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Experimental investigation of *Sterculia foetida* and *Moringa oleifera* as a coagulant for water and wastewater treatment

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ABSTRACT

A study on the coagulant activity of plant-based coagulants, *Sterculia foetida* and *Moringa oleifera*, which identifies their potential in purifying water to curb the crisis of water shortage in developing and underdeveloped nations. This entails the need of a comparatively cheap and affordable water treatment solution to eliminate the shortcomings of chemical aids such as cost and pH. The experimentation is restricted to laboratory-scale treatment of synthetically prepared kaolin solution in distilled water and tap water of initial turbidity 595 and 844 NTU, respectively, and pH 7.8–7.9 with coagulant dosages between 20–800 mg. A novel work on *S. foetida* seeds has been presented which is compared with *M. oleifera* coagulant on the basis of turbidity and pH. The effect of solvents like distilled water, NaCl, and NaOH for active coagulant extraction from seeds is significantly observed on turbidity removal. *S. foetida* shows up to 97% turbidity reduction when NaCl and NaOH are used and 96% with powder dosages. *M. oleifera* extracted in NaCl gives a higher turbidity reduction of 97.4% for 20 mg dosage. The coagulants prepared naturally prove to provide a breakthrough in wastewater treatment, and the industrial scale-up could be a pioneer in cost-effective water treatment methods.

Keywords: Coagulation; *Moringa oleifera*; Soxhlet extraction; *Sterculia foetida*; Turbidity; Wastewater treatment

1. Introduction

Water, as recognized by the United Nation, is one of the basic human rights for sustainable and hygienic living. However, water crisis across the globe is a concern that has gained momentum among various organizations and led them to devise ways to combat contaminated water problems. Globally, about 650 million people lack access to clean and hygienic water resources; whereas India alone has 77 million people who lack access to safe water. In fact, it has been recorded that 21% of communicable diseases are directly related to unsafe water and lack of sanitation. Vellore district in Tamil Nadu suffers from about 89.4% contaminated water sources. Sources of water used for domestic purposes include groundwater, rivers, and ponds which are highly turbid, hence require various stages of treatment before use. The conventional water treatment method comprises of primary, secondary, and tertiary treatment. Primary treatment allows removal of suspended solids up to 50%–60% through coagulation and sedimentation techniques. Presently, the widely recognized water treatment process involves chemical-based coagulants and flocculants like aluminum salts with organic polymers, ferric salts which are really efficient in performance. Coagulation is a method to destabilize colloidal suspensions in water. Colloidal suspensions consist of like-charged particles which tend to settle very slowly as

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they repel each other, when opposite charged coagulant is introduced, particle destabilization occurs. Once the repulsive charges have been neutralized, Van der Waals forces cause agglomeration and micro flocs are formed. These micro flocs are easily settled and separated from water [1,2]. Unfortunately some studies have also proved that intake of water treated by aluminum salts increases the chances of Alzheimer's disease due to high aluminum traces in water, also affects water chemistry [3]. It has been found that some synthetic organic polymers are a cause of neurotoxicity and carcinogenic properties [4]. They also require high cost, large dosage, pH control, and excessive sludge deposition, which demands for an alternative approach which can render cheap and eco-friendly solution to contaminated water crisis in developing countries [5].

The use of natural coagulants has been functional in many developing countries like *Moringa oleifera* seeds, however this traditional method has been in existence for over 4,000 years, but has only recently gained momentum in Indonesia, South America, and North east Africa [6]. Seed of *M. oleifera* is reported to be the most effective water treatment agent for low and high turbidity levels of surface water and groundwater, due to presence of active components identified as cationic peptides, its efficiency ranging from 80%–99% [7]. The plant is cultivated throughout India, Pakistan, and the African continent, its ready availability makes it one of the natural materials to be studied. *Sterculia foetida* has been studied upon due to its uses in bio fuels, medicines, and food. *S. foetida* oil contains cyclopropene fatty acids such as 8,9 methylene-heptadec-8-enoic acid (malvalic acid) and 9,10-methylene-ocadec-9-enoic acid (sterculic acid). The plant is cultivated in E. Asia—India, Sri Lanka, Myanmar, Thailand, Cambodia, Malaysia, and Philippines. Due to easy availability of *S. foetida* seeds, this novel study has been undertaken as a natural coagulant in wastewater treatment. *S. foetida* seeds have been used in biofuel extraction but not in coagulation. The study on *S. foetida* was based on its local availability, cheaper processing cost, and protein content (as widely believed active coagulant agent) as backed by many authors that protein is the active coagulant component in plant-based coagulants [8,9].

