Sustainable Waste Water Treatment In Dyeing Industry – Efficiency Of Natural Coagulants

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Abstract- *The treatment of dyeing industry wastewater is a critical environmental concern due to its high levels of color, turbidity, suspended solids, dissolved solids, and chemical oxygen demand (COD).The study was conducted by first reviewing relevant literature to assess previous findings on natural coagulants and then collecting necessary materials and wastewater samples from a dyeing industry. The wastewater sample was analyzed, with initial measurements showing a pH of 9.2, color at 650 NTU, turbidity at 47 NTU, total suspended solids (TSS) of 38 mg/L, total dissolved solids (TDS) of 2980 mg/L, and a chemical oxygen demand (COD) of 760 mg/L. Following these measurements, the natural coagulants were prepared. Then the efficiency of a natural coagulant prepared from Moringa oleifera seed powder and Soya bean powder in treating dyeing industry wastewater. The natural coagulant was compared with alum using conventional jar test experiments, assessing parameters such as pH, color, turbidity, total suspended solids (TSS), total dissolved solids (TDS), and COD. The results indicate that at an optimum dosage of 80 mg/L, both coagulants effectively reduced pollutants to meet the effluent standards set by the Central Pollution Control Board (CPCB). While alum exhibited superior performance in color and TDS reduction, the natural coagulant demonstrated slightly better turbidity and COD removal. Given its eco-friendly nature, the natural coagulant presents a viable and sustainable alternative for wastewater treatment in the textile industry.*

I. INTRODUCTION

1.1 General

Water pollution caused by industrial activities is a significant environmental concern globally. Industries release a variety of pollutants into water bodies, either through direct discharge of wastewater or through runoff and leaching from industrial sites. These pollutants degrade water quality, harm aquatic ecosystems, and pose risks to human health. Below are the major causes, types of pollutants, and the impacts of industrial water pollution.

1.2Sources of Industrial Water Pollution

Manufacturing Plants: Industries like textile, chemical, pharmaceutical, food processing, and metalworking often generate large quantities of wastewater containing harmful chemicals and heavy metals.

Mining Operations: Mining activities discharge toxic substances like arsenic, mercury, and acid mine drainage into nearby rivers and lakes.

Oil Refineries: These facilities release hydrocarbons, heavy metals, and other organic compounds that can contaminate water.

Pulp and Paper Mills: These plants often discharge high levels of organic matter, leading to oxygen depletion in water bodies.
Textile and Dyeing Factories: The dyeing industry, in particular, is a major polluter, as it releases colored dyes, chemicals, and microfibers into the water.

1.3 Impact of Industrial Water Pollution

Harm to Aquatic Life: Pollutants such as heavy metals, toxic chemicals, and thermal discharges can directly kill aquatic organisms or disrupt their reproductive and feeding patterns. Bioaccumulation of heavy metals can lead to fish poisoning and affect the entire food chain.

Eutrophication: Excessive nutrients from industrial waste can cause rapid algae growth in water bodies. When the algae die, their decomposition consumes oxygen, creating dead zones where aquatic life cannot survive.

Human Health Risks: Polluted water can cause a range of health problems in humans, including gastrointestinal diseases, neurological disorders, and cancer. People who consume contaminated fish or water are at risk of heavy metal poisoning or exposure to toxic chemicals.

Disruption of Water Supplies: Industrial pollution can make water unsafe for drinking, agriculture, and recreational activities. In areas where industries are clustered, local communities may face chronic water shortages and contamination issues.

Economic Costs: The degradation of water bodies can hurt industries dependent on clean water, such as fisheries, tourism, and agriculture. Cleaning up polluted water bodies also requires significant financial resources.

1.4 Pollutants from dyeing industry wastewater

Wastewater from dyeing industries is a significant source of pollution due to the presence of various contaminants. The dyeing process involves the use of numerous chemicals, dyes, and auxiliaries that can adversely affect water quality when released untreated. Below are the major pollutants commonly found in wastewater from dyeing industries:

1.4.1 Synthetic Dyes

These are the primary pollutants in wastewater from the dyeing industry. They include various types such as, Azo dyes, Reactive dyes, Acid and Basic dyes, Disperse dyes, These are widely used, they can break down into toxic aromatic amines, which are carcinogenic.They are used for cotton and other fibers, they form covalent bonds with fabric, and excess dye often washes out, contributing to pollution.Dyes are often resistant to degradation, can persist in the environment, and give the water an intense color, which reduces light penetration and disrupts aquatic ecosystems.

1.4.2Heavy Metals

Heavy metals are often used in dye formulations or as part of the mordanting process to fix dyes to fabrics. Common heavy metals include, Chromium, Copper, Zinc, Lead and Cadmium. Heavy metals can bioaccumulate in aquatic organisms and enter the food chain, leading to long-term ecological and health problems.

1.4.3High Chemical Oxygen Demand (COD)

Dyeing wastewater contains high levels of organic pollutants, including residual dyes, detergents, and sizing agents, which contribute to elevated COD levels.High COD indicates a large amount of organic matter in the water, which consumes dissolved oxygen during decomposition, leading to oxygen depletion and harming aquatic life.

1.4.4 Total Suspended Solids (TSS)

These include fibers, pigments, and other insoluble particles from the dyeing process. TSS increases water turbidity, affecting the penetration of light and disrupting photosynthesis in aquatic plants.Suspended solids can smother aquatic habitats, reduce oxygen levels, and negatively affect aquatic organisms.

1.4.5 Alkalinity and pH

Dyeing processes often involve using acidic or alkaline solutions, and the pH of the wastewater may be very high or very low, depending on the dyes and chemicals used. Reactive dyes, for example, often require an alkaline environment, leading to the discharge of highly alkaline wastewater.Extreme pH levels can harm aquatic ecosystems by killing sensitive organisms and altering the overall water chemistry.

1.4.6 Salts (Electrolytes)

Sodium Chloride and Sodium Sulfate are commonly used in large quantities during the dyeing process to improve dye uptake on fabrics. High salt concentrations can lead to salinization of freshwater resources, negatively impacting aquatic life and reducing the availability of clean water for human and agricultural use.

1.4.7 Surfactants and Detergents

Nonionic, Anionic, and Cationic Surfactants are Used in the washing and cleaning stages to remove unfixed dyes and chemicals from fabrics. These substances can cause foaming in water bodies and may be toxic to aquatic organisms.Surfactants reduce water quality by creating foam and altering the surface tension of water, which can disrupt aquatic ecosystems.

1.4.8 Organic Compounds and Additives

Dye Fixatives are chemicals are used to fix dyes onto fabrics and often contain formaldehyde-based compounds, which can be toxic and carcinogenic.Softening Agents, Dispersants, and Solvents are organic compounds are used in the finishing stages of dyeing and contribute to water pollution.Auxiliary Chemicalslike levelling agents, bleaching agents, and reducing agents (e.g., sodium hydrosulfite) are used in various stages of dyeing, contributing to the overall chemical load of the wastewater.These organic pollutants can be persistent in the environment, toxic to aquatic organisms, and contribute to high COD levels.

