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Removal of Phosphorous in Waste Water using Natural Coagulants

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Abstract: This study aims to explore the feasibility of employing natural coagulants like Cassia alata, Calotropis procera, Hyacinth bean, Banana leaves, Carica Papaya, Acacia mearnsii, Jatropha curcas cactus, tamarind seeds, and watermelon seeds for reducing the content of red phosphorus in industrial wastewater. A series of batch coagulation tests were performed to determine the optimal dosage of coagulants for the purpose of eliminating red phosphorus from the wastewater. The efficacy of each chosen coagulant in removing red phosphorus was depicted graphically. Among the various coagulants evaluated, Hyacinth bean exhibited the highest efficacy in reducing red phosphorus content (75%), surpassing the performance of casuarina leaves and banana leaves. On the other hand, tamarind seeds demonstrated the least effective removal of red phosphorus from the wastewater, achieving a removal rate of 56%. Notably, Hyacinth bean stands out as a potential coagulant for effective removal of red phosphorus, offering promising results akin to its capability in aiding blood clot clearance. By maintaining a pH level of 8 and employing a coagulant dosage of 20 ml, alongside initial and final red phosphorus concentrations of 4372.5 mg/lit and 1072.5 mg/lit respectively, with mixing and settling times of 30 and 45 minutes, the study achieved a significant percentage of red phosphorus removal efficiency.

Keywords: Red Phosphorous, Waste Water, Agriculture, Coagulant

1. Introduction

Water, an essential natural resource crucial for the survival of all living organisms, is currently facing critical challenges. Roughly 3% of the Earth's water constitutes freshwater, of which only 20% is suitable for human and agricultural use. [1] This 20% is primarily stored as polar snow, while other freshwater sources like rivers and lakes grant access to this invaluable resource the distinct properties of water underpin the very existence and progression of all life forms [2].

At present, the global community confronts a significant predicament – water pollution. Considerable volumes of untreated wastewater originating from diverse sources are being discharged into the environment, resulting in a multitude of adverse repercussions. [3] Industries in developing countries, spanning chemicals, food, and manufacturing, contribute substantially to this issue. The wastewater from these sectors carries an array of contaminants, including heavy metals, organic and inorganic compounds, suspended particles, BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), nitrogen, and phosphorus.

One primary contributor, phosphorus, assumes a pivotal role in triggering eutrophication in lakes and surface waters. [4] The initial indicators of eutrophication encompass an excessive proliferation of phytoplankton and filamentous algae. [5] This surge in algae growth raises water turbidity, disrupting the continuous development of bottom-dwelling macro algae.

This, in turn, indirectly reduces sunlight penetration into the depths of lakes, disrupting the natural equilibrium. [6] The consequence is an overabundance of algae, leading to decomposition within pond beds. The sustenance of aquatic life hinges on adequate oxygen levels in lakes and ponds. Regrettably, eutrophication disrupts this balance through the unchecked growth of algae and subsequent decay, causing oxygen depletion. [7] To counter this, appropriate treatment of wastewater before release into water bodies is imperative. An effective treatment approach should be both economically viable and straightforward to implement. Processes such as coagulation and flocculation have proven effective in eliminating phosphorus from industrial effluents. [8] Coagulation entails neutralizing the charge of suspended particles, prompting their aggregation and suspension. Common coagulants and flocculation agents include alum, ferric chloride, and extended-chain polymers. [9] However, the use of coagulants containing aluminum raises concerns about aluminum concentrations in the environment and potential health implications, including potential links to neuro-pathological conditions. Furthermore, these methods yield non-biodegradable sludge, introducing challenges related to disposal and expenses. [10] Escalating costs of treatment compounds further hinder the adoption of such technologies by financially constrained industries. [11] Consequently, exploring alternative coagulants becomes a pressing necessity. Natural coagulants derived from plants present an encouraging solution. [12] These plant-based alternatives yield biodegradable sludge, sidestep issues related to pH-treated effluents, and are both cost-effective and easily obtainable. Leveraging locally sourced natural coagulants can effectively address wastewater treatment requirements and align with sustainability objectives amid prevailing challenges like climate change, resource depletion, and environmental deterioration. To forge a sustainable future, prioritizing the use of plant-based coagulants in industrial wastewater treatment is paramount. [13] These natural substitutes can be evaluated for their efficacy in generating flocs during wastewater treatment, including the removal of red phosphorus from wastewater streams.

