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Turbidity removal through the application of powdered *azadirachta indica* (neem) seeds

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ABSTRACT

Various natural products used for water treatment are becoming more popular due to their general safety, eco-friendly sludge production, ease of degradation, cost-effectiveness, and local availability. This research assessed the efficiency of powdered neem (*Azadirachta indica*) seeds in removing turbidity from the water. Batch experiments determined the optimum coagulant dose, pH level, mixing time, and mixing speed to reduce turbidity from kaolin-based synthetic turbid water. Powdered neem seeds with a pore size of about 0.45 mm were prepared and used in water treatment under optimum conditions. Results showed that a coagulant dose of 3 g of neem seeds/L, 13.2 pH level, 60 mins mixing time at 80 rpm mixing speed could reduce turbidity levels to 35 NTU from 250 NTU (86% removal). Findings suggest that powdered neem seeds can be a potential substitute for conventional chemical coagulants for drinking water treatment.

1. Introduction

Many developing countries face a lack of access to clean drinking water at affordable prices. There is a need to develop low-cost and efficient water treatment alternatives that are feasible and sustainable [1]. Coagulation is a workable water treatment process for removing dissolved organic material and reducing colloidal particles [2,3]. When large amounts of dissolved organic material are present, water may exhibit discoloration and have an unpleasant odour and taste [4,5]. In addition, coagulation can reduce suspended particles and inorganic residues (e.g., iron hydroxides) [6]. The coagulation process can also eliminate some pathogens (i.e., viruses and bacteria) associated with the coagulated particles [7]. The World Health Organization (WHO) reported that up to 84% of viruses and 87% of bacteria could be reduced by sedimentation and coagulation, although results varied considerably [8].

Various synthetic organic polymers [9] and inorganic coagulants (e.g., aluminum sulfate [10,11], ferric chloride [10], calcium carbonate [10]) are often used as coagulants in drinking water treatment systems [12]. Conventionally, these chemicals can be effective in removing impurities from drinking water, but they present certain limitations. These chemicals are often high in price, and the discharge of the resultant sludge can impart environmental costs [13]. Furthermore, some studies showed residual amounts of alum and polyaluminium chloride in treated water, which some researchers claim present health impacts [14]. However, the primary concern in remote areas is simply the availability of coagulants for drinking water treatment.

The coagulation process can effectively remove suspended solids in drinking water despite the potential drawbacks of chemical coagulants. The positive coagulant charge neutralizes the negative charge on suspended particles in water. When this destabilization reaction occurs, the particles begin to bind together (coagulate). The particles will then increase in size to form flocs during flocculation. Finally, sedimentation will occur as larger flocs settle down in the solution.

Researchers are investigating coagulants extracted from natural bioproducts that are biodegradable and non-toxic for human health. Natural coagulants like cactus and okra [15], acorn [16], moringa oleifera [17], etc., offer an alternative way to decrease turbidity in drinking water [18]. Neem (*Azadirachta indica*), a tree belonging to the mahogany family, is a medicinal plant that receives attention for its use in various applications [19]. All the parts of the neem tree, including the leaves [20-22], bark, flowers, fruits, seeds (and seed oil), and roots [23,24], have shown promising results in water and wastewater treatment, as well as Ayurvedic, Unani and homeopathic medicines [25].

This research was conducted to examine the efficacy of applying powdered neem seed as a coagulating agent to reduce turbidity levels in drinking water. The study aims to determine whether powdered neem seeds, an environmentally friendly material, are a safe and cost-effective coagulant capable of removing turbidity in water to reach the WHO permissible limit of less than 5 NTU [26].

2. Materials and Methodology

2.1 Materials

Hydrated aluminum silicate (kaolin) of 99% purity was purchased from Sigma Aldrich (USA). Batch mixing was carried out in a 1 L beaker made of Pyrex glass.

Powdered neem seeds have been shown to display a general chemical structure of $C_{35}H_{44}O_{16}$ (Fig. 1), with a molecular weight of 720 g/mol [27]. A 0.45 mm sieve was used to separate the ground powdered neem seeds for use as a coagulant.