1.4.9 Pesticides and Fungicides

Textile Preservation Chemicals like Pesticides and fungicides are sometimes used to protect raw fibers (like cotton) or textiles during storage. These can leach into the wastewater during the dyeing process.These chemicals are toxic to both aquatic and terrestrial life, leading to bioaccumulation in the food chain.

1.5 Natural Coagulants for Wastewater Treatment

Coagulation and flocculation are essential processes in the treatment of wastewater to remove suspended particles, colloids, and other impurities. Traditionally, synthetic chemical coagulants like aluminum sulfate (alum), ferric chloride, and polyaluminum chloride (PAC) have been widely used to promote particle aggregation, enabling their removal through sedimentation and filtration. While these coagulants are effective, they are often associated with several drawbacks, including high costs, the production of toxic sludge, and potential environmental hazards. The growing concerns about sustainability, environmental preservation, and public health have driven the search for more eco-friendly alternatives. In this context, natural coagulants, derived from biological sources such as plants, seeds, and microorganisms, have gained increasing attention for their ability to offer an environmentally benign approach to wastewater treatment.

Natural coagulants are derived from renewable resources, making them a sustainable solution. These coagulants are biodegradable, non-toxic, and produce fewer harmful byproducts, distinguishing them from synthetic coagulants, which may leave residual chemicals in treated water or produce large volumes of difficult-to-handle sludge. In recent years, various natural materials have been studied for their coagulation properties, including Moringa oleifera seeds, cactus extracts, tannins, and chitosan derived from crustacean shells. Among these, Moringa oleifera has gained significant attention due to its wide availability, low cost, and proven effectiveness in treating various types of wastewater, including effluents from the dyeing and textile industries.

Natural coagulants operate primarily through mechanisms similar to synthetic coagulants: charge neutralization, adsorption, and floc formation. However, unlike synthetic coagulants that often rely on metallic salts or polymers, natural coagulants derive their activity from bioactive compounds like proteins, polysaccharides, and other organic molecules. For example, Moringa oleifera seeds contain cationic proteins that neutralize negatively charged particles in water, leading to flocculation and subsequent removal of turbidity, dyes, and other contaminants. Similarly, chitosan, a biopolymer extracted from the shells of crustaceans, has shown potential as a natural coagulant due to its positive charge, which interacts with negatively charged pollutants, promoting coagulation and sedimentation.

One of the most promising aspects of using natural coagulants is their application in treating wastewater from industries that generate large volumes of effluent, such as the textile and dyeing industries. Wastewater from these industries is often laden with synthetic dyes, chemicals, heavy metals, and high concentrations of organic matter, making it challenging to treat. Natural coagulants, particularly Moringa oleifera, have demonstrated significant efficiency in reducing the color, turbidity, and Chemical Oxygen Demand (COD) of dyeing industry effluents. Studies have shown that natural coagulants can achieve dye removal efficiencies comparable to or even surpassing that of synthetic coagulants, making them a viable alternative for industrial wastewater treatment.

Despite their advantages, the use of natural coagulants in wastewater treatment is still in its nascent stages, with research continuing to explore their full potential. There are several challenges that need to be addressed, such as optimizing dosage, improving the scalability of production, and understanding the long-term impacts of their use on water quality and ecosystems. However, with increasing environmental regulations and the global push for more sustainable water treatment technologies, natural coagulants are poised to play a pivotal role in the future of wastewater treatment

1.6 Objectives

- **To Evaluate the Efficacy of Natural Coagulants:** Assessthe effectiveness of natural coagulants in treating wastewater from the dyeing industry. This will include analyzing their ability to remove pollutants like dyes, suspended solids, and organic matter.
- **To Compare Natural and Synthetic Coagulants:** Compare the performance of natural coagulants with conventional synthetic coagulants in terms of pollutant removal efficiency and environmental impact.
- **To Optimize Coagulation Parameters:** Determine the optimal conditions for using natural coagulants (e.g., dosage, pH, and contact time) to maximize their effectiveness in the treatment of dyeing industry wastewater.

II. LITERATURE REVIEW

Moa Megersaa,b (2016), Inthis study natural coagulants from tubers of Maerua subcordata (Gilg.) DeWolf and seeds of Moringa stenopetala (Baker f.) Cufod were extracted, and examined their potential utility in water treatment. The coagulation activity of the extracts was measured in natural turbid river water and synthetic water made of a kaolin clay suspension. The turbidity removal efficiency was tested using a jar test and spectrophotometric-based assays. Proteins from the extracts were visualized by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) and gel staining. Relevant parameters affecting the effectiveness of coagulation (pH, extraction time, type/concentration of the extracting solvents, and storage duration/conditions) were also investigated. In conclusion, coagulant proteins from these native species could provide a means of water treatment for communities living in rural areas, enabling access to adequate supplies of safe drinking water.

N. S. Donaldben (2019), in this paper, research was carried out to observe the effect of Moringa oleifera seed as natural coagulant to replace synthetic coagulant. Highly turbid water was collected from Gulbi River in Kaura-namoda, Zamfara State. Nigeria. M. oleifera seed was processed into flour and de-fated with different organic solvent and used as a coagulant in place of aluminium sulphate (Alum). Collected water samples were treated with different Moringa oleifera flour coagulants samples The water treated with different coagulants samples were analyzed based on physic-chemical properties. The pH values ranged from 5.6 to 6.7. The turbidity, conductivity, total solid, temperature and coliform

Lorena L. Salazar Gámez (2024), Thisstudy evaluates the effectiveness of three natural coagulants—Moringa Oleifera, Yausa (Abutilon Insigne Planch), and Breadfruit (Artocarpus Altilis)—in reducing water turbidity levels of 40–50 NTU. Among these, two are native plant species potentially applicable in rural Colombian areas, where there are evident disparities in water infrastructure. This research contributes to the development of these coagulants, exploring their integration with existing water treatment methods, determining their optimal concentrations, and efficiencies in turbidity removal. Our findings reveal significant turbidity removal efficiencies: 88.9% for Moringa Oleifera, 83.3% for Yausa, and 67.2% for Breadfruit. These results indicate the feasibility of these agents as sustainable replacements for traditional chemical coagulants, exhibiting a level of effectiveness alike to that observed in Moringa Oleifera. However, challenges in practical implementation and sustainability, covering technical, environmental, economic, and social aspects, are notable obstacles.

Abujazar M.S.S (2022), In this paperthis research washeld to assess the progress of various natural coagulants used for water and wastewater treatment. Besides, several plant-based natural coagulants are also summarized and reviewed. The results reveal that natural coagulants are more successful than chemical coagulants at removing heavy metals and suspended particles from wastewater, with better removal efficiency exceeding chemical coagulants and being more environmentally friendly.

Abderrezzaq Benalia(2024), This review describes the mechanisms of natural coagulants. It provides a good understanding of the two keyprocesses of coagulation-flocculation: adsorption and charge neutralization, as well as adsorption and bridging.Various factors have influence the coagulation/flocculation process, including the effect of pH, coagulant dosage,coagulant type, temperature, initial turbidity, coagulation speed, flocculation speed, coagulation and flocculationtime, settling time, colloidal particles, zeta potential, the effects of humic acids, and extraction density areexplained. The bio-coagulants derived from plants are outlined. The impact of organic coagulants on water quality, focusing on their effects on the physicochemical parameters of water, heavy metals removal, and bacteriological water quality, is examined. The methods of extraction and purification of plant-based coagulants,highlighting techniques such as solvent extraction and ultrasonic extraction, are discussed.