2. Materials and Methods

Gathering Industrial Wastewater: A specimen was acquired from the neighboring Sivakasi fireworks facility and is currently under examination. As the collection occurred under refrigeration, a stock solution was prepared using the obtained sample.

Table 1. Characteristic of Sample Wastewater

S.NO	Parameter	Value(mg/L)
1	pH	8.2 (No unit)
2	Total solids	48000.95
3	Red Phosphorus	4372.5
4	Chlorides	78437.52
5	Sulphates	43893.34

The concentration of the sampled effluent was adjusted as necessary for our research by diluting it with the appropriate volume of distilled water. Subsequently, standard laboratory procedures were employed to assess the properties of the industrial wastewater that had been collected.

2.1 Preparation of Coagulants

For this study, we selected ten diverse types of natural plant-based coagulants, including cactus, cassia alate, acacia meranti, Calotropis procure, banana leaves, carioca papaya leaves, tamarind seeds, jatropha curcas, hyacinth bean, and watermelon seeds. Adequate quantities of these coagulants were procured for experimentation. Initially, the coagulants were subjected to sun drying to eliminate any moisture content. If residual moisture remained, further drying was carried out using an oven until complete desiccation was achieved. Subsequent steps involved finely grinding the dried coagulants into a powder and passing them through a sieve to attain a particle size of 250 µm.

2.2 Estimation of Red Phosphorous

Utilizing a UV spectrophotometer, the estimation of red phosphorus in the wastewater was conducted. In a conical flask, a mixture of 20 ml of the treated sample, 4 ml of ammonium molybdate, and 0.5 ml of stannous chloride was prepared. Notably, the temperature of the final solution influenced the speed and intensity of color development. Spectrophotometric measurement of color absorbance was carried out at 690 nm between 10 and 12 minutes. These values were then compared against a calibration curve, using pure water as the reference. The subsequent formula was applied to quantify the red phosphorus concentration present in the effluent.

Phosphate (mg/l) =mg of P×1000volume of sample

2.3 Batch Coagulation Test

In the pursuit of determining the most efficient natural coagulant among the ten options, the jar test was employed as the customary approach to eliminate red phosphorus from industrial wastewater. Following the standard protocol for batch coagulation investigation, a series of steps were executed. Six 500 mL measuring beakers were employed to hold the wastewater sample, where the chosen coagulants were added incrementally at doses of 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 mL. A rapid mixing phase of 120 seconds was initiated at a stirring rate of 100 rpm, which was succeeded by a slow mixing period of 20 minutes at 35 rpm. Allowing the suspended flocs to settle undisturbed for 30 minutes facilitated their sedimentation. Subsequent to floc settling, the liquid supernatant was analyzed to assess the reduction in red phosphorus levels within the sample. This same process was reiterated to establish the optimal dosage. Furthermore, the pH values were varied (4, 5, 6, 7, 8, and 10) to investigate the influence on removal efficacy, thereby identifying the optimal pH. With the optimal coagulant dosage determined as 20 mL and the pH level set at 8, the subsequent batch study incorporated alterations in the mixing duration of the wastewater sample (10, 15, 20, 25, 30, 35, and 40 minutes). The impact of settling time was also considered by observing the duration from 10 to 55 minutes in 5-minute intervals to ascertain the maximum floc formation. Evaluating red phosphorus removal effectiveness, while maintaining the ideal dose, pH value, mixing time, and settling time, led to the identification of the optimal coagulant.