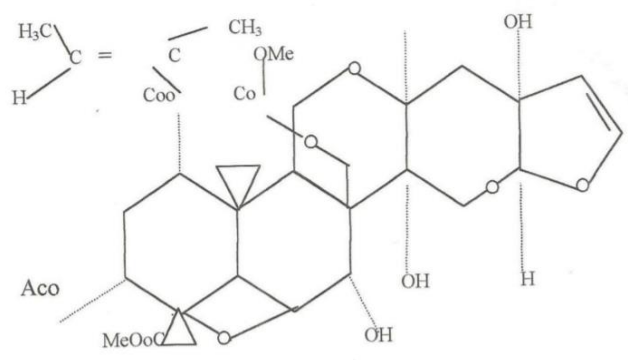

Fig. 1. The chemical structure of a primary component found in *Azadirachta indica* (neem) seeds [28]

2.2 Analytical Methods

Turbidity was measured using a turbidity meter (Lovibond TB 210 IR, USA), and pH was measured using a pH meter (HI 8424, USA). Fourier Transform Infrared Spectrometry (FTIR) (Nicolette IS10, USA) was applied to identify organic molecular groups and compounds. The specific surface area of powdered neem seeds was analyzed through Brunauer-Emmett-Teller (BET) (Autosorb-1 Quanta-chrome der Firma, USA). The BET surface area was calculated by Sear's method using equation (1):

$$S = 32V - 25 \tag{1}$$

Where V (mL) is the volume of sodium hydroxide used to attain a pH range from 3 to 9, and S (m^2) is the surface area [29].

2.3 Preparation of Coagulant

Powdered neem seeds were prepared using various unit operations, including washing, drying, grinding, and filtering. The neem seeds were thoroughly cleaned to remove dust to increase their uniformity. The washed neem seeds were dried at 50°C in an oven to eliminate the moisture content. A grinder converted the neem seeds into fine powder to easily extract the coagulating components.

In practice, the smaller the particle sizes in coagulation, the greater the contact area with the particles to form flocs [30]. In this case, the seeds were ground to form particle sizes of 0.45 mm through a # 45 mesh sieve to screen the coagulant. Powdered neem seeds (100 g) were used to activate the bio-coagulant, mixed in 1 L of distilled water, then agitated with a magnetic stirrer for 1 hr at a constant speed (100 rpm). Then using gravitational separation, the stirred neem seed solution was filtered through filter paper (1µm).

2.4 Preparation of Synthetic Turbid Water

Turbidity was synthetically created in deionized water by adding hydrated aluminum silicate (kaolin) to perform the coagulation experiments. Varying turbidity levels were prepared by adding 0.5 to 5 g of kaolin powder into 1 L of distilled water to make a solution. The mixing speed was initially set to 120 rpm, then reduced in increments of 5 rpm, ultimately determining an optimal mixing speed of 80 rpm. The solution was mixed thoroughly at 80 rpm for 60 mins to get smooth diffusion of the kaolin particles [31]. A turbidity level of 250 NTU was achieved by allowing the solution for 24 hr in the beaker and adjusting pH by adding 0.1 M NaOH/ 0.1 M HCl for different values of pH (i.e., 2, 4, 6, 8, 10, 12 and 14).

2.5 Coagulation and Sedimentation

Jar experiments were performed to assess the coagulant separation through coagulation and sedimentation. For analyzing the coagulation samples at a constant room temperature, 1 L of turbid water at 250 NTU was used in each jar. Different doses (i.e., 1-5 g of powdered neem seeds) were added to each jar and mixed. For mixing, a 1-L beaker was kept on the magnetic stirrer for 1 hr at different mixing speeds (0-120 rpm). A similar method was used with varying intervals of mixing time (0-100 mins) to achieve the highest removal, then the suspended particles in the samples were allowed to settle for 6 hrs.

