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Optimization of Coagulation-Flocculation Process for Wastewater Treatment using Selected Coagulants

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ABSTRACT

Plant-based coagulants represent a new paradigm in wastewater treatment, advancing the transition to a green economy and promoting cleaner production. This research focuses on the coagulation-flocculation process for the treatment of wastewater using indigenous and imported alum combined with the bark of the Brideliaferrugineae (BF) tree as a natural coagulant. Two hundred grams (200 g) of B.F (Iran-Odan) bark was soaked in 2-litres of distilled water for three days, 1:10. The qualitative and quantitative phytochemical parameters of the bark extracts - Alkanoid, Sapon, Tannin, Phloba tannin, Anthraquinone, flavonoid, steroid and Terpenoid, were determined in percentage using Thin-layer chromatography (TLC), High-performance liquid chromatography (HPLC) and UV-Vis spectrophotometry approach. The optimal ratio of BF respectively mixed with imported and indigenous alums. The physicochemical properties of normal and treated wastewater which include pH, E_C, Turbidity, Phosphate, Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD), were also determined. The effectiveness of each dosage of Alum and BF was determined through laboratory analysis. The optimal mixture that produced desirable results as compared with the effluent standard of the Food and Agriculture Organisation (FAO) was determined. The effectiveness of each dosage of Indigeneous Alum - BF mix ranged from 16.56-24.56%. The corresponding value for the Imported Alum - BF mix ranged from 16.41-26.11%. The optimal mix ratio of the coagulation-flocculation process was 50:50 of Alum and BF mix. Both mix effectively treated industrial and domestic wastewater and should be given more attention.

INTRODUCTION

Water is essential to life and is at the center of any sustainable development initiative or policy with household usage for drinking and sanitation purposes very important (Ezekiel and Dominic 2015; Kılıç 2020). It is an important resource for various industrial sectors for the production of goods and services, such as food, energy, transportation, and manufactured products (Long 2020). However, as a result of various problems in the use of water, many other problems spring up in the allocation of water resources (Long 2020; Meng 2023; Safarpour and Spearing 2024). Wastewater is generated immensely from domestic wastes, industrial effluent discharge, and surface runoff that have been contaminated by debris, grit, nutrients, and various chemicals. Treatment and disposal of wastewater effectively is essential for maintaining water quality, and protection as well as sustaining public health (Pratap et al., 2023). Treatment of wastewater is considered an extremely important aspect of environmental management that prioritizes mitigating the adverse effects of urbanization and industrialization on water bodies (Etsuyankpa 2024). Numerous ways are employed in the treatment of wastewater, which includes sedimentation, chlorination, filtration, coagulation, flocculation, and so on. The use of the coagulation/flocculation process is highly versatile in the removal of colloidal or suspended particles from the wastewater generated. The use of the Coagulation-flocculation method is widely accepted because of its efficiency and ease of operation (Imen et al., 2013). Coagulation is an essential chemical-driven process in water and wastewater treatment as evidenced in the widespread use of such technology in food/beverage production, remediation of mine tailings, petroleum refining, and secondary treatment of drinking water (ChemREADY 2025). In rural communities and developing countries, coagulant-flocculant systems are used as an efficient Point-of-Use (POU) treatment to improve water quality for human and animal consumption because suspended materials and contaminants are efficiently removed. Some particles would resist settling for days or months due to small particle size and electrical charges between them. Flocculation and Coagulation thus remove and neutralize the charge density of particles with coagulation and then facilitate particle bounding through flocculation so that the larger aggregated particles easily separate from the water and settle to the bottom (ChemREADY 2025). The efficiency of suspended solid (colloid) separation from water has been achieved by the application of chemical coagulants such as alum, ferric chloride, and polyelectrolyte. This process highlights a water treatment mechanism that stimulates the aggregation of suspended particles to settleable flocs by the destabilization of their charged colloids thus, neutralizing the forces that keep them apart. The factors that influence coagulation-flocculation are among others, temperature, pH, effluent quality, dosage, and coagulant type (Nnaji et al., 2022; Hichem et al., 2024). Some wastewater discharged into the environment after being subjected to treatment through the coagulation/flocculation process using inorganic coagulants still poses a greater threat to the ecosystem. While coagulation-flocculation is a worthy means of wastewater treatment, it has never been a standalone solution because of the need to be carefully considered in conjunction with other treatment methods to ensure effective and environmentally sound wastewater management (Iwuozor 2019; Anyaene et al., 2024; Hichem et al., 2024). Iwuozor (2019) reports that using Alum alone which is the most used coagulant in wastewater treatment usually results in a reduction of SO42- compounds in the sludge to H2S in the anaerobic sludge digestion process. This may lead to serious corrosion problems in pipes/ equipment as well as an increase in the total solids (sodium and sulfates) contents of the effluents which will necessitate neutralization after the coagulation process and ultimately higher chemical costs. Some researchers have worked on wastewater treatment using the coagulation-flocculation process in Nigeria including Igwegbe et al., (2021) using Green Coagulant from Garcinia kola Seeds alone to treat aquacultural wastewater in Agu-Awka, Nigeria; Amuda et al., (2006) uses Fe2(SO4)3·3H2O as coagulant to treat wastewater from a beverage industry in Ibadan Nigeria among others. Their finding proposes further treatment processes. Therefore, there is great interest in improving inorganic coagulants by employing polymeric organic and natural coagulants for the treatment of wastewater. This study evaluates the performance of the Indigenous alum, imported alum, and the selected natural coagulant - BF bark extract for the treatment of wastewater, determining the optimum dosage of each and comparing the efficacy of the inorganic coagulants (Indigenous and imported alum) and the selected organic (natural) coagulant in the wastewater treatment and make appropriate recommendations on the suitability of the natural coagulant in coagulation-flocculation treatment process.