2. Material

Materials used in this study were *S. foetida* seeds, *M. oleifera* seed coagulant, *n*-hexane, NaCl, NaOH, distilled water, kaolin, drier, Soxhlet apparatus, domestic grinder (Ascent-AS-11MG), digital nephelometer (Deep Vision 331), digital pH meter, jar test apparatus (Deep Vision, model 1924), electronic weighing balance, and heater.

3. Method

3.1. Collection, preparation, and processing of natural coagulant

The plant material for coagulation tests was collected locally. The seeds of *S. foetida* used for primary treatment of water were freshly collected from VIT University, Vellore, premises and *M. oleifera* was bought from a local market in Vellore. The collected seeds were cleaned and washed with deionized water to remove dirt. Processing of seeds is a crucial step to ensure a good quality coagulant. The important steps involve drying and conditioning which remove moisture and improve flaking, and oil extraction methods using Soxhlet apparatus [10].

3.2. S. foetida seed powder

The seed of *S. foetida* is covered with three layers of shell, the top most layer is manually removed, the middle layer was removed by soaking in distilled water for 15 min, the inner most layer, which is the hardest, requires exposure to high temperatures up to 70°C–90°C for 30 min for de-shelling [12], with careful supervision to avoid roasting of seeds. The seeds contain *S. foetida* oil which was extracted using hexane as a solvent in a Soxhlet apparatus [11]. The dried kernel was homogenized in a domestic grinder before each extraction process to ensure greater surface area for oil removal. Also oil-free seed powder was homogenized and sieved to obtain uniformity. After solvent extraction, a batch of seed powder was dissolved in NaCl and NaOH solution for active coagulant extraction. NaCl and NaOH were each prepared of 1M concentration. About 6g of coagulant powder was dissolved in 200 mL of extraction solvent using a domestic blender for 2 min. The suspension from the blender was filtered through a filter paper and the filtrate was further used as the coagulant. Care was taken to prevent any aging effects due to decay of plant material during storage and experiments were performed with freshly prepared coagulants.

3.3. Oil extraction from S. foetida seeds

Soxhlet apparatus is a semi-batch liquid–solid extraction apparatus which is used here for *S. foetida* oil removal. The solvent used was hexane based on its low boiling point (69°C), high volatility, and low-sensible heat (335 kJ/kg), it is easier to separate from solids and oil. Also hexane is selective and does not affect proteins or sugars in food material [9].

The crushed *S. foetida* seeds, approximately 21 g, are placed in a thimble inside the extraction column of the Soxhlet apparatus of 100 mL capacity. Hexane is placed in the round bottom flask (500 mL) below the extraction column, and it is heated to 70°C. Hexane vapors condense in the condenser column and trickle on the powder. The operation time was 4 h for each batch of powder and each batch extracted 48%–50% by weight of oil from the powder.

3.4. M. oleifera seed powder

The *M. oleifera* seeds were dried along with the pods in a drier at 70°C–80°C for 2–3 h, the seeds were removed from the sticks and the seeds have a greenish white three-sided cover [12]. Two batches of seed powder were prepared; one with seed cover and the other without the cover. The seed kernel was crushed using a domestic mixer and grinder. Homogenized powder was blended in different solvents for 2 min for the purpose of active coagulant extraction [13]. The solvents used for study on *M. oleifera* were distilled water and NaCl (1M). About 6 g of *M. oleifera* coagulant was dissolved in 200 mL each of distilled water and NaCl. Selection of solvents was based on existing studies with variation in concentration [14]. Further, filtration of the suspension gave filtrate of coagulant extract which was used in floc tests in a jar test apparatus.

3.5. Preparation of synthetic water

All the tests of natural coagulants (*S. foetida* and *M. oleifera*) were performed on synthetic water which was prepared using kaolin clay. Both tap and distilled water were used to prepare kaolin solution. About 5 g of kaolin powder was dissolved in 500 mL of each batch of water. Sodium bicarbonate solution of 100 mg/L concentration was prepared, and 500 mL of sodium bicarbonate solution was mixed with 500 mL of kaolin solution to prepare 1 L solution of synthetic water [4,15]. This solution was stirred at 200 rpm for 60 min to allow proper dispersion of particles [15]. After stirring, the solution was left for 24 h to allow the clay particles to hydrate [14]. This method was followed to prepare stock for coagulation experiments throughout the study.

