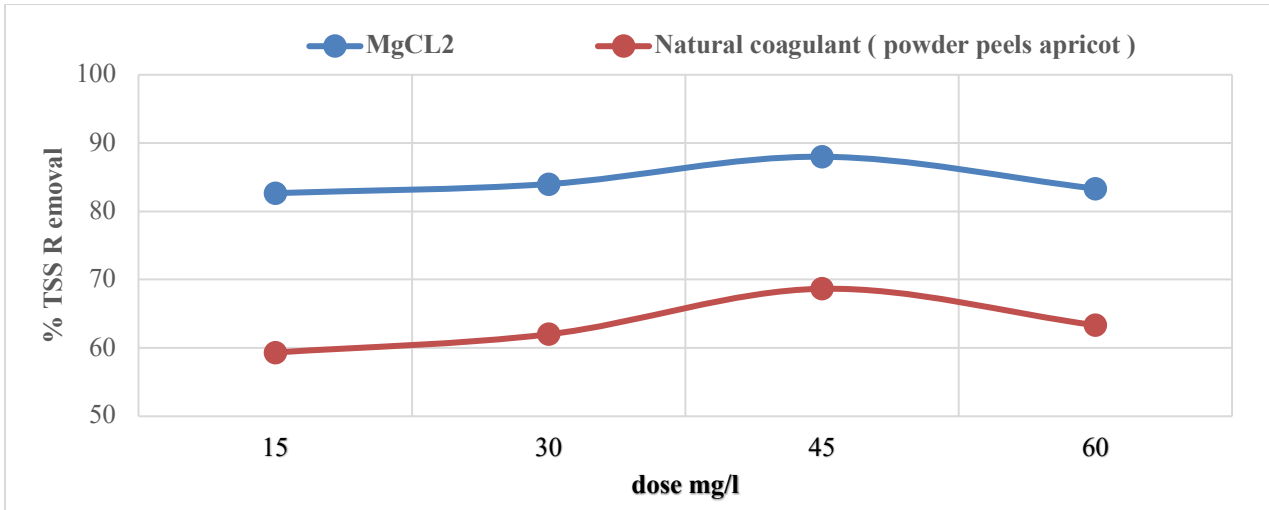


Figure 7. Comparison of TSS Removal Efficiency Using MgCL2 and Natural Coagulant (Apricot Peels Powder) at Different Dosages