MATERIALS AND METHODS

Materials

Inorganic coagulants (indigenous and imported alum) and natural coagulant- Iran-Odan, Brideliaferrugineae (BF) bark extracts were sourced in Ogbomoso town.

Collection of Wastewater Samples and Analysis

Domestic wastewater was collected from Living-Soul Garden Continental Hotel and industrial wastewater was collected from Tuyil Pharmaceutical Industry Oko-Erin, Ilorin. The wastewaters were collected from the waste pipe and the septic tank. Samples were collected in clean, sterilized 2 L containers to prevent contamination and maintain sample integrity by specification (QH 2024). Each sample was labeled with the date, time, and exact location of collection, ensuring precise documentation for subsequent analysis. Mechanical sieving was done to remove solid materials. The wastewater analysis was done at FEMTOP laboratory, Ologuneru, Ibadan.

Preparation of coagulant

The bark of the BF (Iran-Odan) tree was soaked in water for three days (200g of bark extracts to 2 liters of distilled water, at a ratio of 1:10). After the expiration of the days, the juice extracts were then collected and preserved for use. The procedure described by Afolabi and Omotade (2014) was used; 0.5 g of finely grounded sample was weighed into a 50 ml Erlenmeyer (conical) flask. 20 ml of chloroform and methanol at a ratio of 2:1 was added: the mixture was shaken thoroughly and allowed to stand for 15 minutes at room temperature.

Experimental Procedures for Treating the Wastewater Samples

The Coagulation/flocculation processes involves using an inorganic coagulant (alum) prepared by dissolving its granules in distilled water (1g to 10 ml) and the soaked BF bark extract as a natural coagulant, a mixture of the alum and natural BF bark extract concentration dose at proportion of 100% to 0% v/v and then at intervals of 10% reduction and 10% increase in proportions of alum to BF bark extract respectively. The control sample was coagulated with $Al2(SO4)$ alone. A 100 % proportionate dosage (100 ml) of inorganic coagulant (Alum $Al2(SO4)$) was added to 250 ml of domestic wastewater to prepare the test control sample. The proportioning percentage of natural coagulants to inorganic coagulants was observed. The assays were conducted in the jar test apparatus (micro-controlled model Milan-JT 203/6) with 250.0 ml of wastewater quickly agitated for 30 seconds (120 rpm), followed by 15 mins slow agitation (20 RPM) (De Souza et al., 2014). The inorganic coagulants were added before the agitation, then natural coagulants after the quick agitation. Uni-variate optimization was performed for pH, coagulant, and mucilage dosages. After 60 minutes of stabilization, the supernatant was then collected for analysis. The same process was repeated for industrial wastewater.