After sedimentation, the samples were collected from the top of the jars and filtered through Whatman filter paper (1 µm) to eliminate residual sediments. The turbidity (TS) of the filtered samples was measured using a turbidity meter. The same process was also applied without adding a coagulant to check the removal of synthetic turbid water's initial turbidity (TA). Every test was repeated thrice for reliability and accuracy. The bio-coagulation activity was calculated by using equation 2 as follows [32]:

$$\text{The percentage of coagulation activity} = \frac{T_A - T_S}{T_A} \times 100 \quad (2)$$

Where TA= Turbid water without coagulant and TS = Turbid water with coagulant

2.6 Batch Experiment

Jar experiments were performed both with and without coagulant (i.e., powdered neem seeds) to determine the optimal coagulant dose for eliminating turbidity at various mixing times, speeds, and pH levels.

3. Results and Discussion

3.1 Fourier Transform Infrared Spectrometry (FTIR) Analysis

FTIR was used to identify the functional groups in the neem material. Different vibration frequencies of functional groups change when light falls on a sample [33]. The wavenumber of the instrument was adjusted at 500-4000 cm^{-1} (Fig. 2). Table 1 indicates the observed wavelengths emitted by the powdered neem seed, which correspond to hydroxyl, alkyl, carbonyl, alkane, and acetate functional groups.

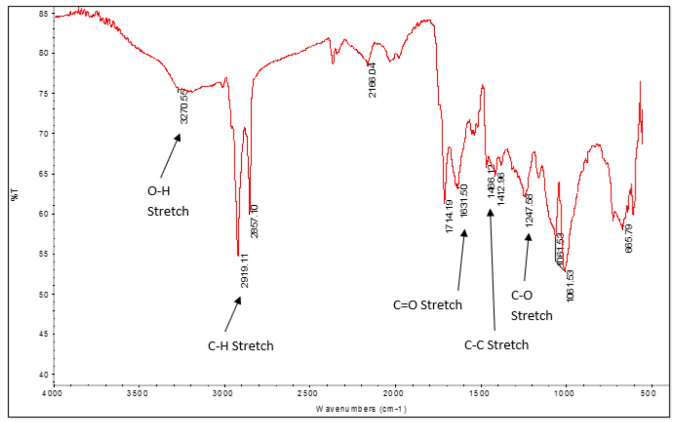

Fig. 2. FTIR spectrum of powdered neem seeds

Table 1

FTIR analysis of powdered neem seeds

Frequencies (cm^{-1})	Functional Groups	Assignments
3270.55	Hydroxyl group	O-H Stretch
2919.11	Alkyl group	C-H Band
1631.50	Carbonyl group	C=O Stretch
1466.12	Alkane group	C-C Stretch
1247.58	Acetate group	C-O Stretch

3.2 Mixing Time Effects

Experiments examining the effects of mixing time were conducted for a maximum of 100 min, with samples taken at 20 min interval. The maximum (48%) turbidity removal was achieved at 60 min. The turbidity removal rate increased with increasing mixing time, and this increase continued up to 60 min, while during higher mixing times, the removal efficiency decreased. As a result, 60 min was chosen as the optimum mixing time. This decrease in removal efficiencies could be due to the re-suspension of colloidal particles after enough floc formation [34]. At optimum mixing time, large floc generation was achieved and began to settle, so the efficiency plateaued (Fig. 3).

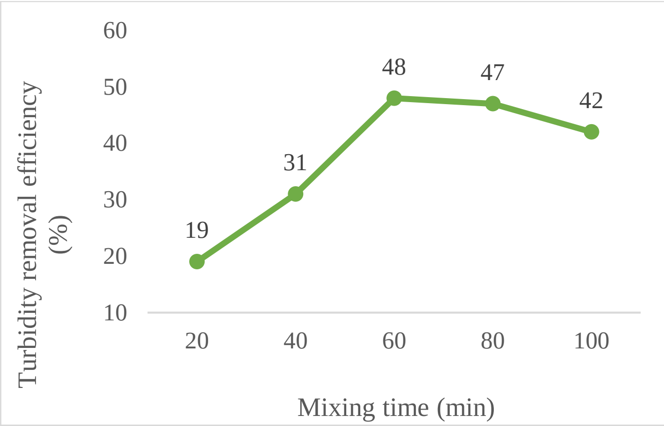

Fig. 3. Effect of mixing time on turbidity removal

3.3 Coagulant Dose Effects

Coagulant dose is one of the most critical parameters to ascertain the optimum performance of coagulation and flocculation processes. Insufficient or overdose can lead to poor performance in the flocculation process. Thus, it is also essential to find out the optimum dose to reduce the cost of coagulant and sludge production to achieve optimum performance [22].