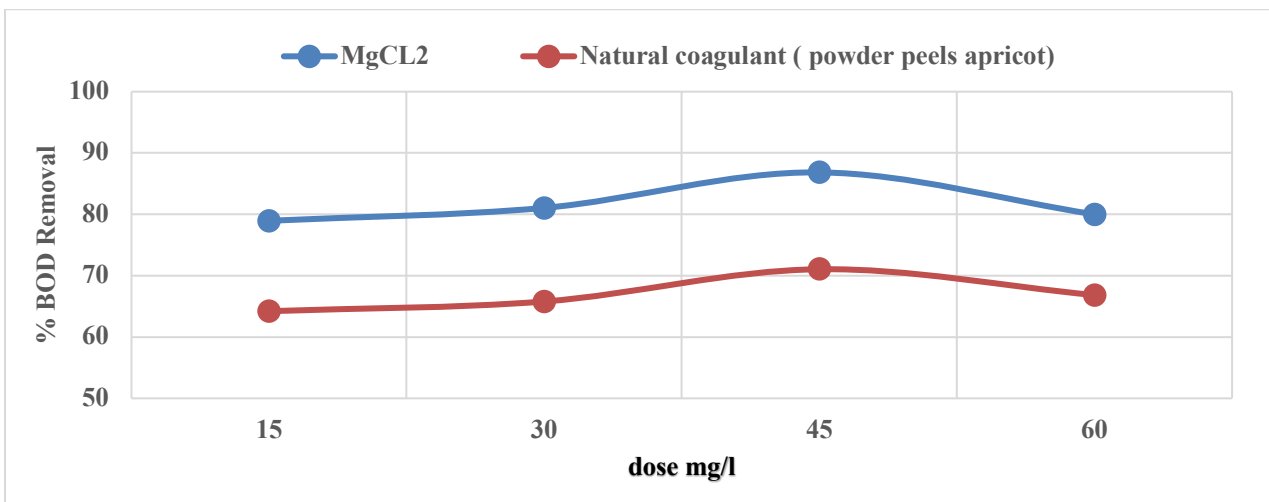


Figure 8. Comparison of BOD Removal Efficiency Using MgCL2 and Natural Coagulant (Apricot Peels Powder) at Different Dosages.

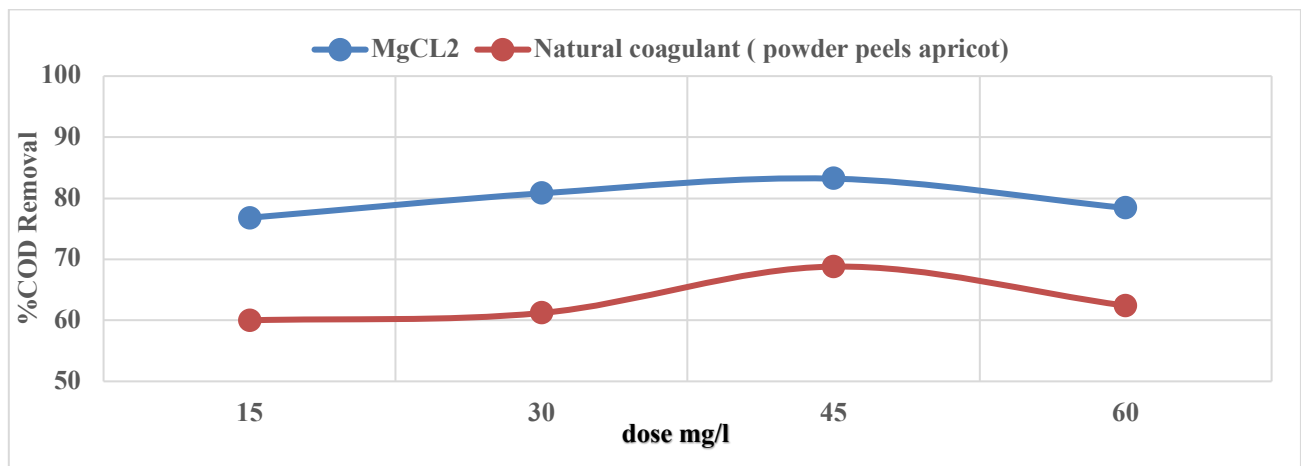


Figure 9. Comparison of COD Removal Efficiency using MgCL2 and Natural Coagulant (Apricot Peels Powder) At Different Dosages.

3.2 Identifying the Optimal Doses of Combined Coagulants, Both Chemical and Natural, for the Removal of Turbidity, Total Dissolved Solids, Total Suspended Solids, COD, and BOD

To determine the ideal dose for a combination of the optimal fixed dose of magnesium chloride, it was 60 mg/l, and various doses of powder peels apricot, ranging from 15 mg/l to 60 mg/l, another set of experiments was carried out with the help of a jar test. The goal of these studies was to determine the optimal dose for the combination. The ideal mixing dose was 60mg/l of magnesium chloride and 45mg/l of apricot seeds. This combination of doses resulted in a turbidity clearance of up to 93%, as depicted in Figure 4. In contrast, a series of experiments were conducted by using a jar test in order to determine the ideal dose for a mixture of the optimal fixed dose of magnesium chloride, which was 15 mg/L, and various doses of apricot seeds, which ranged from 15 mg/L to 60 mg/L. The results of these experiments yielded the optimal dose for the mixture. As can be seen in Figure 5, the ideal mixing dose consisted of 15 mg/L of magnesium chloride and 45 mg/L of apricot seeds. This combination of doses results in a turbidity reduction ratio of up to 95.8%. These findings are consistent with those reported by (Gangwar et al.,2012), who demonstrated that the combination of natural and chemical coagulants significantly improved turbidity removal efficiency in dairy wastewater treatment [26]. The capacity of apricot peel powder to destabilize suspended particles through charge neutralization and inter-particle bridging processes is responsible for an exceptionally high level of turbidity reduction. This is in addition to the significant effect of the formation of Aluminium coagulation decomposition products, which is considered to be the most important reason for the destabilization of suspended solids. This information is illustrated in the detailed diagrams presented in the figures below (9, 10, 11).