Analysis of the Natural Coagulant

Phytochemical analysis was done on the juice extract from BF using Standard methods involving both qualitative and quantitative approaches. Qualitative analysis identifies the presence of different phytochemical compounds, while quantitative analysis determines their specific concentrations. Thin-layer chromatography (TLC) was used for qualitative screening of the phytochemicals to identify different compounds, and High-performance liquid chromatography (HPLC) and UV-Vis spectrophotometry were used for separating and quantifying individual phytochemicals concentrations in the juice. The procedure outlined by Sagar (2023) was adopted for the TLC. HPLC was done using methods outlined by Sagar (2024) and UV-Vis spectrophotometry as outlined by Cosimo and Haller (2025) and analyzed using GBC Cintra 3030 UV-Vis spectrophotometer model.

RESULTS AND DISCUSSION

Properties of Brideliaferruginea (BF) and Their Efficacy

The properties of Bridelia Ferruginea (BF) Table 1, highlight its potential as a natural coagulant in the coagulation-flocculation process. The table shows the presence of bioactive compounds that play crucial roles in the coagulant efficacy of plant-based substances. The alkaloid concentration in BF bark extract was 0.97%. Alkaloids are known for their antimicrobial and biological activities, which could aid in the treatment of wastewater by inhibiting the growth of harmful microorganisms, thereby enhancing the purification process. Similarly, alkaloids have been identified as key contributors in various studies focusing on the use of natural coagulants in water treatment (Yin et al., 2020). Saponin content was 4.00 % and enhanced the BF juice treatment potential. Saponins act as biosurfactants that enhance the solubilization of pollutants and facilitate their removal from wastewater. Research by Singh et al., (2019) on the use of plant-based coagulants observed lower concentrations of saponins in other plants, such as Moringa oleifera, which also exhibited coagulant properties but at a lower efficiency than BF bark extract due to the lower saponin content. Tannin and phlobatannin concentrations are 1.71 % and 2.94 %, respectively. Both compounds are polyphenolic and have strong binding properties, making them effective in trapping contaminants in wastewater. Their presence in BF bark extract suggests that the plant can be effective in removing organic and inorganic pollutants. Tannins, in particular, have been extensively studied for their coagulant properties in natural water treatment systems. Studies such as that of Ahmed et al., (2021) have shown similar tannin concentrations in other plant-based coagulants, demonstrating comparable results in coagulation efficiency when applied to industrial wastewater treatment.

Table 1: Properties of Natural Coagulant (Brideliaferruginea)

Parameter	Concentration (%)
Alkaloid	0.97
Saponin	4.00
Tannin	1.71
Phloba-tannin	2.94
Anthraquinone	2.67
Flavonoid	1.27
Steroid	4.84
Terpenoid	2.42

Anthraquinone and flavonoid concentrations are 2.67 % and 1.27 %, respectively. These compounds are known for their antioxidant properties and contribute to the stabilization of flocculated particles in the coagulation process. Anthraquinones, in particular, can act as coagulant aids by promoting the solidification of suspended solids, while flavonoids enhance the flocculation of fine particles. The presence of both compounds in BF bark extract gives it an edge over other natural coagulants, as reported in the study by Kumar et al., (2020), where the absence of flavonoids in other coagulants led to reduced performance in flocculation. The concentrations of steroids and terpenoids in BF bark extract are

4.84 % and 2.42 %, respectively. Plant steroids help it withstand unfavorable conditions like temperature extreme, salinity among others (Feki 2023). This is capable of bringing the treatment process under control. Terpenoids control microbial growth and potentially degrade pollutants in wastewater, contributing to improved water quality and, a more sustainable and environmentally responsible wastewater management approach for remediating water (Alonso-Dasques et al., 2024).

