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A Comparative Study of Inorganic and Natural Coagulants for Dairy Wastewater Treatment using Alum Sulphate and Moringa Oleifera

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Abstract

The treatment of dairy wastewater is essential to reduce its environmental impact, particularly in terms of organic load and suspended solids. This study investigates the application of alum sulphate as an inorganic coagulant for dairy wastewater treatment and compares its effectiveness with the natural coagulant Moringa oleifera. The performance of both coagulants was evaluated based on key water quality parameters, including pH, Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS). Experimental procedures involved coagulation-flocculation tests, with alum sulphate solutions prepared and applied under controlled conditions using a JAR Test Flocculator Apparatus. Results indicated that alum sulphate achieved superior reductions in BOD (from 200 mg/L to 60 mg/L) and TSS (from 500-600 mg/L to 200-220 mg/L), demonstrating its high efficiency in removing organic matter and suspended particles. In contrast, Moringa oleifera exhibited greater efficiency in TDS reduction. While alum sulphate is a cost-effective preliminary treatment for dairy wastewater, a multi-stage approach incorporating biological or advanced treatment methods may be necessary for comprehensive wastewater treatment and regulatory compliance. This study highlights the potential of alum sulphate as an effective coagulant while underscoring the need for integrated treatment strategies.

Keywords: Wastewater treatment, inorganic coagulant, aluminum sulphate, biochemical oxygen demand, moringa oleifera

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INTRODUCTION

The dairy industry is a significant contributor to global food production, providing essential products such as milk, cheese, butter, and yogurt. However, it is also a major source of industrial wastewater, characterized by high organic loads, suspended solids, fats, oils, and nutrients such as nitrogen and phosphorus. Dairy wastewater (DWW) contains high concentrations of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), which can lead to severe environmental pollution if not adequately treated [1]. The uncontrolled discharge of untreated or poorly treated dairy wastewater into water bodies can result in eutrophication, depletion of dissolved oxygen, and harm to aquatic life [2]. Furthermore, the presence of pathogenic microorganisms, residual antibiotics, and heavy metals in dairy effluents poses additional risks to public health and ecosystem stability [3].

Several treatment methods have been explored for managing dairy wastewater, broadly classified into physical, chemical, and biological processes. Physical treatments include sedimentation, filtration, and flotation, which primarily remove suspended solids and fats. Biological treatments, such as activated sludge processes, anaerobic digestion, and constructed wetlands, aim to degrade organic matter through microbial activity. [4] While biological processes are widely employed due to their cost-effectiveness and efficiency in organic matter removal, they often struggle with fluctuations in wastewater composition, long retention times, and challenges in handling high-fat content [5].

Chemical treatment methods, including coagulation-flocculation, electrocoagulation, and advanced oxidation processes, have gained increasing attention due to their rapid pollutant removal capabilities. Among these, coagulation-flocculation using inorganic coagulants has emerged as a viable approach to enhance the treatment efficiency of dairy wastewater. Coagulation involves the destabilization of colloidal particles by charge neutralization, followed by the aggregation of these particles into larger flocs that can be easily removed by sedimentation or filtration [6].

Despite advancements in dairy wastewater treatment, significant challenges remain. Biological treatment methods, though effective, often fail to completely remove nutrients and residual organic compounds, leading to secondary pollution [7]. Similarly, physical treatments alone do not adequately address the high organic load present in dairy effluents. Many studies have explored the use of organic and natural coagulants, but their effectiveness varies significantly with wastewater composition and requires optimization [8]. Furthermore, the selection of the most suitable inorganic coagulant, optimal dosages, and operating conditions for dairy wastewater treatment remains an area of active research, warranting further investigation to enhance process efficiency and sustainability.

Inorganic coagulants, such as aluminum sulfate (alum), ferric chloride, and poly-aluminum chloride, are widely used in wastewater treatment due to their high efficiency in pollutant removal and cost-effectiveness [9] These coagulants facilitate the removal of suspended solids, fats, and nutrients while improving the settling characteristics of sludge. Compared to biological treatments, inorganic coagulants offer the advantage of rapid treatment times and minimal operational complexity. Additionally, recent studies suggest that inorganic coagulants can enhance the biodegradability of dairy effluents, making them more suitable for subsequent biological treatment steps [10].

The effectiveness of inorganic coagulants in dairy wastewater treatment is influenced by factors such as pH, dosage, and wastewater composition. Research is ongoing to optimize these parameters and explore hybrid treatment approaches that integrate coagulation with other treatment technologies for improved performance and sustainability [11]. Addressing these challenges can lead to more efficient and cost-effective treatment solutions for dairy wastewater, reducing its environmental impact and ensuring regulatory compliance.