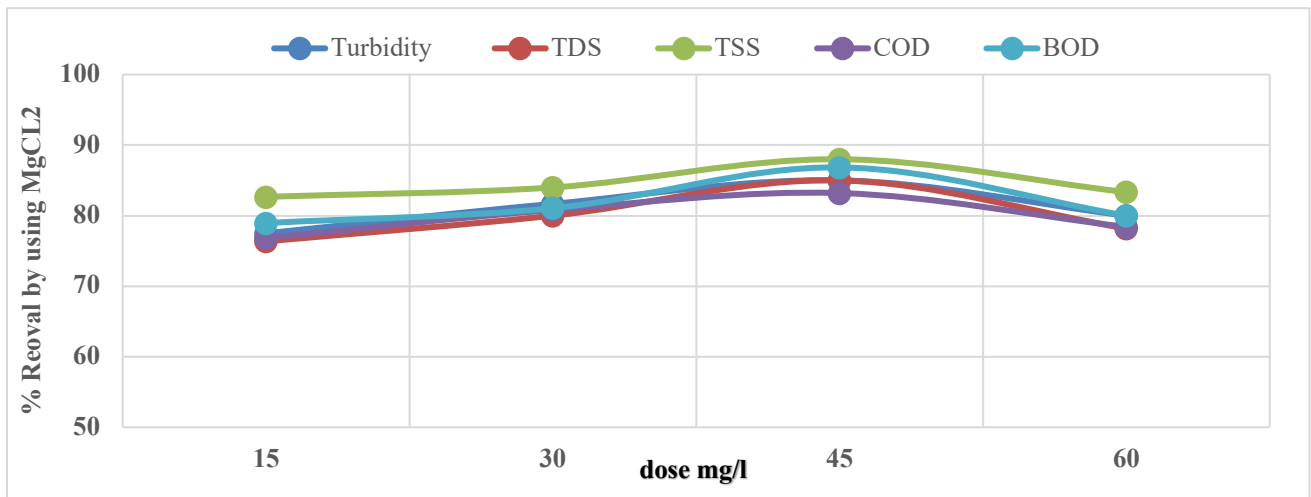


Figure 10. The Effect of Chemical Coagulant (MgCL2) Doses on the Efficiency of Removing Various Contaminants.