3.2 Properties of the Sourced Wastewater Before Treatment

The physicochemical properties of the wastewater are depicted in Table 2, They reveal distinct differences in parameters such as pH, conductivity, chloride levels, chromaticity, turbidity, and various chemical concentrations in wastewater from the two sources. These values are essential for understanding the behavior of coagulants and the efficacy of the coagulation-flocculation process in wastewater treatment. The pH values for the industry samples show strong acidity, with an average of 3.695. This low pH suggests the presence of acidic effluents, possibly from chemical or manufacturing processes. In contrast, the hotel samples have an average pH of 6.5, which is closer to neutral and indicative of less industrial contamination. pH is a significant factor in the coagulation-flocculation process, as it influences the performance of coagulants. Research by Tang et al., (2019) highlights the importance of pH optimization, noting that coagulation efficiency tends to increase in near-neutral conditions.

Therefore, the relatively neutral pH of hotel wastewater may improve the performance of coagulants like BF bark extract compared to the more acidic industrial wastewater. Electrical conductivity is another critical parameter, with the industrial wastewater showing an average EC of 782.5 µS/cm and the hotel wastewater exhibiting slightly lower conductivity at 760.5 µS/cm. Higher electrical conductivity in wastewater is often associated with the presence of dissolved salts, which affect the overall ionic strength of the water. These values indicate that both wastewater sources have relatively high ion concentrations, which could facilitate the coagulation process by promoting particle aggregation. Studies by Kuo et al., (2020) have similarly shown that elevated EC can enhance the destabilization of suspended particles, aiding in coagulation. Furthermore, turbidity levels follow a similar pattern, with the industrial samples showing an average turbidity of 42.37 NTU, compared to 26.735 NTU in hotel wastewater. Turbidity is a direct measure of the concentration of suspended solids in the water, and higher values often indicate the need for more rigorous treatment. Natural coagulants such as BF have been shown to reduce turbidity effectively, as demonstrated by Abebe et al., (2022), making them suitable for industrial wastewater treatment where turbidity is particularly high. The chemical parameters, such as total alkalinity, sulfate, phosphate, and nitrate concentrations, also vary between the two sources. The industrial wastewater shows higher average values for total alkalinity at 266.925 mg/L and phosphate at 121.435 ppm, compared to the hostel wastewater, which has lower averages of 194.895 mg/L for alkalinity and 107.89 ppm for phosphate. Research by Ibrahim et al., (2020) suggests that natural coagulants can remove phosphate effectively depending on the initial concentration and coagulant dosage.

Properties of the Sourced Wastewater after Treatment

After the treatment of the wastewater with the varying proportion of alum to BF, the results were shown in Tables 3a and 3b indicating the effects of these treatments on the wastewater. The alkalinity shows a declining trend as BF concentration increases, with the highest industrial wastewater at 266.925 mg/L for the 100 % alum-treated sample and 205.371 mg/L for the 50:50 mix. Hotel wastewater follows a similar pattern, with a notable drop from 239.764 mg/L at the 70:30 mix to 191.894 mg/L at 30:70. These findings are consistent with the hypothesis that BF can act as a pH stabilizer, reducing the total alkalinity of wastewater and making it less prone to significant fluctuations. Zhang *et al.,* (2021), who reported that low total alkalinity enhances the coagulation efficiency of natural coagulants, contributing to better floc formation and removal of contaminants, have discussed the importance of maintaining proper alkalinity for optimal coagulation.

Table 2: Physico-chemical Properties of Industrial and Domestic Wastewater

Parameters	Industry			Hotel		
	Sample A	Sample B	Average	Sample A	Sample B	Average
Ph	3.69	3.7	3.695	6.49	6.51	6.5
E_C (us/cm)	783	782	782.5	762	759	760.5
chloride (mg/L)	79.96	84.14	82.05	59.98	64.14	62.06
Chromacity	503	502	502.5	377	375	376
Turbidity (NTU)	42.39	42.35	42.37	26.78	26.69	26.735
Total Alkalinity (mg/L)	267.15	266.7	266.925	195.04	194.75	194.895
Sulphate (mg/L)	198.21	194.49	196.35	198.01	197.03	197.52
Phosphate (ppm)	120.77	122.1	121.435	107	108.78	107.89
Nitrate (mg/L)	8.78	8.81	8.795	5.53	5.58	5.555
COD (ppm)	2351.03	2346.35	2348.69	1762.1	1752.75	1757.425
BOD (ppm)	335.86	335.19	335.525	251.73	250.39	251.06