3.6. Collection of sewage water

Sewage water from wastewater treatment plant located in VIT University Vellore campus was collected to test the potential of *S. foetida* seed. The sample collected had initial turbidity of 455 NTU, and each test was performed on the same sample.

3.7. Mechanism of coagulation and flocculation

Most suspended particles in sludge and colloidal solutions have negative surface charge that tends to repel each other and reduce its tendency of settling and agglomeration. Various factors like particle density, size, and liquid density also affect the particle settlement. Coagulation and flocculation allows particle destabilization in a colloidal solution, and the positive-charged coagulant particles allow charge neutralization and micro floc formation which agglomerate and settle down. The process involves addition of coagulants, followed by rapid mixing, and then slow mixing [16] as shown in Fig. 1.

In case of natural coagulants, previous studies have found that natural coagulants contain polymers-repeated functional group units in their structure which govern their coagulation capabilities. Based on the functional group present, they are categorized as cationic or anionic polyelectrolytes and all of the polyelectrolytes are typical hydrophilic colloids. Similar to chemical coagulants, plant-based materials such as *M. oleifera* seeds function too. Protein-based bio materials have found to be effective natural coagulants, previous studies have stated the presence of lipids, carbohydrates, and alkaloids containing free –COOH and –OH groups also affect coagulation. *S. foetida* seed analysis suggests presence of carboxylic acid and amines groups apart from other functional groups through Fourier transform infrared spectrum which confirm its coagulation properties.

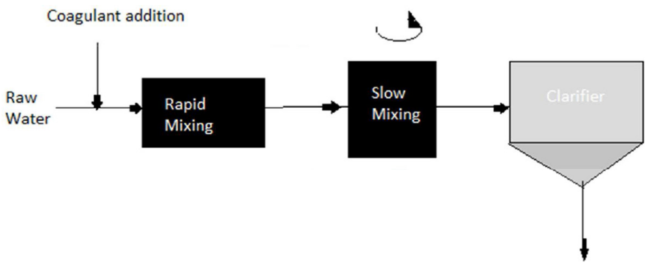

Fig.1. Mechanism of coagulation and flocculation.

3.8. Coagulation test

Coagulation and flocculation was done in a jar test apparatus (Deep Vision, model 1924) equipped with six paddles. Six coagulant mixtures were set for flocculation simultaneously according to the conventional rapid and slow mixing procedures [17]. Initially the mixtures were stirred at 150 rpm for 5 min under rapid mixing to ensure colloidal destabilization and formation of floc nucleus. Later the mixture was stirred slowly at 80 rpm for 40 min to establish contact between destabilized particles [6]. The colloidal solution was left to settle for 24 h. Turbidity and pH after each experiment were measured using a nephelometer (Deep Vision, Model 331) and pH meter, respectively.

4. Results and discussions

4.1. Performance of plant coagulants on turbidity

For coagulation and flocculation to occur conveniently, amount of coagulant used is a key factor. Use of a dosage lower than optimum would affect the performance of the coagulant whereas overdosing would have reversal of coagulation activity by restabilization of suspended solids [7]. From the studies on effect of dosage on floc formation, it has been found that low dosages may not ensure enough energy for formation of bonds [18]. To determine an optimum dose for each coagulant used, a series of tests with varying dosage were performed. The nomenclature of seed used in different solvents and the samples tested is shown in Tables 1 and 2

The optimum dosage (Fig. 2) of extracts of *M. oleifera* (MO-1, MO-2, MO-3, Tables 2 and 3) for the treatment of synthetic kaolin solution prepared in tap water was 20 mg in 350 mL. Each of the three extracts of *M. oleifera* had the

Table 1
Nomenclature of seed coagulant used in different solvents

Different types of seed (as natural coagulant)	Solvent for extraction	Seed covering	Nomenclature
Moringa oleifera	NaCl (1M)	(Removed)	MO-1
	NaCl (1M)	(Intact)	MO-2
	Distilled water	(Intact)	MO-3
Sterculia foetida	NaOH (1M)	(Removed)	SF-1
	NaCl (1M)	(Removed)	SF-2
S. foetida powder	–	(Removed)	SF-3