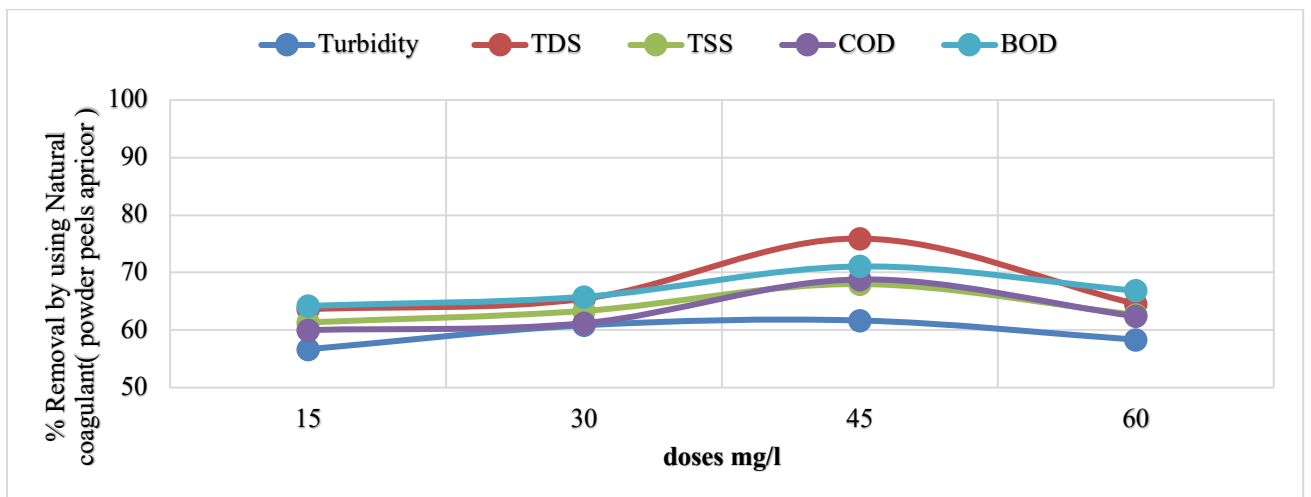


Figure 10. The Effect of Natural Coagulant Doses on the Efficiency of Removing Various Contaminants.

Table 5. Efficiency Removal of Contaminants Using a Combination of Chemical Coagulant MgCl₂ and Natural Coagulant (Powder Peels Apricot)

Pollutants	Concentration of chemical and Natural coagulant (MgCl ₂ + powder peels apricot)	Removal ratio
Turbidity	15+45Mg/L	95.8%
TDS	15+45Mg/L	95%
TSS	15+45Mg/L	94%
BOD	15+45Mg/L	96%
COD	15+45Mg/L	94.7%

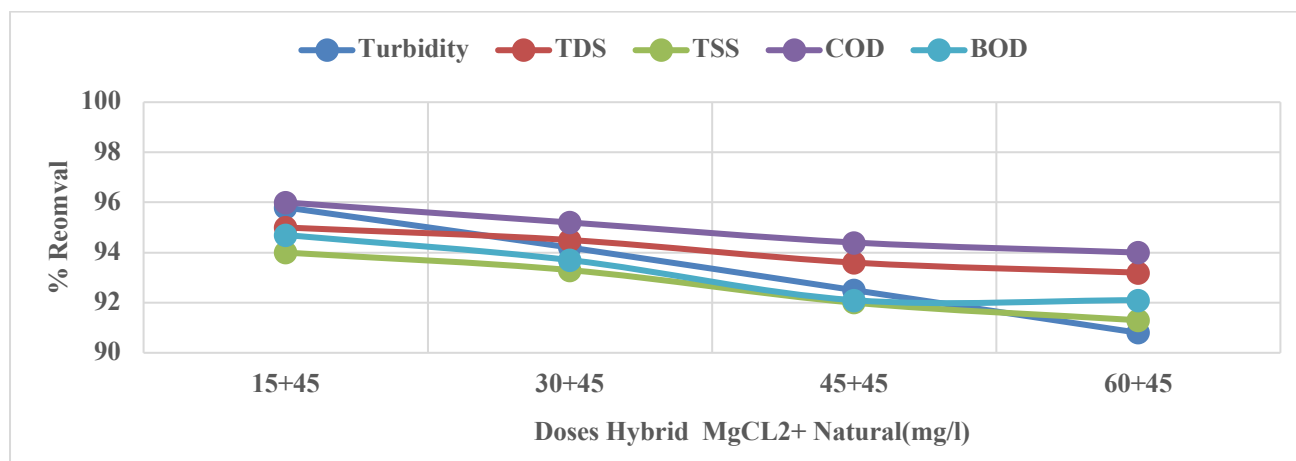
Figure 11. The effect of Different Doses of Hybrid Coagulant (MgCl₂ + Natural coagulant) on The Efficiency of Contaminant Removal.