For the initial turbidity (i.e., 250 NTU), the turbidity removal efficiencies of 44%, 61%, and 86% were achieved at doses of 1, 2, and 3 g/L, respectively (Fig. 4).

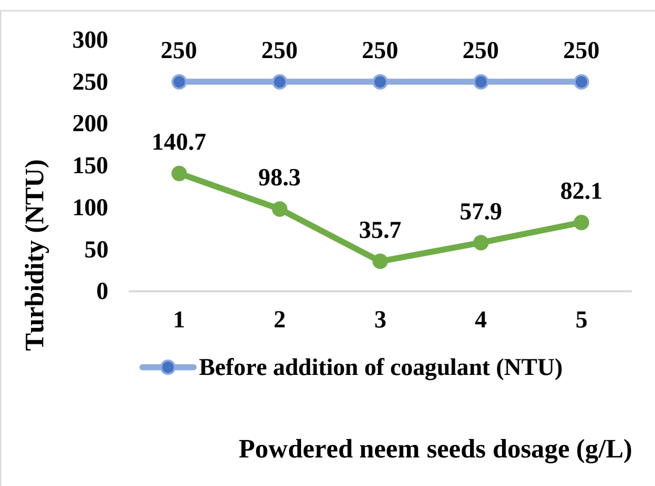

Fig. 4. Effect of powdered neem seed dosage on turbidity removal

For 4 and 5 g/L, removal efficiencies were reduced to 77% and 67%, respectively. The effectiveness at 3 g/L is higher than that at 4 and 5 g/L. The coagulation function did not work well at a coagulant dosage above 3 g/L due to floc formation failure. It is likely that the polymers in the powdered neem seed cover the whole surface area of the suspended particles. Consequently, there is little adhesion, which hinders the flocculation process and allows colloidal particles to return to or remain in suspension [35,36]. Therefore, 3 g/L was taken as the optimum dosage, which resulted in the highest (86%) turbidity removal.

3.4 Mixing Speed Effects

The mixing speed of the stirrer is a critical factor in the coagulation process [37]. Various speeds up to 120 rpm were attempted to achieve the ideal rpm for tests. The optimum speed was found to be 80 rpm (Fig. 5), which resulted in the highest turbidity removal efficiency of 86%. The speed is instrumental in producing flocs due to flocs' thickness and weight, which might be affected by the speed of the impeller or the sharp edge of a blade during the coagulation process.

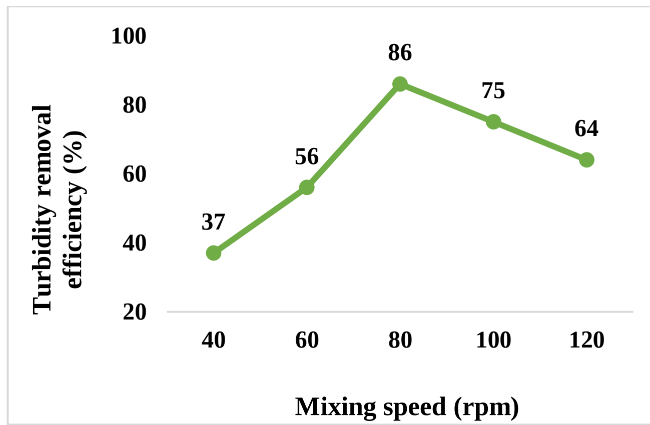

Fig. 5. Effect of mixing speed (rpm) on turbidity removal

3.5 Effect of pH

Coagulation is significantly influenced by pH [38], a phenomenon observed in this study (Fig. 6).