Table 2
Type and properties of sample water used

Type of sample water	Initial turbidity (NTU)	Initial pH
Kaolin solution in distilled water	595	7.8
Kaolin solution in tap water	844	7.9
Sewage water (WWT plant)	455	7.9

optimum dosage at the same value, where the percentage turbidity reduction was maximum. For MO-1, MO-2, and MO-3 the turbidity reduction was 97.24%, 97.44%, and 97.64%, respectively. This indicates MO-3 being more effective in turbidity reduction. The efficiency of percentage turbidity removal by *M. oleifera* fell steeply after 40 mg dosage.

Similar experimental sampling done with *S. foetida* powder (Fig. 3(a)) pointed out that the optimum dosage for maximum turbidity reduction is 150 mg in synthetic kaolin solution prepared in tap water. However, percentage turbidity reduction fluctuated throughout the study due to series of floc formation and restabilization of solids.

Experiments of *S. foetida* powder done in samples of synthetic kaolin solution prepared in distilled water signify that the turbidity is not as comparable (Fig. 3(b)) as in the case of samples prepared in tap water. Better turbidity reduction in synthetic tap water samples can be accounted to the presence of bivalent cations (Ca^{+2} and Mg^{+2}) in tap water which absorb active components and form net-like structure [6,19]. The maximum reduction in turbidity achieved here is 78.39% for powder dosage of 50 mg in 350 mL. But the pH trend (Figs. 3(c) and (d)) is similar as in case of synthetic samples prepared from tap water, that is, as the dosage increases the pH decreases.

The presence of sterculic acids in traces of sterculic oil in seed powder shifts the pH from basic to slightly acidic (6.5) on pH scale (Figs. 3(c) and (d)) as the coagulant dosage increases.

For the extracts of *S. foetida* extracted using NaOH and NaCl, the reduction in turbidity (Figs. 4(a) and (b)) is quite satisfying. In the case of SF-1, the optimum dosage for the highest turbidity reduction reaches at 50 mg in 350 mL.

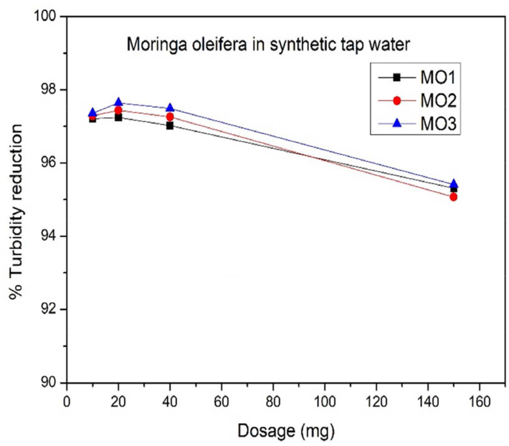

Fig. 2. Percentage turbidity reduction by MO-1, MO-2, and MO-3 in synthetic kaolin prepared in tap water.