Table 6. Dairy Wastewater Quality Parameters: A Compliance Study with Iraqi Specifications (IQS) and World Health Organization (WHO) Standards.

Parameters	Unit	Before treatment	After treatment	Iraqi Standards	WQI
Turbidity	UNT	600	22	≤ 5 NTU	≤ 5 NTU
TDS	Mg/L	1100	46	≤ 1000 Mg/L	≤ 1000 Mg/L
TSS	Mg/L	750	24	< 10	< 10
COD	Mg/L	1250	43	< 100 Mg/L	< 125 Mg/L
BOD ₅	Mg/L	950	38	< 40 Mg/L	< 20 – 30 Mg/L

4 Conclusion

The benefits and possible effectiveness of employing powder peel apricot as a natural coagulant for the pretreatment of wastewater from the dairy sector were assessed in this study. The powdered apricot seed showed encouraging characteristics in lowering COD and turbidity. It was mixed with magnesium chloride (MgCl₂), a widely used chemical coagulant, to improve therapeutic efficacy. With a removal effectiveness of 95.8%, the findings showed that the ideal combination dose for turbidity removal (from an initial concentration of 600 NTU) was 60 mg/L, the combined dosage of 45 mg/L powder peels, apricot and 15 mg/L magnesium chloride demonstrated excellent pollutant removal efficiencies in dairy wastewater treatment. Turbidity, TDS, TSS, BOD₅, and COD were effectively reduced by 95.8%, 95%, 94%, 96%, and 94.7%, respectively. These results confirm the synergistic effect of using natural and chemical coagulants, highlighting their potential as an effective and sustainable solution for improving effluent quality.

Study Contributions By showing how well apricot seed powder works as a natural coagulant for treating dairy effluent, both alone and in conjunction with artificial coagulants like MgCl₂, this study advances the field. In order to maximize the removal of pollutants (TSS, TDS, BOD₅, COD, and turbidity), it emphasizes the best doses, mixing conditions, and pH levels. **Limitations** The study may not accurately reflect field differences

because it was carried out using synthetic dairy effluent in a controlled laboratory setting. Furthermore, only one kind of natural coagulant was investigated. **Future Research** should examine alternative locally accessible natural coagulants, evaluate long-term environmental effects, and examine sludge management techniques. It should also look into large-scale experimental applications utilising actual and industrial effluents.

appendix A presents supplementary experimental data and procedural details that support the methodology and enhance the transparency of the study.

Declaration of Competing Interest

Regarding publishing this paper, the authors affirm that there are no conflicts of interest.

Funding Information

No entity supported this research financially.

Author Contributions

The author first presented Dr. Ali Jwied Jameel Al-Shammari with the study problem. Raheem Khalaf Azeez compiled current, pertinent material and arranged it in an understandable and efficient way. Throughout the investigation, Dr. Al-Shammari offered scientific oversight and assistance. Raheem Khalaf Azeez Al-Kaabi was responsible for the study design, data analysis, result interpretation, and final article writing.

Acknowledgments

The project was supported by Wasit University's Faculty of Engineering and Department of Civil Engineering in Wasit, Iraq, for which the authors are grateful. Sincere gratitude is also extended to Dr. Ali Jwied Jaeel Al-Shammari for his guidance on the scholarly composition of this work.

List of notations

Abbreviations	Meaning
<i>COD</i>	“Chemical Oxygen Demand”
<i>BOD</i>	“Biochemical Oxygen Demand”
<i>TDS</i>	“Total Dissolved Solids”
<i>TSS</i>	“Total Suspended Solids”
<i>PH</i>	“Power of Hydrogen”
<i>MgCL2</i>	“Magnesium chloride”
<i>NTU</i>	Nephelometric Turbidity Unit
<i>APHA</i>	“American Public Health Association”
<i>WHO</i>	World Health Organization
<i>WQI</i>	Water Quality Index
<i>IQS</i>	Iraqi Quality Standards