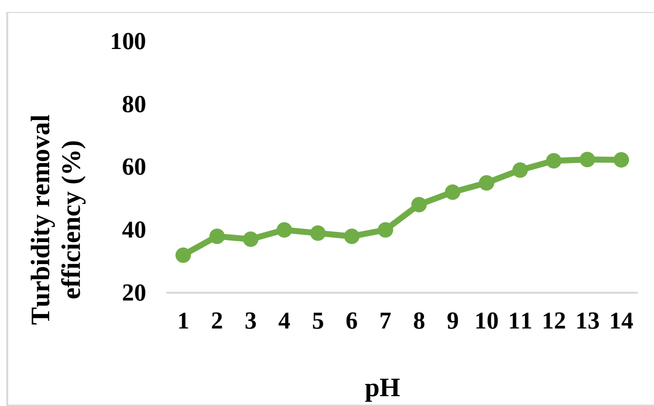

Fig. 6. Effect of pH on turbidity removal

The coagulation efficiency was highest (86%) at a basic pH level of 13.2, while the powdered neem seeds at a pH value of 3 attained the lowest removal efficiency of suspended particles. With increasing pH levels, the turbidity removal efficiency was raised, and it continued up to a pH value of 13.2. In contrast, the turbidity removal efficiency remained almost constant at a higher pH level. Neutral or alkaline conditions of solution showed higher removal efficiencies than acidic conditions. It also depicted a direct relation between pH and turbidity removal efficiency of powdered neem seeds [34].

3.6 Comparison with Conventional Chemical Coagulants

Table 2 compares powdered neem seeds, a natural plant-based product, with conventional chemical products. Although alum and iron provide removal efficiencies of about 99% [39-44], these can cause environmental burdens due to hazardous sludge production [13], and can lead to health issues such as neurological and carcinogenic impacts [14,45]. Although powdered neem seeds provide a removal efficiency of about 86% which is less than standard coagulation-inducing chemicals, it has the added benefit of ensuring environmental safety and human health [16-18]. This study suggests powdered neem seeds may serve as an alternative to traditional chemical coagulants.

Table 2

Comparison of powdered neem seeds as a bio-coagulant with conventional chemical coagulants

S.No.	Coagulants	Turbidity causing agents	Types of water	Starting NTU	Dose	pH	Time Mins.	Speed (rpm)	Efficiency	Reference
1	Powdered neem seeds	Kaolin	Synthetic turbid water	250	3 g/L	13.2	60	80	86%	Current study
2	Alum	Mud	Muddy water	250	0.25 g/L	6	30	100 rpm for 2 min	80%	[46]
3	Alum	-	Surface water	40	0.1 - 0.3 g/L	7	10	100 rpm for 10 min	90%	[43]
.4	Alum	-	Wastewater	1275	1.09 g/L	10.6	1-5	80-250	98.5%	[41]
5	Alum	-	Domestic wastewater	150	30 mg/L	6.2	8	-	91%	[44]
6	Alum	-	Landfill leachate	50	600 mg/L	4	20	300	60.4%	[39]
7	Iron	Kaolin	De-ionized water	15	0.07 mg/L	8.5	11	250 rpm fast; 40 rpm slow	96.3%	[40]
.8	Iron (potassium ferrate)	-	Water and wastewater	-	2.5 mg/L	< 8	18	-	99.9%	[42]

4. Conclusion

This study aimed to determine the effectiveness of powdered neem seeds as a coagulating agent for water treatment by optimizing coagulant dose, pH level, mixing time, and mixing speed. Results revealed that the powdered neem seeds provided maximum turbidity removal of approximately 86% at 3 g of neem seeds/L, 13.2 pH level, 60 mins mixing time at 80 rpm mixing speed. It was observed that the removal efficiency exhibits a direct relation to increases in pH. This research was conducted on synthetic water, but further research on real water is recommended. This environmental-friendly bio-coagulant has the potential to treat turbid water and warrants further investigation to explore new inedible options of natural sources of coagulants with medicinal properties. It is concluded that the powdered neem seeds can contribute to achieving the sixth UN Sustainable Development Goal (6.1) that ensures equitable access to safe and affordable drinking water for all.

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