3. Results and Discussions

Efficient Coagulant Discovery: Employing a batch coagulation study, the optimal coagulant dosage required for phosphorus removal from wastewater was determined. The 10 pre-prepared coagulants were subjected to this batch research. In the course of the jar tests, coagulant quantities of 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 mL were introduced into individual 500 mL measuring beakers. Each beaker underwent swift mixing for 120 seconds at a velocity of 100 rpm, followed by a subsequent moderate mixing phase lasting 20 minutes at a rate of 35 rpm. Following the mixing process, the floc was allowed to settle uninterrupted for 30 minutes. Based on the acquired results, the optimal dosage was determined and subsequently applied to the remaining coagulants. Utilizing the same optimal dose across the other coagulants, a batch study was carried out to identify the most effective coagulant. After the floc had settled, the level of phosphorus in the wastewater was gauged by examining the supernatant liquid extracted from the measuring beaker. The relationship between various coagulants and the percentage of red phosphorus removed was plotted in Figure 1.The depicted graph unequivocally illustrates that hyacinth bean exhibits the highest efficacy in red phosphorus elimination, with a rate of 75%. It is followed closely by casuarina leaves at 74% and banana leaves at 73%. Conversely, tamarind seed exhibited the lowest removal efficacy, registering at 56%. Evidently, the graph underscores hyacinth bean as a dependable coagulant choice for effectively removing red phosphorus from wastewater.

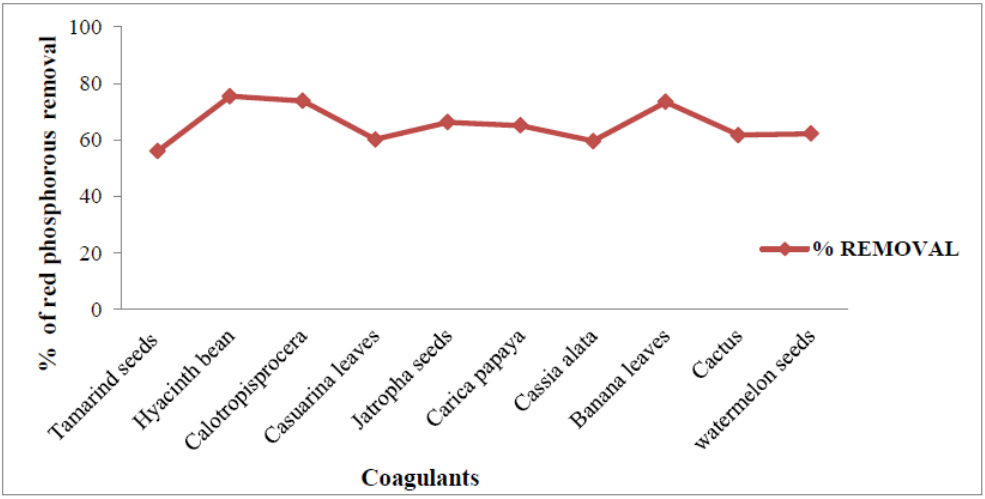

Figure1. Removal % of red phosphorus for each natural coagulant

3.1 Effect of Coagulant Dose

Conducting the batch study on the coagulation process involved systematically introducing various dosages into the sample to ascertain the optimal coagulant dose. The prepared coagulant solution was administered in different quantities to a 500 mL beaker, starting with 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 mL. Following thorough mixing at the specified rate, the beakers were left undisturbed to allow for floc settling. Subsequently, the liquid supernatant was examined to quantify the remaining red phosphorous content. To create the graph depicted in the figure, the effectiveness of red phosphorous removal by the chosen coagulants was calculated.

The graph above clearly indicates that the efficiency of red phosphorus removal starts declining beyond the 20 mL dosage. This decrease in removal efficiency can be attributed largely to the phenomenon of deflocculation. Hence, for the most effective elimination of red phosphorus from the wastewater, it is advisable to maintain the optimal coagulant dose at 20 mL. Impact of pH: In order to carry out the optimization study, alterations were made to the pH of the wastewater sample, covering a range of 4, 5, 6, 7, 8, and 10. This pH adjustment was achieved by introducing appropriate chemicals – sodium bicarbonate and Concentrated H2SO4 – to respectively raise or lower the pH level. Sodium bicarbonate can be added in either a prepared standard solution form or as a salt. Conversely, Concentrated H2SO4 is used to decrease pH, while sodium bicarbonate solution is employed to increase it. The initial phase of the optimization research was initiated once the pH level reached 4. Figure 3 illustrates the relationship between pH and the effectiveness of red phosphorus removal.