Angélica Geovanna Zea Cobos (2024), This study assesses the efficacy of Moringa oleifera paste as a natural coagulant to reduce turbidity in mining wastewater compared to the efficacy of aluminum sulfate. Coagulation and flocculationtests determined the optimal doses and efficiency of both coagulants. The results indicated that Moringa oleifera achieved an 85% turbidity reduction compared to a 92% reduction with aluminum sulfate. This demonstrates its viability and effectiveness as a sustainable, economical, and safe alternative for water purification, promoting environmentally friendly practices in the mining industry

Bhupendra Koul (2022), This review provide the current state of natural coagulants and their application in the purification of surface water as sufficient clean water is required for household needs, health security, and environmental safety. The work provides explicit information related to natural coagulants and their merits and limitations, outlines methods to increase their coagulation performance, and highlights their coagulation mechanism, efficacy, valorization potential, and sustainability. From the information obtained, it can be concluded that although chemical coagulants are efficient in WT, they are usually expensive, toxic, associated with health issues, and thus non-sustainable. A sustainable alternative is the use of natural coagulants, which are readily available, economical, easy to use, biodegradable, non-toxic, eco-friendly, effective, and generate lower sludge volumes. They work via an adsorption process that involves polymeric bridging or neutralization of the charge. The WT efficiency of natural coagulants ranges from 50–500 nephelometric turbidity units (NTUs), which is similar to chemicals. Thus, they can be deployed in WT regimes and can contribute to the health security of rural populations in developing countries. It is unfortunate that, despite the known benefits of natural coagulants, their acceptance, commercialization, and widespread industrial application across the globe are still low. Therefore, there is a need for more exhaustive investigations regarding the mode of action, adoption, and commercialization of natural coagulants as a sustainable alternative to chemicals for a circular economy.

Sook Yan Choy (2014), From this study we learn **tu**rbidity reduction is often accomplished using chemical coagulants such as alum. The use of alum is widely associated with potential development of health issues and generation of voluminous sludge. Natural coagulants that are available in abundance can certainly be considered in addressing the drawbacks associated with the use of chemical coagulants. Twenty one types of plant-based natural coagulants categorized as fruit waste and others are identified and presented collectively with their research summary in this review. The barriers and prospects of commercialization of natural coagulants in near future are also discussed.

Nur Aina Nadhillah Muhamad (2020), This study investigate the potential of plant-based materials as coagulants for surface water treatment. Two types of locally available plant-based materials were selected as natural coagulants in this study are soybean and banana peel. Their efficiency in removing turbidity and color from raw surface water were analysed. Findings from the present study showed that the coagulation efficiency using soybean and banana peel were comparable to conventional chemical coagulants. The treatment of surface water using soybean and banana peel coagulant were found to be the most effective at dosage of 120 mg/L. The turbidity removal efficiency for soybean and banana peel are 23.2% and 15% respectively. In present works, both plant-based coagulants were found to be a suitable coagulant for surface water on the basis of removal of turbidity and color, respectively.

Kebreab A(2005), This paper discusses water and salt extraction of a coagulant protein from the seed, purification using ion exchange, its chemical characteristics, coagulation and antimicrobial properties. The coagulant from both extracts is a cationic protein with pI greater than 9.6 and molecular mass less than 6.5 kDa. Mass spectrometric analysis of the purified water extract indicated that it contained at least four homologous proteins, based on MS/MS peptide sequence data. The protein is thermo resistant and remained active after 5 h heat treatment at 95 1C. The coagulant protein showed both flocculating and antibacterial effects of 1.1–4 log reduction. With samples of high turbidity, the MO extract showed similar coagulation activity as alum. Cecropin A and MO extract were found to have similar flocculation effects for clay and microorganisms. Simple methods for both the purification and assay of MO coagulating proteins are presented, which are necessary for large-scale water treatment applications.

III. NATURAL COAGULANT PREPARATION AND SAMPLE COLLECTION

3.1. Material

Soybean, Moringa seeds, Alum (Aluminium Sulphate) used in this study are obtained from local market. This study is to investigate the potential of plant-based material- soya bean and Moringa seed as natural coagulants for the treatment of wastewater from dyeing industry.The different coagulant dosages should be varied for identifying the optimum dosage and removal efficiency of the natural coagulants in treating the wastewater from dyeing industry.

3.2 Alum as Coagulant

An alum is type of chemical compound, which is usually a hydrated double sulphate salt of alumwith general formula XAl (SO4)2.12H2O, where X is a monovalent cation such as potassium orammonium. Alum often refers to potassium alum, with the formula kAl(SO4)2.12H2O. Otheralums are named after the monovalent ion, such as sodium alum and ammonium alum. Thename alum is also used, more generally, for salts with the same formula and structure, exceptthat aluminium is replaced by another trivalent metal ion like chromium, and or sulphur isreplaced by other chalcogen like selenium. The most common of these analogs is chrome alumkcr(so4)2.12 H2O. In some industries, the name alum is used to refer to aluminium sulfateAl2(SO4)2.12H2O. Most industrial flocculation done with alum actually uses aluminium sulfate.In medicine, alum may also refer to aluminium hydroxide gel used as a vaccine adjuvant.

3.2.1 Types of Alum

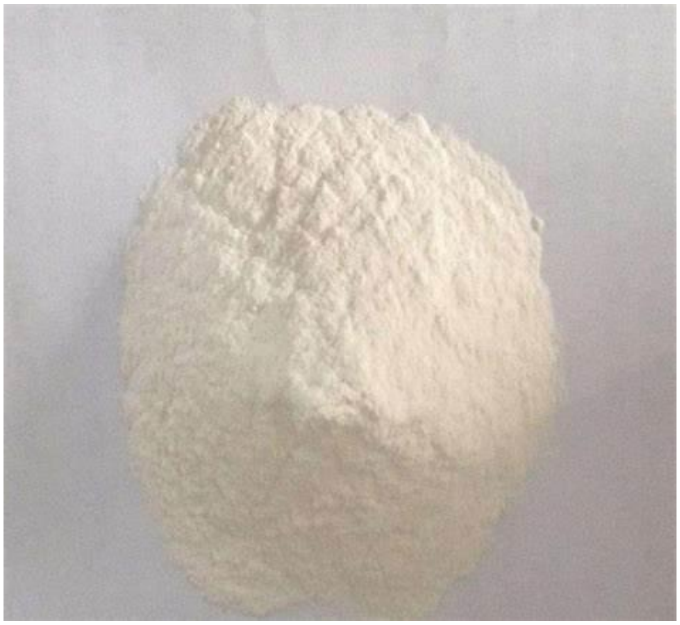
Aluminium-based alums are named by the monovalent cation. Unlike the other alkali metals,lithium does not form alums; a fact attributed to the small size of its ion. The most importantalums are:

- Potassium alum, KAl(so4)2.12 h2o, also called potash alum or simply alum.