References

- [1] F. Xia *et al.*, “Distribution and source analysis of heavy metal pollutants in sediments of a rapid developing urban river system,” *Chemosphere*, vol. 207, pp. 218–228, 2018, doi: 10.1016/j.chemosphere.2018.05.090.
- [2] K. H. Hama Aziz, F. S. Mustafa, K. M. Omer, S. Hama, R. F. Hamarawf, and K. O. Rahman, “Heavy metal pollution in the aquatic environment: efficient and low-cost removal approaches to eliminate their toxicity: a review,” *RSC Adv.*, vol. 13, no. 26, pp. 17595–17610, 2023, doi: 10.1039/d3ra00723e.
- [3] N. Timothy and E. Tagui Williams, “Environmental Pollution by Heavy Metal: An Overview,” *Int. J. Environ. Chem.*, vol. 3, no. 2, p. 72, 2019, doi: 10.11648/j.ijec.20190302.14.
- [4] R. A. A. Meena, P. Sathishkumar, F. Ameen, A. R. M. Yusoff, and F. L. Gu, “Heavy metal pollution in immobile and mobile components of lentic ecosystems—a review,” *Environ. Sci. Pollut. Res.*, vol. 25, no. 5, pp. 4134–4148, 2018, doi: 10.1007/s11356-017-0966-2.
- [5] S. Kurwadkar, S. R. Kanel, and A. Nakarmi, “Groundwater pollution: Occurrence, detection, and remediation of organic and inorganic pollutants,” *Water Environ. Res.*, vol. 92, no. 10, pp. 1659–1668, 2020, doi: 10.1002/wer.1415.
- [6] M. K. Hasan, A. Shahriar, and K. U. Jim, “Water pollution in Bangladesh and its impact on public