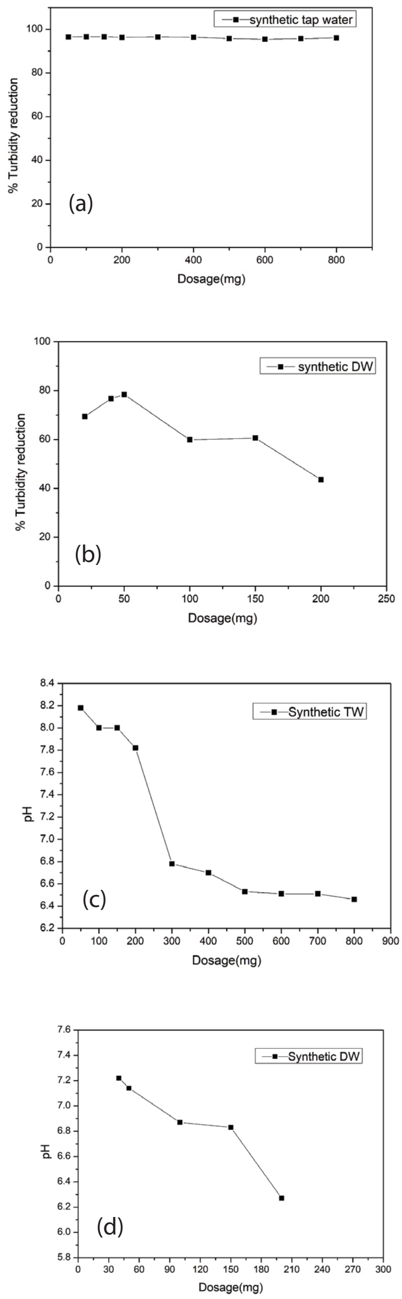

Fig. 3. (a) Effect of *Sterculia foetida* on turbidity reduction for synthetic tap water. (b) Effect of *S. foetida* on turbidity reduction for synthetic distilled water. (c) Effect of *S. foetida* on pH for synthetic tap water. (d) Effect of *S. foetida* on pH for synthetic distilled water.

Table 3
Turbidity reduction by *Moringa oleifera* in synthetic kaolin prepared in tap water

Seed coagulant	Sample water	Initial pH	Initial turbidity (NTU)	Final turbidity (NTU)	Effective dosage (mg)	Percentage turbidity reduction
MO-1	Kaolin in tap water	7.9	844	22	20	97.4
MO-2	Kaolin in tap water	7.9	844	21.6	20	97.44
MO-3	Kaolin in tap water	7.9	844	19.92	20	97.64

But to the contrary in case of SF-2 optimal dosage is 40 mg in 350 mL. The reduction of turbidity for both SF-1 and SF-2 at optimum dosage is 97.54% and 97.42%, respectively. Both solvents have worked remarkably with *S. foetida*. The pH vs. dosage curve obtained from the above results also shows different behavior in both the cases. *S. foetida* extracted in NaOH solvent affected the pH greatly; hence, would require additional pH adjustments if used for coagulation purpose. The results are tabulated as shown in Table 4.

Comparison between *M. oleifera* and *S. foetida*, when synthetic kaolin solution in distilled water was used, exhibits *M. oleifera* is a better coagulant than *S. foetida* powder. The observation states that MO-1 was more effective (Fig. 5) in turbidity reduction of the samples followed by MO-2. *S. foetida* is less effective than MO-1 and MO-2 in turbidity removal for the synthetic kaolin solution prepared in distilled water. The maximum reduction achieved was 93.30% using MO-1.

4.2. Sewage water analysis

Effect of *S. foetida* (SF-1 and SF-2) on turbidity removal of sewage water was tested in dosages of 20, 40, 60, 80, and 100 mg per 400 mL of sample solution. The results of SF-1 were found (Fig. 6 and Table 5) to be more satisfactory than SF-2. Optimum dosage of SF-1 and SF-2 was 60 mg

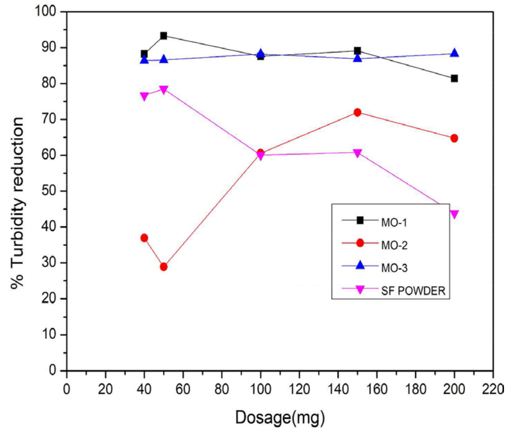

Fig. 5. Comparison of percentage turbidity reduction of *Moringa oleifera* and *Sterculia foetida* in synthetic water prepared in tap and distilled water.

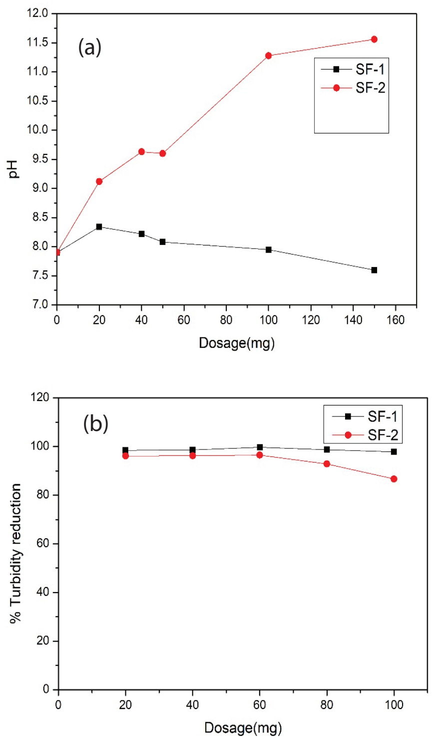

Fig. 4. (a) Effect of pH on dosage of *Sterculia foetida* in solvents. (b) Effect dosage on turbidity reduction of *S. foetida* in solvents.