- Sodium alum, NaAl(SO4)2.12 H2O, also called soda alum.
- Ammonium alum, NH4Al(SO4)2.12H2O.

3.2.2 Function Of Alum

The floc attracts other fine particles and suspended material in raw water, settle down at thebottom of the container. The water over this sediment is almost clean other than some fineparticles dissolve in it. Dirty water is colloid. Alum acts as an a electrolyte and helps incoagulation.



Alum Powder

3.3 Soyabean as natural Coagulant

Soybean (Glycine max) has emerged as a promising natural coagulant for wastewater treatment due to its high protein content and the presence of bioactive compounds. The soybean plant's seeds contain proteins that can act similarly to conventional coagulants by neutralizing the charges of suspended particles, thereby facilitating their aggregation and removal from wastewater. In the context of the dyeing industry, where wastewater is often laden with synthetic dyes, chemicals, and other pollutants, soybean-based coagulants offer a sustainable alternative to synthetic options like alum and polyaluminum chloride (PAC).

1. Mechanism of Action

Soybeans are rich in proteins, particularly glycine, which possess cationic (positively charged) functional groups that can neutralize the negative charges on suspended particles and dye molecules in wastewater. This charge neutralization promotes the aggregation of particles, leading to the formation of flocs, which are larger, easily removable particles. These flocs can then be removed through sedimentation or filtration processes.

Charge Neutralization: The proteins in soybean extract neutralize the negatively charged dye molecules and colloidal particles in the wastewater.

Flocculation: After neutralization, the particles aggregate into larger flocs, which can be easily separated through sedimentation or filtration, resulting in clearer water.

2. Effectiveness in Dye Removal

In the previous studies the soybean-based coagulant has shown significant potential in removing various types of dyes from wastewater. This is particularly important for the dyeing industry, where effluents contain a mix of reactive, acidic, and azo dyes, which are difficult to degrade using traditional methods.

Dye Removal Efficiency: Studies suggest that soybean extracts can remove 60-80% of dyes, depending on the dye type, concentration, and dosage of the coagulant. Reactive dyes, which are commonly used in textile manufacturing, have shown particularly high removal rates when treated with soybean-based coagulants.

Reduction of Color and Turbidity: The use of soybean as a coagulant has been effective in reducing the color intensity and turbidity of wastewater, which are critical parameters in meeting discharge standards.

3. Reduction in Chemical Oxygen Demand (COD) and Turbidity

Chemical Oxygen Demand (COD) is a key measure of organic pollutants in wastewater. High COD levels indicate the presence of a significant amount of organic matter, which can lead to oxygen depletion in receiving water bodies.

COD Reduction: Soybean-based coagulants have demonstrated significant reductions in COD levels, with some studies reporting reductions of up to 70%. This suggests that soybean proteins can effectively coagulate not only dyes but also organic contaminants present in the wastewater.

Turbidity Removal: The turbidity (cloudiness) of wastewater, caused by suspended particles, is also reduced using soybean coagulants. This makes the treated water clearer and more suitable for reuse or discharge.

D. Advantages of Soybean as a Natural Coagulant

Renewable and Biodegradable: Soybeans are a readily available, renewable resource that is biodegradable and non-toxic. Unlike synthetic coagulants, which may leave harmful chemical residues, soybean proteins break down naturally in the environment.

Cost-Effective: As a widely cultivated crop, soybeans are relatively inexpensive, especially in regions where they are grown in abundance. This makes them a cost-effective alternative to more expensive synthetic coagulants.

Low Sludge Production: Soybean-based coagulants typically produce lower volumes of sludge compared to synthetic coagulants like alum or ferric chloride. This reduces the cost and complexity of sludge handling and disposal.

E. Challenges and Limitations

Optimization of Coagulant Dosage: One of the challenges with using soybean as a coagulant is determining the optimal dosage for different types of dyeing wastewater. Variations in dye concentration, pH, and wastewater composition can affect the coagulation efficiency, and overdosing can lead to re-stabilization of particles.

Processing and Shelf Life: Soybean-based coagulants need to be processed and stored properly to retain their coagulation properties. Further research is needed to improve the extraction, storage, and application of soybean proteins in large-scale wastewater treatment operations.

F. Potential for Combined Use with Other Coagulants

Soybean extracts can also be combined with other natural or synthetic coagulants to enhance their performance in wastewater treatment. For instance, blending soybean coagulants with plant-based coagulants like Moringa oleifera expecting to improve overall pollutant removal efficiency while maintaining the sustainability benefits

3.4 Moringa oleifera as a Natural Coagulant

Moringa oleifera, commonly known as the drumstick tree or horseradish tree, has gained attention as a natural coagulant in the treatment of industrial wastewater, including that from the dyeing industry. Its seeds contain active compounds that can coagulate and flocculate suspended particles, organic matter, and dyes from water. This makes it a promising eco-friendly alternative to synthetic coagulants, which are often associated with environmental hazards and toxicity.

A. Mechanism of Action

The coagulant properties of Moringa oleifera seeds arise from the presence of cationic proteins, particularly a protein known as moringa coagulating protein (MOCP). These positively charged proteins neutralize the negatively charged particles in the wastewater, causing them to clump together and form larger flocs that can be easily removed through sedimentation or filtration.

Charge Neutralization: The cationic proteins in Moringa oleifera interact with the negatively charged dye molecules and other suspended solids, neutralizing their charge and allowing aggregation.

Floc Formation: The particles coagulate into larger aggregates (flocs), which then settle out of the solution, making the water clearer.

B. Removal of Dyes

Moringa oleifera has shown significant effectiveness in removing a variety of dyes, including both synthetic and reactive dyes, commonly found in textile industry effluents. Studies have demonstrated its potential in reducing the color of wastewater, an essential factor in mitigating the environmental impact of dyeing industry discharges.

Color Removal Efficiency: Experimental studies have reported dye removal efficiencies ranging from 50% to 90%, depending on the type of dye, initial concentration, and the dosage of the Moringa oleifera coagulant used. Higher concentrations of the coagulant typically lead to more effective dye removal.

Reactive Dyes: For reactive dyes, Moringa oleifera seeds have shown an ability to significantly reduce the color intensity, offering a potential solution for treating highly colored textile wastewater.

C. Reduction in Chemical Oxygen Demand (COD)

In addition to dye removal, Moringa oleifera effectively reduces the Chemical Oxygen Demand (COD) of wastewater. COD is an indicator of the amount of organic matter present in the water, and high COD levels can lead to oxygen depletion in aquatic environments.

COD Reduction: Moringa oleifera has been observed to achieve COD reductions of up to 60-70%, depending on the type of wastewater and the operating conditions. This makes it a promising alternative for treating dye-laden wastewater that contains high levels of organic pollutants.

Environmentally Safe: Unlike synthetic coagulants that may introduce harmful residual chemicals into the environment, Moringa oleifera is biodegradable and non-toxic, minimizing its impact on the receiving water bodies.

D. Turbidity reduction

Turbidity, which refers to the cloudiness of water caused by suspended particles, is another important parameter in wastewater treatment. Moringa oleifera has been found to effectively reduce the turbidity of dyeing wastewater by coagulating and settling out suspended solids.