- health,” *Heliyon*, vol. 5, no. 8, p. e02145, 2019, doi: 10.1016/j.heliyon.2019.e02145.
- [7] J.C. Espíndola, N. Scaccia, I.B. Segundo, D.d.S. Diniz, J.U. Diniz, and J.C. Mierzwa, “Evaluation of the Pathway of Contaminants in the Environment: A Case Study of Different Aquatic Environmental Compartments,” *Sustainability*, vol. 16, no. 10, p. 3927, 2024. doi: 10.3390/su16103927.
- [8] S. Madhav *et al.*, “Water Pollutants: Sources and Impact on the Environment and Human Health,” no. March 2021, pp. 43–62, 2020, doi: 10.1007/978-981-15-0671-0_4.
- [9] B. Sarker, K. N. Keya, F. I. Mahir, K. M. Nahiun, S. Shahida, and R. A. Khan, “Surface and Ground Water Pollution: Causes and Effects of Urbanization and Industrialization in South Asia,” *Guigoz. Sci. Rev.*, no. 73, pp. 32–41, 2021, doi: 10.32861/sr.73.32.41.
- [10] S. K. Koli and A. Hussain, *Status of Electronic Waste Management in India*, no. August. 2018. doi: 10.4018/978-1-5225-5754-8.ch014.
- [11] A. Owonka, E. F. Fubara, and O. B. Justice, “Wastewater Quality- It’s Impact on the Environment and Human Physiology: A Review,” *Int. J. Adv. Res. Innov.*, vol. 9, no. 4, pp. 43–58, 2021, doi: 10.51976/ijari.942107.
- [12] Y. Sharma and R. Jaiswal, “Physicochemical Characteristics Of A Hypertrophic Fresh Water Pond Of District Mirzapur,” *Biochem. Cell. Arch.*, vol. 11, no. 1, pp. 255–259, 2011.
- [13] R. R. Karri, G. Ravindran, and M. H. Dhegihan, “Wastewater—Sources, Toxicity, and Their Consequences to Human Health,” in *Wastewater Treatment: Advanced Processes and Technologies*, 1st ed., no. October, 2021. doi: 10.1016/B978-0-12-824463-0.00001-X.
- [14] H. R. Shamsollahi *et al.*, “Evaluation of the physical and chemical characteristics of water on the removal efficiency of rotavirus in drinking water treatment plants and change in induced health risk,” *Process Saf. Environ. Prot.*, vol. 130, pp. 6–13, 2019, doi: 10.1016/j.psep.2019.07.014.
- [15] K. O. Iwuzor, “Prospects and Challenges of Using Coagulation-Flocculation Method in the Treatment of Effluents,” *Adv. J. Chem. Sect. A*, vol. 2, no. 2, pp. 105–127, 2019, doi:10.29088/SAMI/AJCA.2019.2.105127.
- [16] H. Tahraoui *et al.*, “Evaluating the Effectiveness of Coagulation–Flocculation Treatment Using Aluminum Sulfate on a Polluted Surface Water Source: A Year-Long Study,” *Water (Switzerland)*, vol. 16, no. 3, 2024, doi: 10.3390/w16030400.
- [17] C. C. Castro-Jiménez, J. C. Saldarriaga-Molina, and E. F. García, “Physical-chemical characterisation of an alum-based water treatment sludge in different raw water turbidity scenarios,” *Heliyon*, vol. 10, no. 17, 2024, doi: 10.1016/j.heliyon.2024.e37579.
- [18] N. D. Tzoupanos and a I. Zouboulis, “Coagulation-Flocculation Processes in Water / Wastewater Treatment : the Application of New Generation of Chemical Reagents,” 6th IASME/WSEAS Int. Conf. HEAT Transf. Therm. Eng. Environ., no. May, pp. 309–317, 2008.
- [19] S. O. Akinawo, P. O. Ayadi, and M. T. Oluwalope, “Chemical coagulation and biological techniques for wastewater treatment,” *Ovidius Univ. Ann. Chem.*, vol. 34, no. 1, pp. 14–21, 2023, doi: 10.2478/auoc-2023-0003.
- [20] A. Nath, A. Mishra, and P. P. Pande, “A review natural polymeric coagulants in wastewater treatment,” *Mater. Today Proc.*, vol. 46, pp. 6113–6117, 2019, doi: 10.1016/j.matpr.2020.03.551.
- [21] C. Y. Yin, “Emerging usage of plant-based coagulants for water and wastewater treatment,” *Process Biochem.*, vol. 45, no. 9, pp. 1437–1444, 2010, doi: 10.1016/j.procbio.2010.05.030.
- [22] B. Tawakkoly, A. Alizadehdakhel, and F. Dorosti, “Evaluation of COD and turbidity removal from compost leachate wastewater using *Salvia hispanica* as a natural coagulant,” *Ind. Crops Prod.*, vol. 137, no. March, pp. 323–331, 2019, doi: 10.1016/j.indcrop.2019.05.038.
- [23] A. M. Rajalakshmi, T. Silambarasan, and R. Dhandapani, “Small scale photo bioreactor treatment of tannery wastewater, heavy metal biosorption and CO₂ sequestration using microalga *Chlorella sp.*: a biodegradation approach,” *Appl. Water Sci.*, vol. 11, no. 7, pp. 1–12, 2021, doi: 10.1007/s13201-021-01438-w.
- [24] B. L. Choong Lek *et al.*, “Treatment of palm oil mill effluent (POME) using chickpea (*Cicer arietinum*) as a natural coagulant and flocculant: Evaluation, process optimization and characterization of chickpea powder,” *J. Environ. Chem. Eng.*, vol. 6, no. 5, pp. 6243–6255, 2018, doi: 10.1016/j.jece.2018.09.038.
- [25] G. L. Muniz, M. D. S. Pereira, and A. C. Borges, “Dairywastewater treatment with organic coagulants: A comparison of factorial designs,” *Water (Switzerland)*, vol. 13, no. 16, pp. 1–18, 2021, doi:10.3390/w13162240.