MATERIALS AND METHODS

Effluent Collection

Dairy wastewater collected from Parag Dairy cold storage, which is situated at Jhansi, Uttar Pradesh.

Apparatus

Jar test apparatus, pH paper, weighing machine, mechanical stirrer, stopwatch, BOD bottles, pipettes, conical flask, BOD incubator,

Material

Sample of dairy wastewater from Parag Dairy Jhansi, distilled water, aluminum sulphate, natural coagulant (moringa oleifera).

Experimental Procedure for pH measurement

a. *Sample Preparation:* A 300 mL sample of dairy wastewater is taken in two separate 500 mL jars. The initial pH of the sample is measured and recorded.
b. *Preparation of Alum Sulfate Solution:* A solution is prepared by dissolving 2.5 g of alum sulfate in 200 mL of distilled water.
c. *Coagulation and Mixing Process:* The wastewater sample is stirred at 600 rpm using a mechanical stirrer for 30 minutes to ensure uniform mixing.
d. *The prepared alum sulfate solution is introduced into the wastewater samples:* 10 mL is added to the first beaker. 20 mL is added to the second beaker.

   The flocculation apparatus speed is then reduced, allowing gentle stirring for another 30 minutes.
e. *Settling and pH Measurement:* The mixture is allowed to settle for 20-30 minutes to facilitate floc formation.

   After settling, the pH of the treated water in both beakers is measured and recorded.

Figure 1 illustrates the JAR Test Flocculator Apparatus used in the study.

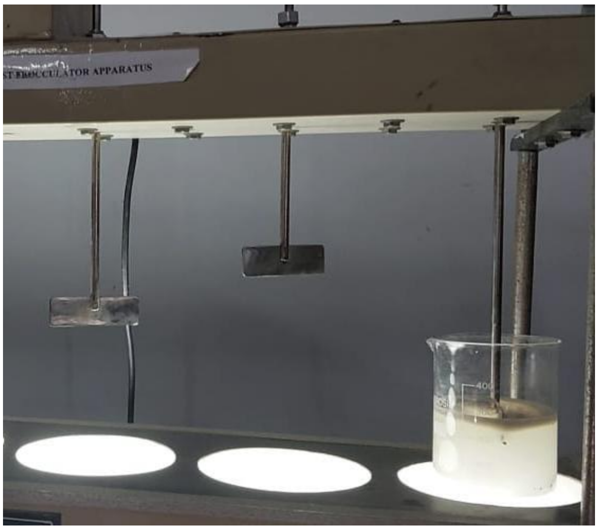

Figure1. JAR Test Flocculator Apparatus

Experimental Procedure for Determination of BOD

Collect the water sample directly from the Parag Dairy Industry in Jhansi. To analyze its biochemical oxygen demand (BOD), a 200 mL BOD bottle is meticulously filled, ensuring no air bubbles are trapped. This sample was then diluted with distilled water. For the first analysis (Sample 1), 2 mL of manganese sulphate is introduced into the bottle, carefully dispensing below the water's surface to prevent air bubble formation. Following this, 2 mL of alkali-iodide-azide reagent was added. The bottle was then sealed and gently inverted several times to thoroughly mix the contents, allowing the resulting precipitate to settle. Subsequently, 2 mL of concentrated sulfuric acid was carefully added, to avoid air bubbles. The bottle was resealed and mixed until the precipitate was fully dissolved. Next, we transferred 30 mL of this prepared sample into a conical flask using a pipette. This solution was then titrated against 3 mL of sodium thiosulfate. As the solution transitioned to a pale-yellow hue, 2 mL of starch solution was added. The titration continued until the blue color disappeared, indicating the endpoint.

For the second analysis (Sample 2), another 200 mL sample was prepared and placed in a BOD incubator (see Figure 2) for five days at 20°C. On completion of the incubation period, 2 mL of manganese sulphate solution was added to it (sample 2). The similar steps are followed for Sample 2 as did for Sample 1, including the addition of alkali-iodide-azide reagent, sulfuric acid, and the subsequent titration with sodium thiosulfate and starch.

Figure 2. BOD Incubator

RESULT AND DISCUSSION

Optimization of pH

The pH of the sample measured with indicator paper directly after sampling. The untreated effluent exhibited a pH of 8-9. After treatment with 10 mL of alum sulfate, the pH shifted to 5-6. A 20 mL alum sulfate treatment resulted in a pH of 4-5.