Turbidity Removal: Studies have reported turbidity reductions of up to 90% in dye-laden wastewater when using Moringa oleifera seed extracts as a coagulant. This significant reduction helps improve water clarity and makes the effluent more suitable for further treatment or reuse.

E. Optimal conditions for coagulation

The effectiveness of Moringa oleifera as a natural coagulant is influenced by various factors, such as coagulant dosage, pH, and initial dye concentration.

Dosage: The optimal dosage of Moringa oleifera coagulant varies depending on the characteristics of the wastewater. In general, higher doses result in better removal efficiencies, but excessive amounts can lead to re-stabilization of particles, reducing effectiveness.

pH Sensitivity: Moringa oleifera is most effective within a pH range of 6 to 8, which makes it suitable for treating dyeing industry wastewater, as many textile effluents fall within this pH range. It does not require significant pH adjustments, reducing the need for additional chemicals.

F. Advantages over synthetic coagulants

Moringa oleifera offers several advantages over conventional synthetic coagulants such as alum, ferric chloride, or polyaluminum chloride (PAC), which are commonly used in wastewater treatment.

Eco-friendliness: Moringa oleifera is biodegradable, non-toxic, and sourced from natural materials, making it an environmentally sustainable alternative. Unlike alum and other synthetic coagulants, it does not introduce harmful residues into the treated water.

Lower Sludge Volume: The use of Moringa oleifera produces lower volumes of sludge compared to synthetic coagulants, reducing the disposal and management challenges associated with sludge generation.

Cost-effective: As a readily available and renewable resource, Moringa oleifera seeds can be sourced inexpensively, particularly in regions where the tree is abundant. This makes it a cost-effective solution for dyeing industries, especially in developing countries.

Non-Corrosive: Unlike some chemical coagulants that can corrode pipes and equipment, Moringa oleifera is non-corrosive, reducing the maintenance costs associated with wastewater treatment infrastructure.

While Moringa oleifera has shown promise in numerous studies, there are several areas where further research is needed to optimize its application, address challenges, and scale up its use for industrial wastewater treatment.One of the primary gaps in the current research is the lack of standardized dosing protocols for Moringa oleifera in treating different types of dyeing industry wastewater. Factors such as dye type, dye concentration, pH, and the presence of other chemicals can significantly affect the coagulation efficiency. Research is needed to establish optimized dosages for different wastewater characteristics.Further studies are needed to understand the influence of operational parameters (e.g., temperature, mixing speed, and sedimentation time) on the coagulation efficiency of Moringa oleifera.

3.3 Preparation of Natural coagulant

4.3.1 Soya bean powder

Soybean was prepared by washing and boiling, fermenting, drying and powdering method. Soybean was washed with distilled water several times to remove dirt and contaminants, followed by boiling with fresh water and washing again and kept @ 40℃ for fermentation by adding yeast in it for 48 hours in oven. Then it is stirred and dried in oven at 105℃ for 24 hours to ensure the water content in the beans is absorbed fully. The dried samples were then blend using domestic blender until it turned into powder. Then, the soybean powder was sieved using 0.02 mm sieve to remove large size particles to make a good natural coagulants solution.

3.3.2. Moringa Oleifera seed powder

Obtained dried Moringa oleifera seeds and removed the outer husks (seed coat) to expose the whitish inner kernel. The kernel is the active part of the seed that contains the coagulant proteins. Cleaned the kernels to remove any dirt or impurities.ground the seeds into a powder. The finer the powder, the more effective the extraction of the active coagulant proteins.The powder is sieved through a fine muslin cloth to ensure uniformity of particle size.

Moringa Olifera Seed powder and Soyabean Powder

3.3.3 Preparation of Natural coagulant solutions

The Moringa oleifera seed powder and Soya bean powder should be taken at the ratio of 1:1,3:4 & 4:3 respectively. The seed powder is dissolved in a small amount of distilled water or tap water (100 mL of water for each gram of powder).Stir the mixture thoroughly for about 10–15 minutes in magnetic stirrer to release the active proteins from the seed powder into the water. After stirring, filter the mixture through a muslin cloth or fine sieve to remove any larger seed particles. The filtered solution should be clear or slightly turbid, containing the active coagulant proteins

3.4 Sample Collection

Waste water Samples of 5 Litres was collected from dyeing industry. 1 litre of sampled water used for analysis of untreated wastewater of dyeing industry. Where, remaining 4 litres of sample will be used for determining the optimal dosage to treat the wastewater of dyeing industry.

Fig 4.1 Collected Sample

3.5 Sample Analysis

The analysis of untreated Domestic waste water is carried out to determine the initial contaminants of untreated Domestic Waste water. The parameters analysed were pH, EC, Color, Turbidity, TSS, TDS and, COD.

3.5.1 pH

Take 250 ml beaker rinse with distilled water.Take 200 ml amount of sample into a beaker.Measure the temperature of the sample. Measure the Temperature using temperature probe control to the measured value of the temperature of the sample.Keep the sample beaker on base plate of the electrode stand.Immerse the electrode properly in the sample.Allow the sufficient time for electrode to attain the temperature of the solutions.Press the pH mode and read the value of pH after display the ready mode.Raise the electrode from solution and remove the container with sample. Wash the electrode with distilled water and blot clean with tissue paper.

3.5.2 EC

Take 200 ml of Standard Reference solution into a 250 ml beaker.Measure the temperature of the sample using inbuilt temperature controller. Rinse the cell with distilled water. Immerse the cell into sample beaker.Press to set the mode to Conductivity mode. Read the displayed reading after display the ready mode.Wash the electrode with distilled water and blot clean with tissue paper.Keep the cell immersed in distilled water when not in use. The platinum cell is directly in touch with the deposits, the cell may be washed by cleaning it in 2% of HCL.

3.5.3 Color

Remove turbidity by filter the sample until the sample is clear.Compare the filtered sample with distilled water to ensure that turbidity has been removed. If the sample is clear, then compare with the standards having colours units of 10, 15, 20, 25, 30, 35, 40, 45, 50, 60 and 70 (by diluting 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, and 7.0 ml standard chloroplatinate solution with distilled water to 50 ml).

If the colour exceeds 70 units, dilute the sample with distilled water until the colour is in the range of the standards. If the colour less than 10 units, concentrate the sample until the colour is in the range of the standards.

Where:
A = Estimated colour of diluted sample, and
V = Volume in ml of sample taken for dilution

3.5.4 Turbidity

Formazin(I) In a 100 ml volumetric flask, mix 5.0 ml solution I (Dissolve 1.0gm of Hydrazine sulphate, $(NH_2)_2.H_2SO_4$, in distilledwater and dilute to 100 ml) and 5.0 ml solution II(Dissolve 10.0gm of hexamethylene tetramine, $(CH_2)_6N_4$, in distilled water and dilute to 100 ml). Let stand for 24 hours at 25 ± 3^oC. Dilute to 100 ml with DM water. The turbidity of this suspension is 400 NTU. Dilute 10.0 ml of stock turbidity suspension to 100 ml with distilled water. The turbidity of this suspension is 40 NTU.