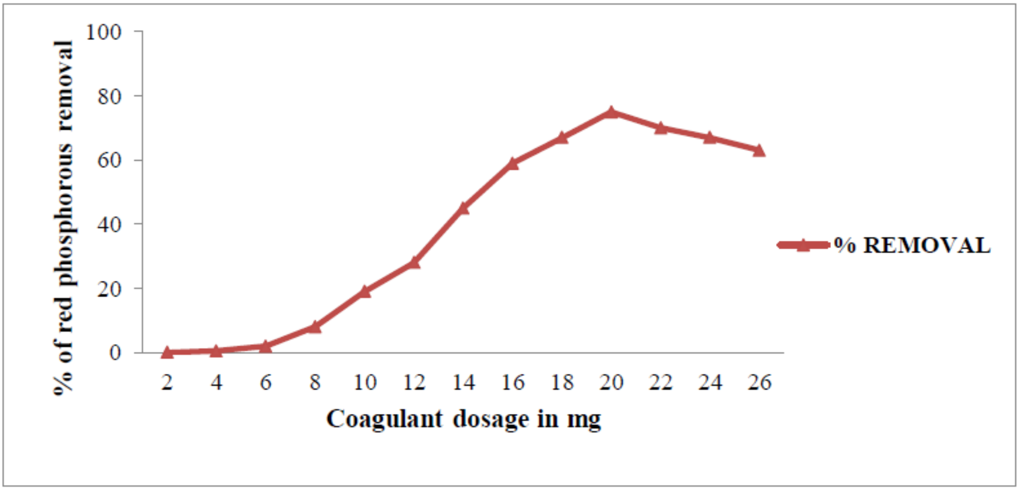

Figure 2. Removal % of red phosphorus at different coagulant dosage

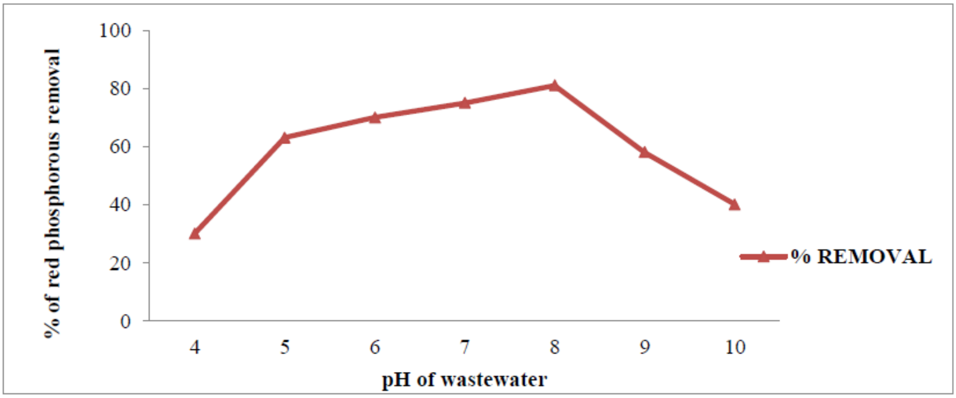

Figure 3. Removal % of red phosphorus at different pH level

The efficacy of red phosphorus removal exhibits a notable increase at a pH level of 8, illustrating a positive correlation between phosphorus removal efficiency and pH level. Nonetheless, a decline in removal effectiveness becomes evident as the pH approaches and surpasses 8. Effect of mixing time: As depicted in Figure 4, the impact of mixing time was assessed by plotting a graph of time in minutes against the volume of collected floc.

Based on the findings, the optimal mixing duration was determined to be 30 minutes, resulting in a maximum floc settling volume of 2.5 mL. Furthermore, it was observed that extending the mixing period led to an increase in floc settling. However, beyond a certain point of extended mixing, floc development began decline.