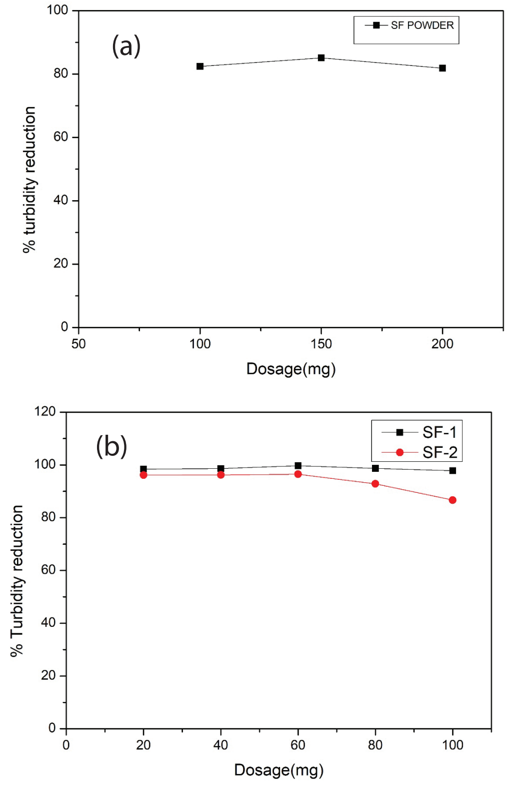

Fig. 6. Performance of *Sterculia foetida* in sewage water sample.

Table 4
Turbidity reduction by *Sterculia foetida* (SF-3) in synthetic kaolin prepared in tap and distilled water

Seed coagulant	Sample water	Initial pH	Initial turbidity (NTU)	Final turbidity (NTU)	Effective dosage (mg)	Percentage turbidity reduction
SF-1	Kaolin in tap water	7.9	844	20.76	50	97.54
SF-2	Kaolin in tap water	7.9	844	21.77	40	97.42

Table 5
Turbidity reduction by SF-1 and SF-2 in kaolin prepared in tap water

Seed coagulant	Sample water	Initial pH	Initial turbidity (NTU)	Final turbidity (NTU)	Effective dosage (mg)	Percentage turbidity reduction
SF-1	Sewage water	7.9	455	5.0	60	99
SF-2	Sewage water	7.9	455	15.7	60	96.54

each in 400 mL of wastewater sample. A total of 99% and 96.4% turbidity reduction was achieved with SF-1 and SF-2, respectively.

5. Conclusion

Tests with *S. foetida* as a biomaterial for coagulation and flocculation was found to be more satisfactory with seeds extracted in NaOH (1M) and NaCl (1M) solvents; where turbidity reduction up to 97.54% and 97.42% was obtained with an optimum dose of 20 mg in 350 mL, compared with *S. foetida* powder. Addition of *S. foetida* coagulant affected the pH of water slightly, shifting the pH down the scale with increase in dosage; exception in case of NaOH as solvent where pH gradually increased with increasing dosage. *S. foetida* seed extracted in solvents showed remarkable results in treating highly turbid sewage water (455 NTU) with an optimum dosage of 60 mg in 400 mL in appreciable settling time of 4 h. Results have justified its real-time application for primary treatment of wastewater.

Study on *M. oleifera* achieved percentage turbidity removal up to 97.24% with seeds extracted in NaCl solvent of 1M concentration in synthetic kaolin water (595 NTU). Optimum dosage of 20 mg in 350 mL of water was noted for highest efficiency. Both sodium chloride (NaCl) and sodium hydroxide (NaOH) are found to be good solvents for active coagulant extraction from plant-based material, with similar percentage turbidity reduction by each.

From the results, it can be inferred that *S. foetida* has the potential to be used as a natural coagulant for high turbid water and its low dosage, feasibility, and minimal effect to pH makes it a viable option for primary treatment of wastewater.

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