Procedure

Warm up the instrument for 5 minutes.calibrate the instrument foreach range, otherwise run at least one standard in the range to be used.

Turbidity less than 40 units:

Shake the sample to disperse the solids Wait until air bubbles disappear.Pour sample into turbid meter tube and read turbidity directly from the instrument scale or from calibration curve.

Turbidity greater than 40 units:

In case turbidity values are greater than 40 units, dilute the samplewith turbidity- free water to bring the values within range.Take readings of diluted sample. Compute the turbidity of the original sample from the turbidity of the diluted sample and the dilution factor.

Calculate the turbidity of the diluted sample from turbidity value of diluted sample and dilution factor as follows:

$$\text{Turbidity (NTU)} = \frac{A \times (B + C)}{C}$$

A - NTU found in diluted sample
B - Volume of dilution water in ml and
C - Sample volume taken for dilution

3.5.5 TSS

Place the glass fibred filter on the filter apparatus and apply the vacuum, wash the dish with three successive 20 ml volume of distilled water.Remove the filter from filter apparatus and dry in an oven at 103 - 105 ^oC for 1 hour.Transfer to a desiccators and weigh after half an hour. Weigh immediately before use. After weighing, handle the filter with forceps only.

Volume of sample taken esteemed from value of Turbidity. Filter sufficient sample so that non – filterable residue is 50 to 100 mg.Assemble the filtering apparatus and begin suction.Wet the filter with a small volume of distilled water to seat it against the fitted support.Shake the sample vigorously and quantitatively transfer predetermined sample volume (approx: 100 ml) in to filter using graduated cylinder.Filter the sample through continuing applying of vacuum.Wash the graduated cylinder, filter non- filterable residue with portion of distilled water allowing complete drainage between washings.Remove all the traces of water by applying vacuum after the wash water has passed through. After filtration, transfer the filter along with contents to an oven and dry at 103 – 105^{o}C for 1 hour. Cool in desiccators and weigh.'Repeat the drying cycle to constant mass till the difference in the successive mass is less than 0.5 mg.

Total SuspendedSolids as mg/l = $\frac{1000 \times M}{V}$

Where,
M – Mass in mg of Non – Filterable residue
V - Volume of sample taken in ml

3.5.6 TDS

Place the glass fibre filter disk into the filtration apparatus with wrinkled surface up & Heat the clean evaporating dish to 180^{0}C for one hour.Cool and store in the desiccators until for the use. Filter a portion of the sample through filter assembly.Volume of sample taken esteemed from value of specific conductance. Preferably this has residue between 25 to 250 mg.Stir volume of sample with magnetic stirrer or shake it vigorously, pipette the required volume of sample from filtrate into weighed evaporating dish.Evaporate the sample using steam bath or drying oven at 98^{0}C (approx.)After evaporation, transfer the dish to an oven at 180°C±2°C dry to constant mass (usually 1h to 2h). Cool the dish in desiccators and weigh as soon as possible, avoid the long time storage.

Total Dissolved Solids as mg/l = $\frac{1000X\ M}{V}$

Where,
M – Mass of residue in mg
V - Volume of sample taken

3.5.7 COD

Procedure for High COD Sample (>50mg/l)

Place 0.4 g $HgSO_4$ in a reflux tube.Add 20 ml or and aliquot of sample diluted to 20 ml with distilled water.Mix well, so that chlorides are converted into poorly ioinized mercuric chloride. Add 10ml standard $K_2Cr_2O_7$ solution and then add slowly 30 ml sulphuric acid which already containing silver sulphate.Mix well, if the colour turns green, take fresh sample with smaller aliquot. Final concentration of concentrated.H_2SO_4 should be always 18 N.Connect the tubes to condensers and reflux for 2 h at 150 ±2^{o}C. Cool and wash down the condensers with 60 ml distilled water. Cool and titrate against standard ferrous ammonium sulphate using ferroin as indicator.

Near the end of the titration colour changes sharply form green blue to wine red.Reflux a reagent blank simultaneously with the sample under identical condition.

COD, mgO2/l = $\frac{(B – S)\ N \times 8000}{V}$

Where
B=Volume of FAS required for titration against the blank in ml;
S=Volume of FASrequired for titration against the sample, in ml;
N = Normality of FAS and
V = Volume of sample taken for testing, in ml.

3.6. Dyeing Industry Wastewater Analysis Report

The wastewater sample from the dyeing industry has been analyzed to evaluate key parameters relevant to water quality and environmental impact. The following report provides the values observed in the sample and briefly discusses their implications.

3.6.1. pH

Observed Value: 9.2

The pH level of 9.2 indicates that the wastewater is slightly alkaline. This may result from chemical dyes and other alkaline agents used in the dyeing process. Alkaline wastewater can negatively impact aquatic life if discharged untreated, as it may disrupt biological functions in aquatic ecosystems. It is important to treat or neutralize this pH to bring it closer to the neutral range (6-8.5) recommended for safe discharge.

3.6.2. Color

Observed Value: 650 Hazen

The high color intensity in the wastewater reflects the presence of dyes and colorants that are challenging to treat. Such levels of color may severely reduce water transparency, affecting light penetration and, consequently, aquatic life in receiving bodies. This high color level highlights the need for effective coagulation or oxidation treatment steps before discharge.

3.6.3. Turbidity

Observed Value: 47 NTU

The turbidity level of 47 NTU indicates the presence of suspended particles and colloidal matter in the wastewater. High turbidity can hinder light transmission through water and may carry pollutants that contribute to further contamination. Treating turbidity is essential to prevent sedimentation and contamination in natural water sources.

3.6.4. Total Suspended Solids (TSS)

Observed Value: 38 mg/L

TSS measures the amount of solid particles suspended in the water. A TSS value of 38 mg/L, although moderate, contributes to the turbidity and can deposit as sludge if untreated. Reducing TSS is necessary for meeting discharge standards and minimizing environmental impact on sedimentation and siltation.

3.6.5. Total Dissolved Solids (TDS)

Observed Value: 2980 mg/L

High TDS levels, as indicated by the 2980 mg/L measurement, are common in industrial wastewater and reflect significant dissolved inorganic matter. Elevated TDS levels may impact freshwater sources by altering the osmotic balance required by aquatic organisms. Pretreatment to lower TDS can help in compliance with discharge norms and reduce ecological harm.

3.6.6. Chemical Oxygen Demand (COD)

Observed Value: 760 mg/L

The COD value of 760 mg/L suggests a high concentration of organic and inorganic matter in the wastewater that demands oxygen for decomposition. High COD values are indicative of potential pollution from dyes, detergents, and other organic materials, which could lead to oxygen depletion in aquatic systems. Reducing COD is crucial before discharge to mitigate the impact on receiving water bodies.