The chemical parameters: sulfate, phosphate, nitrate, COD, and BOD further illustrate the efficiency of the coagulant mixture. Sulfate levels remain relatively constant across the different mixes, with industrial samples showing a slight decrease with increasing BF concentration. Similarly, phosphate levels are slightly lower in the hotel wastewater treated with more BF. This reduction is critical, as high phosphate levels can lead to eutrophication in receiving water bodies. According to research by Tang et al., (2019), natural coagulants, particularly plant-based ones, show a notable capacity to bind phosphate ions, resulting in effective removal. Nitrate concentration in both types of wastewater exhibits minimal variation, but the trend suggests that BF may contribute to a slight decrease in nitrate levels. This is especially important in industrial wastewater, where nitrates are generally higher due to the presence of nitrogen-based compounds. The ability of natural coagulants to remove nitrates has been documented in various studies, including Kuo et al., (2020), who emphasized the role of plant extracts in nitrate reduction through adsorption mechanisms.

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are critical indicators of the organic load in wastewater. Both parameters are significantly higher in industrial wastewater compared to hotel wastewater. The results indicate that the 90:10 alum-to-BFmix produces the most considerable reduction in COD, dropping from 2348.69 ppm in the 100 % alum-treated industrial sample to 1825.438 ppm in the 70:30 mix. Similarly, BOD levels decrease from 335.525 ppm to 293.891 ppm in the 50:50 mix. For hotel wastewater, COD and BOD values are lower overall, but the trends are consistent with industrial wastewater, showing significant reductions as BF concentration increases. This aligns with findings from a study by Adeyemi et al., (2021), which reported that natural coagulants, particularly those

Table 3a: Physico-Chemical Properties of Treated Wastewater using Indigenous Alum-Brideliaferruginea Mix.

Sample 1: Indigenous Alum (%)	Sample 1: Iran-Odan (%)	pH (Ind)	pH (Hos)	E_C (us/cm)(Ind)	E_C (us/cm) (Hos)	Chloride (mg/L) (Ind)	Chloride (mg/L) (Hos)	Turbidity (NTU) (Ind)	Turbidity (NTU) (Hos)	Total Alkalinity (mg/L) (Ind)	Total Alkalinity (mg/L) (Hos)
100	0	3.695	6.5	782.5	760.5	82.05	62.06	42.37	26.735	266.925	194.895
90	10	5.215	4.351	772.6	779.8	72.83	81.64	36.512	39.215	213.893	237.318
70	30	4.687	5.678	764.7	765.1	88.46	56.32	32.176	25.134	220.452	239.764
50	50	6.502	3.827	778.2	774.7	75.62	93.78	45.213	31.412	205.371	207.564
30	70	5.342	4.712	770.9	773.6	64.23	72.58	40.516	26.672	262.835	191.894
10	90	4.648	5.345	754.2	762.4	51.24	68.97	37.834	33.456	256.743	232.891

Table 3b: Physico-Chemical Properties of Treated Wastewater using Indigenous Alum-Brideliaferruginea Mix.

Sample 1: Indigenous Alum (%)	Sample 1: Iran-Odan (%)	Sulphate (mg/L) (Ind)	Sulphate (mg/L) (Hos)	Phosphate (mg/L) (Ind)	Phosphate (mg/L) (Hos)	Nitrate (mg/L) (Ind)	Nitrate (mg/L) (Hos)	COD (ppm) (Ind)	COD (ppm) (Hos)	BOD (ppm) (Ind)	BOD (ppm) (Hos)
100	0	196.35	197.52	121.435	107.89	8.795	5.555	2348.69	1757.425	335.525	251.06
90	10	198.53	190.42	115.712	108.769	8.634	6.479	2061.98	2201.68	319.754	283.812
70	30	191.64	195.72	124.413	116.914	7.732	7.421	1825.438	1948.951	328.493	305.653
50	50	197.12	191.83	111.928	122.745	8.154	5.912	1809.372	2361.482	293.891	296.748
30	70	193.57	194.56	102.816	125.134	6.782	7.654	2013.431	1999.893	311.576	287.923
10	90	190.65	190.94	109.145	122.876	8.323	6.924	2268.457	1793.654	281.512	303.496