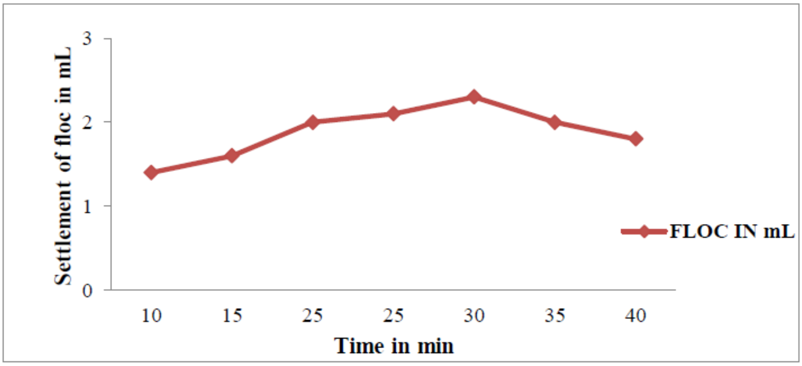

Figure 4. Floc settlement at different mixing time

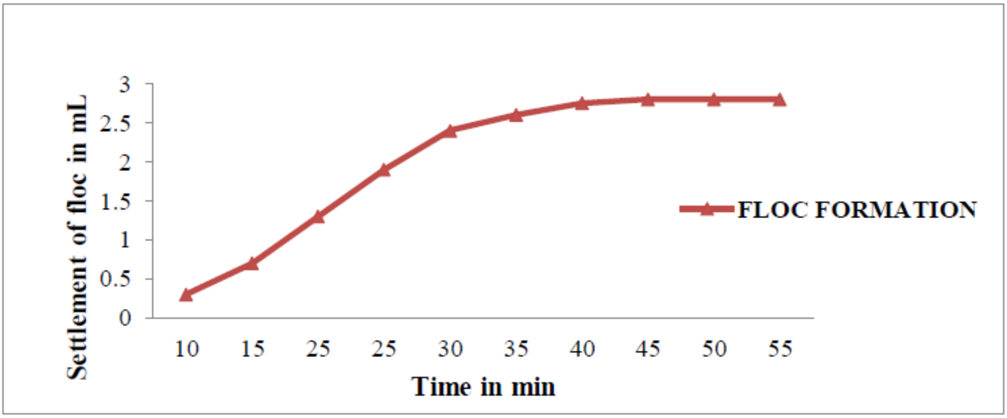

Figure 5. Floc settlement at setting time period

The batch study was conducted to establish the optimal floc settling time, which involved varying the settling duration for the wastewater between 10 and 55 minutes, at 5-minute intervals. This batch coagulation investigation maintained the prescribed parameters of optimal dose, pH level, and mixing duration. The wastewater sample was treated with the recommended 20 mL dose, set at a pH of 8, and subjected to a mixing period of 30 minutes.

Following the completion of mixing, the sample was left undisturbed to facilitate floc settling. By allowing the sample to settle for varying durations between 10 and 50 minutes, the floc's settling time was calculated. It was observed that an increase in settling time corresponded to enhanced floc formation. However, beyond a certain threshold, the floc formation began to decline after a specific duration had elapsed.

4. Conclusion

The primary objective of this study was to identify the most effective coagulant for the removal of red phosphorus, achieved through a batch coagulation investigation. The optimum coagulant dose, yielding the highest removal efficiency, was determined to be 20 mL. Among various pH levels, it was found that a pH of 8 facilitated the most efficient removal of red phosphorus. Moreover, a mixing duration of 30 minutes and a floc settling period of 30 minutes were established as the optimal timeframes. Upon careful analysis, the hyacinth bean exhibited the highest effectiveness in red phosphorus removal, followed by Calotropis procera, banana leaves, and tamarind seeds with comparatively lower removal efficiencies. Consequently, the hyacinth bean emerged as the most suitable natural coagulant for effective red phosphorus removal. Furthermore, the hyacinth bean proved to be the most optimal natural coagulant for removing red phosphorus from industrial effluent. Given that the generated sludge contains valuable phosphorus, it holds potential as a natural fertilizer for agricultural purposes.

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