3.7. Experimental run

A conventional jar test apparatus was used in the experiments to coagulate, flocculate, and facilitate the sedimentation of the wastewater sample using a natural plant-based coagulant and alum. Before adding the coagulants to the sample, the pH was adjusted between 6-8, within which the coagulation process was effective. Different doses of the natural coagulant extract and alum were added to each beaker of wastewater. The natural coagulant and alum concentrations used in this experiment were 40 mg/L, 80 mg/L, and 120 mg/L, respectively. The mixtures were rapidly stirred at 140 rpm after the addition of the coagulant for a duration of three (3) minutes. Then, the mixtures were stirred slowly at a speed of 20 rpm to allow flocculation for 30 minutes. The flocs then underwent a sedimentation process for 30 minutes, bringing the total contact time of the coagulant to 60 minutes. Subsequently, the sample was taken for TDS, TSS, turbidity, color, and COD removal analysis.

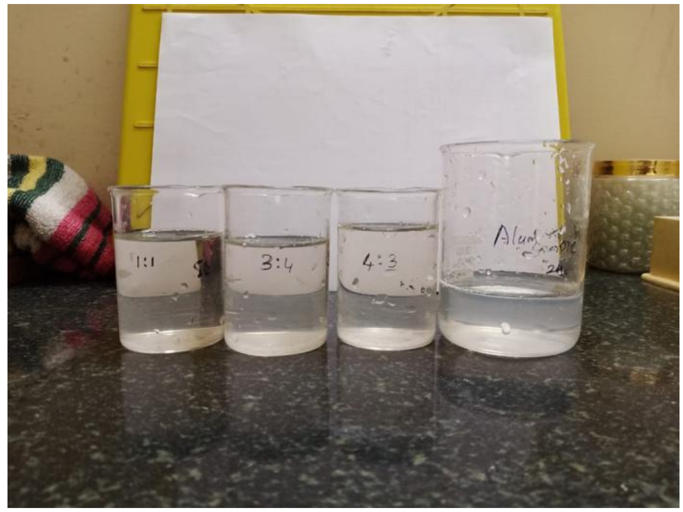


Fig 4.1 Collected Sample

IV. RESULTS AND DISCUSSION

Parameters	**1:1 Natural Coagulant**			**CPCB Standard**
	40 mg/L	**80 mg/L**	**120 mg/L**	
pH	8	7.8	7.9	6.0–8.5
Colour (Hazen)	650	320	281	≤ 400
Turbidity (NTU)	28	5	3	No standard
Total Suspended Solids (TSS) (mg/L)	38	4	6	≤ 100
Total Dissolved Solids (TDS) (mg/L)	2980	650	387	No standard

Chemical Oxygen Demand (COD) (mg/L)	760	215	103	≤ 250

Parameters	**3:4 Natural Coagulant**			**CPCB Standard**
	40 mg/L	**80 mg/L**	**120 mg/L**	
pH	7.8	7.3	7.4	6.0–8.5
Colour (Hazen)	654	312	214	≤ 400
Turbidity (NTU)	23	4	3	No standard
Total Suspended Solids (TSS) (mg/L)	31	4	2	≤ 100
Total Dissolved Solids (TDS) (mg/L)	2649	634	315	No standard
Chemical Oxygen Demand (COD) (mg/L)	720	224	111	≤ 250

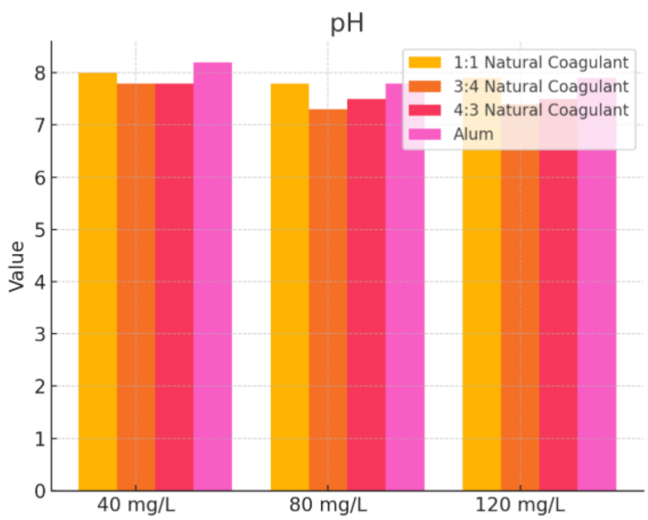
Parameters	**4:3 Natural Coagulant**			**CPCB Standard**
	40 mg/L	**80 mg/L**	**120 mg/L**	
pH	7.8	7.5	7.5	6.0–8.5
Colour (Hazen)	652	332	220	≤ 400
Turbidity (NTU)	27	4	5	No standard
Total Suspended Solids (TSS) (mg/L)	34	5	5	≤ 100
Total Dissolved Solids (TDS) (mg/L)	2649	642	326	No standard
Chemical Oxygen Demand (COD) (mg/L)	720	231	107	≤ 250

Parameters		**Alum**		**CPCB Standard**
	40 mg/L	**80 mg/L**	**120 mg/L**	
pH	8.2	7.8	7.9	6.0–8.5
Colour (Hazen)	670	294	275	≤ 400
Turbidity (NTU)	30	6	2	No standard
Total Suspended Solids (TSS) (mg/L)	29	5	3	≤ 100
Total Dissolved Solids (TDS) (mg/L)	2520	576	412	No standard
Chemical Oxygen Demand (COD) (mg/L)	745	220	114	≤ 250

Results and Discussion

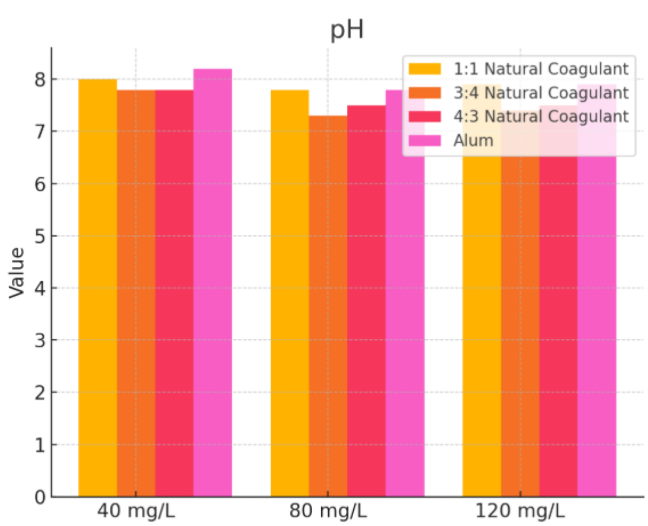
pH

The pH values for all coagulants remained within the CPCB standard range (6.0–8.5). The 1:1 Natural Coagulant showed the highest pH at 40 mg/L (8.0), which slightly decreased with higher dosages. The 3:4 Natural Coagulant showed a more significant drop at 80 mg/L (7.3) but remained stable at 120 mg/L. Alum showed consistent pH values, maintaining slightly higher stability. This indicates that natural coagulants do not drastically alter pH, making them suitable alternatives.