Key: Ind is the Industry wastewater sample; Hos is the Hotel wastewater sample (Domestic wastewater) derived from plant extracts, are effective in reducing both COD and BOD by promoting the removal of organic matter through adsorption and flocculation.

The Optimal Dosage of Coagulant

Optimal Dosage of Indigenous Alum-Brideliaferruginea (BF) Mix

The effectiveness of the Indigenous Alum-BF mix in the coagulation process is presented in Figure 1, which details the removal efficiency achieved with varying dosages of alum and BF. This data provides a nuanced understanding of how different ratios of these two coagulants impact the treatment of wastewater, with efficiency percentages offering insights into the optimal combination for maximum coagulation. Starting with the 100 % Indigenous Alum treatment, an efficiency of 22.77% is achieved. This result demonstrates the ability of alum, a well-established coagulant in wastewater treatment, to reduce suspended particles and organic matter effectively. However, the efficiency at this dosage is lower than might be expected for pure alum, suggesting that additional components, such as natural coagulants, may enhance its performance. Furthermore, as the proportion of Brideliaferruginea increases to 10 %, the efficiency drops to 16.56 %, indicating that a small amount of BF may not provide significant synergy with alum at this stage of the coagulation process. This reduction in efficiency suggests that low concentrations of the natural coagulant may interfere with the alum's ability to perform optimally. Similar results were noted by Adeyemi et al., (2021), who observed that combining natural coagulants with alum at lower ratios did not always improve efficiency and, in some cases, even led to a decrease due to the interaction of various components in the mix. Interestingly, at a 70:30 ratio of Indigenous Alum to BF, the efficiency rises to 19.43%. This improvement suggests that increasing the proportion of the natural coagulant begins to enhance the overall coagulation performance, possibly due to the increased flocculation effect induced by the plant-based material. Ibrahim et al., (2020) also reported similar outcomes where higher doses of plant extracts in coagulant mixes improved floc formation, resulting in higher efficiency in removing suspended solids and reducing turbidity. The alum and BF are combined in equal parts, and at 50:50, the efficiency peaks at 24.04 %. This outcome points to a significant synergy between the two coagulants, where their combined effects maximize the removal of pollutants from the wastewater. The presence of BF likely enhances the coagulation and flocculation process by introducing additional binding agents that improve particle aggregation.

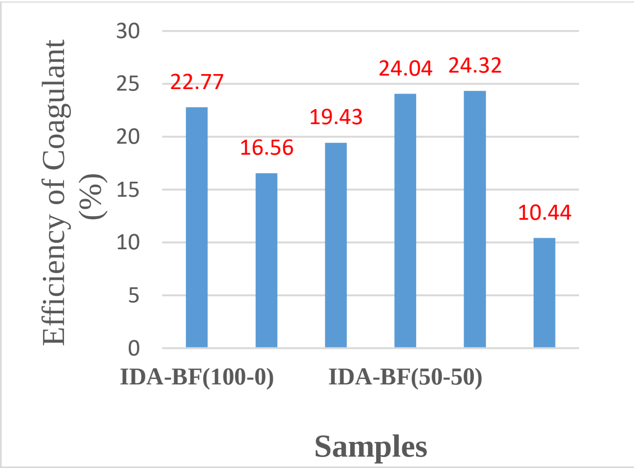

Figure 1: Effectiveness of each dosage in the coagulation process of Indigenous Alum-BF Mix.