Determination of total suspended solids (TSS)

It's crucial to understand that suspended solids are not just surface debris; they are particles dispersed within the water. The amount of total suspended solids (TSS) is a key indicator of water quality and a significant consideration in wastewater treatment. High TSS levels are known to diminish oxygen availability in aquatic environments. Before treatment, effluent samples often contain TSS concentrations in the range of 500-600 mg/L. However, through physical and biological treatment, these levels can be reduced to 200-220 mg/L. The TSS parameter is vital for designing wastewater treatment infrastructure and for establishing the appropriate duration of primary treatment.

In a study, a comparative study of Ferrous sulphate and Alum revealed the following facts: Both coagulants achieve the lowest turbidity around pH 4-5, indicating their best performance in acidic conditions. Alum shows a sharp increase in residual turbidity from pH 5 onwards, reaching its highest turbidity (~110 NTU) around pH 7-8, suggesting reduced coagulation efficiency at neutral to alkaline pH. Ferrous Sulphate also shows an increase in turbidity but to a lesser extent, peaking at ~60 NTU around pH 7. Ferrous sulphate maintains lower residual turbidity across a wider pH range compared to alum, making it potentially more effective for wastewater treatment in neutral to slightly alkaline conditions. [Loloei, et al. 2014] [12].

Determination of Total Dissolved Solids (TDS)

Determining the total dissolved solids (TDS) in dairy wastewater effluent is essential for assessing water quality and ensuring compliance with environmental regulations. TDS encompasses both organic and inorganic substances dissolved in water, originating from sources such as cleaning agents, milk residues, and processing chemicals. The standard procedure for measuring TDS involves filtering a known volume of the effluent sample to remove suspended particles, evaporating the filtrate to dryness, and then drying the residue at 103-105°C to a constant weight. The mass of the remaining residue, expressed in milligrams per liter (mg/L), represents the TDS concentration. This gravimetric method is detailed in protocols like ASTM D5907-18, outlining test methods for filterable (TDS) and nonfilterable matter in water. Accurate determination of TDS is vital, as high levels can adversely affect aquatic ecosystems and may indicate inefficiencies in wastewater treatment processes. The TDS in the dairy wastewater was obtained as 1437 and 1360 mg/L, before and after treatment, respectively (Table 1).

Table 1. Comparison of the results after treatment from inorganic coagulant (alum sulphate).

Parameter	Before treatment	After treatment
pH	8-9	4-6
BOD	200 mg/L	60 mg/L
TDS	1437	1360
TSS	500-600	200-220

Determination of Biochemical Oxygen Demand (BOD)

The determination of Biochemical Oxygen Demand (BOD) in dairy wastewater is essential for evaluating its organic pollutant load and potential environmental impact. Dairy wastewater contains high concentrations of biodegradable organic matter, including lactose, proteins, and fats, which contribute to elevated BOD levels and can lead to oxygen depletion in aquatic ecosystems if not adequately treated (Kumar et al., 2021). [14] The standard method for BOD analysis, typically the five-day BOD test (BOD_5), involves incubating a wastewater sample under controlled conditions and measuring the oxygen consumption by microbial activity (APHA, 2017). [13] Factors such as microbial population, temperature, and nutrient availability can influence the accuracy of BOD measurements (Metcalf & Eddy, 2014). [15] Alternative techniques, including Respiro metric analysis and real-time BOD sensors, have been explored to enhance monitoring efficiency and provide rapid assessment of wastewater quality (Rieger et al., 2012). [16] Accurate BOD determination is crucial for optimizing biological treatment processes, ensuring compliance with environmental regulations, and minimizing the ecological footprint of dairy industries.

To assess the treatment's effectiveness, BOD samples were immediately processed for initial oxygen levels and incubated for five days at 20°C. This analysis revealed a reduction in BOD from 200 mg/L in the untreated effluent to 60 mg/L in the treated effluent.

Comparative Study

The comparative study is carried out between natural and inorganic coagulants. The characteristics of the inorganic coagulant (alum sulfate) in the treatment of dairy wastewater have been studied and performed experimentally. Various parameters like pH, TDS, TSS and BOD have been recorded by the jar test experiment performed in the laboratory. A comparison has been done between inorganic coagulants and natural coagulants. Table 2 presents the compiled initial and final values of different parameters used in the study.