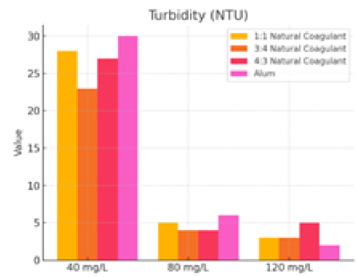
Colour (Hazen)

Reduction in colour was observed for all coagulants, with higher dosages showing better removal efficiency. At 120 mg/L, the 3:4 Natural Coagulant exhibited the best colour removal (214 Hazen), followed by 4:3 Natural Coagulant (220 Hazen) and 1:1 Natural Coagulant (281 Hazen). Alum performed well, reducing colour to 275 Hazen at 120 mg/L, showing comparable performance to natural coagulants. This suggests that natural coagulants can be an effective replacement in terms of colour removal



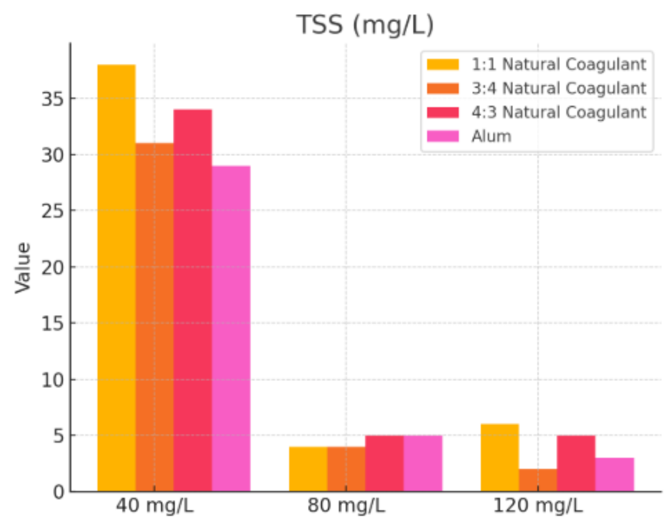
Turbidity (NTU)

Turbidity removal was highly efficient for all coagulants at increasing dosages. The 1:1 Natural Coagulant reduced turbidity from 28 NTU to 3 NTU at 120 mg/L, whereas the 3:4 and 4:3 Natural Coagulants achieved similar reductions to 3 NTU and 5 NTU, respectively. Alum performed similarly, reducing turbidity to 2 NTU at 120 mg/L. The comparable results indicate that natural coagulants can be a viable eco-friendly alternative to alum for turbidity removal.



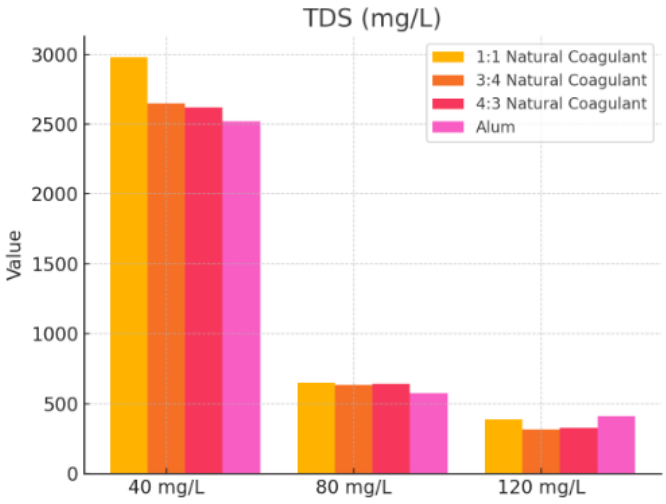
Total Suspended Solids (TSS)

A significant reduction in TSS was observed for all coagulants, with values well below the CPCB standard limit of 100 mg/L. The 3:4 Natural Coagulant demonstrated the most efficient removal, reducing TSS from 31 mg/L to 2 mg/L at 120 mg/L dosage. The 4:3 and 1:1 Natural Coagulants also showed considerable reductions, comparable to Alum (3 mg/L at 120 mg/L dosage). These results confirm the potential of natural coagulants in solid particle removal.



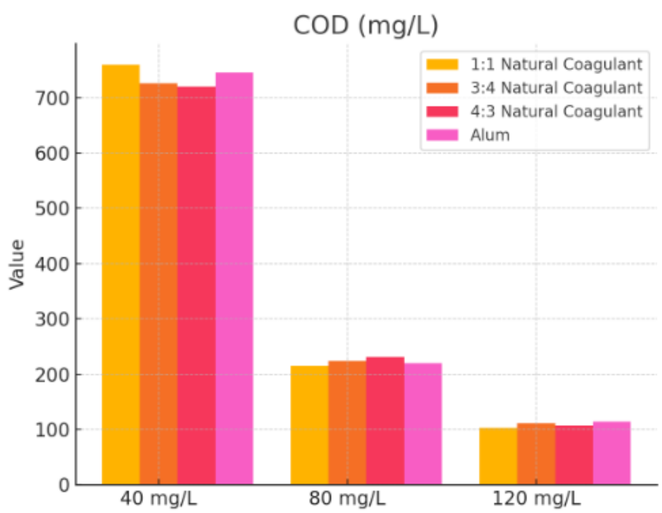
Total Dissolved Solids (TDS)

Natural coagulants effectively reduced TDS, with 1:1 Natural Coagulant achieving the highest removal (from 2980 mg/L to 387 mg/L at 120 mg/L dosage). The 3:4 and 4:3 Natural Coagulants also showed significant reductions, performing slightly better than Alum (reducing TDS from 2520 mg/L to 412 mg/L at 120 mg/L dosage). Although no specific CPCB standard exists for TDS, natural coagulants showed promising results in reducing dissolved contaminants.



Chemical Oxygen Demand (COD)

All coagulants demonstrated effective COD reduction, with 1:1 Natural Coagulant achieving the highest reduction (760 mg/L to 103 mg/L at 120 mg/L dosage), closely followed by 3:4 and 4:3 Natural Coagulants. Alum showed comparable performance, reducing COD to 114 mg/L. Since the CPCB standard for COD is ≤250 mg/L, all tested coagulants met the requirement, proving that natural coagulants are suitable for wastewater treatment.



Optimum Dosage

For both alum and the natural coagulant, the optimum dosage was determined to be 80 mg/L. At this dosage, both coagulants met the CPCB effluent standards for pH, color, turbidity, TSS, and COD. Alum exhibited slightly better performance in color and TDS reduction, while the natural coagulant showed a slight edge in turbidity and COD removal. The choice of coagulant can depend on factors such as cost, availability, and environmental sustainability. The natural coagulant, being eco-friendly, could be a preferable option if the marginal differences in performance are acceptable.

IV. CONCLUSION

The initial analysis of dyeing industry wastewater highlights significant pollution levels, with high pH, color, turbidity, TSS, TDS, and COD values, indicating the need for effective treatment prior to discharge. The promising potential of soybean and Moringa oleifera as natural coagulants presents an environmentally friendly alternative to conventional alum treatment.

The study highlights that natural coagulants (1:1, 3:4, and 4:3 ratios) performed comparably to alum in terms of colour, turbidity, TSS, TDS, and COD removal. 3:4 and 1:1 Natural Coagulants showed the best overall performance in reducing pollutants. Given their biodegradable and eco-friendly nature, natural coagulants can be an effective alternative to alum for water and wastewater treatment applications.

This approach not only aims to reduce reliance on chemical coagulants but also promotes the use of sustainable, biodegradable options in wastewater management, contributing to improved environmental and ecological outcomes.