These findings are consistent with Zhang et al., (2021), who demonstrated that natural coagulants, when mixed in optimal ratios with chemical coagulants, produce better results in terms of pollutant removal and water clarity. The highest efficiency recorded, 24.32 %, occurs when the alum concentration is reduced to 30 % and the BF extract proportion reaches 70%. This suggests that a predominantly natural coagulant-based treatment can still achieve high-efficiency levels, potentially due to the plant extract's ability to introduce active compounds that promote coagulation. Tang et al., (2019) highlighted that plant-based coagulants can sometimes outperform chemical ones due to their biodegradable nature and lower toxicity, making them especially suitable for reducing organic matter and turbidity in wastewater treatment. However, at the lowest alum concentration of 10 % and a 90 % proportion of BF extract, the efficiency significantly drops to 10.44%. This decrease indicates that while the BF extract is effective, it may not be sufficient on its own to achieve optimal coagulation without the chemical support provided by alum. These results are corroborated by the research of Kuo et al., (2020), which found that natural coagulants require a minimal presence of chemical agents to stabilize the coagulation process and ensure consistent performance. At the optimal ratio of 30%:70% indigenous alum to BF treatment, the harmful parameters of both wastewater meet the Food and Agricultural Organization (FAO 2020) guideline for wastewater disposal.

3.4.2 Optimal Dosage of Imported Alum Brideliaferruginea (BF) Mix

Figure 2 illustrates the effectiveness of varying dosages of Imported Alum and BF in the coagulation process. The efficiency percentages reflect the performance of different mixtures in treating wastewater, shedding light on the optimal combination of these coagulants. Starting with the 100 % Imported Alum treatment, the efficiency is recorded at 22.77 %. This result is consistent with the established role of alum as a chemical coagulant, known for its effectiveness in flocculating suspended particles and organic matter in wastewater (Jha et al., 2020). Although this figure highlights alum's robust performance, it also suggests that further improvements might be achieved through the incorporation of natural coagulants. However, when the dosage of BF is increased to 10%, the efficiency slightly decreases to 16.41%. This reduction indicates that a modest addition of the natural coagulant may not synergistically enhance the coagulation process at this concentration. This observation is supported by Adeyemi et al., (2021), who noted that introducing small amounts of natural coagulants into traditional systems sometimes resulted in decreased efficiency due to potential interference with the coagulation mechanism. At a 30 % dosage of BF and 70% Imported Alum, the efficiency increases to 22.39%. This improvement suggests that a higher proportion of the natural coagulant begins to positively impact the coagulation process, possibly by enhancing floc formation and settling. This finding aligns with the research of Zhang et al., (2021), which demonstrated that intermediate ratios of natural coagulants can enhance the effectiveness of chemical coagulants by improving particle aggregation. Furthermore, the mixture with an equal ratio of 50 % Imported Alum and 50% BF achieves the highest efficiency of 26.12%. This peak performance highlights the potential for synergy between the chemical and natural coagulants, where their combined effects result in improved treatment outcomes. This result is consistent with Tang et al., (2019), who found that optimal combinations of natural and chemical coagulants could significantly enhance the efficiency of the coagulation process. As the BF proportion increases to 70 % and the Imported Alum decreases to 30 %, the efficiency slightly decreases to 23.32 %. Although this value is still high, it suggests that while the natural coagulant contributes positively, a higher percentage of alum might still be needed to maintain optimal performance. This outcome is in line with findings by Ibrahim et al., (2020), which indicated that while natural coagulants are effective, they often require a balance with chemical coagulants to achieve the best results.

Finally, when the dosage of Imported Alum is reduced to 10% and BF is increased to 90%, the efficiency falls to 9.44%. This significant decrease illustrates that a predominantly natural coagulant mix may not be as effective without adequate chemical support, reaffirming the importance of a balanced approach in coagulant application. Kuo et al., (2020), who noted that a predominance of natural coagulants without sufficient chemical coagulants could lead to sub-optimal performance in wastewater treatment, observed similar trends.

The combination of Indigenous Alum and Brideliaferruginea (BF) demonstrates varying effectiveness based on their ratio. While alum alone is effective, its performance improves significantly with BF. The optimal ratio is 50:50, where the natural coagulant complements the alum in pollutant removal, and a balanced mix of Imported Alum and BF enhances coagulation efficiency.