Preparation of Natural Coagulant

The seeds of Moringa oleifera were dried at 40°C in an oven. A sieve measuring 150 µm was used to power and filter the seeds. After soaking two grams of powder in distilled water and blending, the mixture was increased to 100 ml. For every 100 ml of solution, 0.5 ml of HCl was added as a preservative. The coagulation investigation made use of this suspension [Bangar et al. 2017] [17].

Procedure of natural coagulation process

The experiment was conducted using six beakers, each holding 100 mL of sample, to determine the optimal coagulant dosage and pH for reducing turbidity. The more details can be found elsewhere (Loloei, et al. 2014). [12] The samples were simultaneously treated with varying concentration of coagulant, varying from 0.01 to 1 mg/l. Next, the paddles were adjusted to mix rapidly for one to two minutes at a speed of roughly 100 rpm after the engine was turned on. Thereafter, the mixing speed was decreased to 30 to 40 rpm, and the flocculation process began. This procedure lasted for 20 minutes. In order to encourage sedimentation, or the settling of pollutants, the motors were then turned off and the samples were allowed to settle for a duration of 20 to 60 minutes.

Once the sediment had settled, the supernatant from each beaker was collected with a pipette to ensure it didn't become disturbed. The percentage of turbidity reduction was determined using a turbidity metre. By assessing the turbidity removal corresponding to various amounts of natural coagulant, the optimal coagulant dose was ascertained. It was recorded which dose produced the maximum removal.

The ideal pH was then determined by adding Moringa oleifera, the optimal coagulant dosage, after that. The samples were subjected to a pH range of 5 to 9, and the ideal pH was identified as the one that produced the greatest reduction in turbidity. The best coagulant dosage and pH level for effective turbidity removal were found using this methodical technique, which is essential for water treatment procedures [Bangar et al. 2017] [17].

Table 2. Comparison of the results from moringa oleifera [Bangar et al. 2017] [17].

Parameter	**Initial value**	**Final value**
pH	7.4	7.1
BOD	1700	1450
TDS	3800	2650
TSS	29	20

Table 1 and 2 presents the compiled values attended in the study before the processing and after processing the samples. This study investigated the application of alum sulfate as an inorganic coagulant for treating dairy wastewater. The results of inorganic coagulants (alum sulphate are compared with natural coagulants (moringa oleifera). The comparison of treatment efficiency between alum sulfate and Moringa oleifera as coagulants for dairy wastewater reveals significant differences in their performance (Tables 1 and 2).

pH Adjustment: Alum sulfate demonstrated a notable reduction in pH from 8-9 to 4-6, indicating its strong coagulation and acidifying effect. In contrast, Moringa oleifera caused only a slight pH reduction from 7.4 to 7.1, suggesting a milder impact on acidity.

BOD Reduction: Alum sulfate significantly lowered BOD from 200 mg/L to 60 mg/L, whereas Moringa oleifera showed a much smaller reduction, from 1700 mg/L to 1450 mg/L. This suggests that alum sulfate is more effective in removing biodegradable organic matter.

TDS Removal: The reduction in Total Dissolved Solids (TDS) was minimal with alum sulfate (1437 mg/L to 1360 mg/L), whereas Moringa oleifera led to a more substantial decrease (3800 mg/L to 2650 mg/L). This indicates that Moringa oleifera is more effective at reducing dissolved solids.

TSS Removal: Alum sulfate reduced Total Suspended Solids (TSS) significantly from 500-600 mg/L to 200-220 mg/L, whereas Moringa oleifera showed a smaller reduction from 29 mg/L to 20 mg/L.

CONCLUSIONS

This study assessed the effectiveness of alum sulfate as an inorganic coagulant for treating dairy wastewater, comparing its performance with the natural coagulant Moringa oleifera. The ability of alum sulfate to effectively destabilize and remove suspended solids and organic matter contributed to improved wastewater clarity and a significant reduction in BOD levels. Despite its advantages, alum sulfate has certain limitations. While it efficiently removes suspended particles, it has minimal impact on TDS, meaning additional treatment processes may be required to meet stringent discharge regulations. Biological treatment methods, for example, could complement alum sulfate by further reducing organic and nutrient levels. In conclusion, alum sulfate serves as an effective initial treatment option for dairy wastewater, offering a simple and cost-efficient approach to improving water quality. However, for comprehensive wastewater management and regulatory compliance, a multi-stage treatment process incorporating biological or advanced treatment methods may be necessary. Alum sulfate proves to be a more effective coagulant for reducing BOD and TSS, making it suitable for the initial treatment of dairy wastewater. However, Moringa oleifera demonstrates better TDS removal, suggesting its potential role in complementing alum sulfate in a multi-stage treatment process.

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