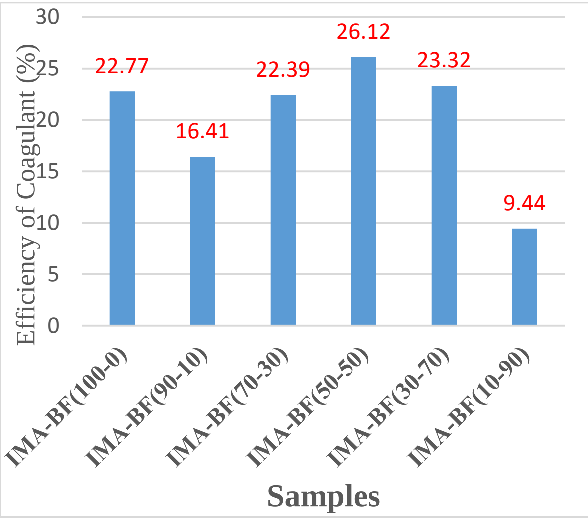

Figure 2: Effectiveness of each dosage in the coagulation process of Imported Alum-Brideliaferruginea Mix.

Overall, using specific ratios of these coagulants improves the treatment process and effectiveness in wastewater treatment. This emphasized the synergy between the chemical and natural coagulants, where their combined effects at optimum ratio result in improved treatment outcomes (Tang et al., 2019).

The study confirmed that alum alone is effective in wastewater treatment for example achieving 22.77 % treatment using imported alum in this study but its efficacy is improved by adding natural coagulant at optimal level achieving 26.12%. Thus, optimal combinations of natural and chemical coagulants significantly enhance the efficiency of the coagulation process (Tang et al., 2019). This study found that adding the natural coagulant at a concentration below and above the optimal ratio reduces the efficiency of the alum in the treatment of wastewater. This aligns with a study by Amuda et al., (2006) using $Fe_2(SO_4)_3 \cdot 3H_2O$ as a coagulant to treat wastewater from a beverage industry in Ibadan Nigeria, and Igwegbe et al., (2021) using Green Coagulant from Garcinia kola Seeds alone to treat aquacultural wastewater in Agu-Awka, Nigeria and found that the efficacy increases with increasing coagulant concentration but decreases above the optimum concentration.

CONCLUSION

Chemical coagulant leaves residues in treated water and generate much sludge, which is detrimental to human health and the ecosystem. Brideliaferruginea (BF), with its varied bioactive compounds combined, shows great promise as a natural coagulant for wastewater treatment. The high concentrations of saponins, steroids, and terpenoids, along with moderate levels of tannins and alkaloids, significantly enhance its ability to remove contaminants from both domestic and industrial wastewater effectively. The study confirmed that alum alone is not as effective in wastewater treatment as incorporating other coagulants especially natural plant-based at optimal ratio dosage. Adding the natural coagulant at a concentration below or above the optimal level reduces the efficiency of the combination in the treatment of wastewater. The physicochemical properties of wastewater from the industry and hotel differ significantly in terms of pH, conductivity, chloride, chromaticity, turbidity, and various chemical concentrations. These differences have implications for the coagulation-flocculation process, with industrial wastewater posing greater challenges due to its higher levels of pollutants but reveals that the combination of Indigenous alum with Brideliaferruginea bark extract effectively treats industrial and hotel wastewater as the Brideliaferruginea notably enhances the coagulation-flocculation-process-at-level-suitable-for-industrial-applications.

Stakeholders should create and commercialize wastewater treatment processes that incorporate BF's bioactive compounds to enhance coagulation as a primary or supplementary coagulant in wastewater treatment or integrate Brideliaferruginea into current wastewater treatment processes. There is a need to Perform large-scale pilot tests to determine the optimal dosage of BF in various wastewater treatment scenarios and refine treatment protocols for effective application. The environmental and economic impacts assessment of Brideliaferruginea to ensure its use is sustainable and cost-effective will support broader adoption in wastewater treatment practices.

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