Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.1003977

57 (2016) 5488–5497
March

Taylor & Francis
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Experimental study on parameter estimation and mechanism for the removal of turbidity from groundwater and synthetic water using *Moringa oleifera* seed powder

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Received 25 June 2014; Accepted 29 December 2014

ABSTRACT

In the present work, *Moringa oleifera* seed powder was prepared and it was applied for the removal of turbidity from the groundwater and synthetic water. The characterization of the *M. oleifera* seed powder was carried out by Fourier transform infrared spectroscopy (FT-IR) and scanning electron microscopy (SEM) analyses. The FT-IR results observed the presence of different chemical functional groups in the *M. oleifera* seed powder and the SEM analysis showed a smooth surface with rough peaks and pores in the *M. oleifera* seed powder. The laboratory jar test procedures were applied for the conduct of experimental runs. The turbidity of the groundwater and synthetic water were varied from 50 to 135 NTU. The effect of operating parameters such as initial turbidity, *M. oleifera* dosage, and pH of the solution were optimized for the maximum removal of turbidity. The results of the coagulation activity of *M. oleifera* showed that the removal of turbidity lay in between 55 and 75% for synthetic turbid water and only 46–69% for groundwater at an optimum pH of 6–7. The obtained experimental values were applied to the Langmuir and Freundlich isotherm model, to check the influence of sorption of the particles onto the *M. oleifera* seed powder. The goodness of fit of experimental data was observed with Langmuir isotherm model, indicating a monolayer sorption of particles onto the *M. oleifera* seed powder. It was observed from the isotherm study indications that the sorption may also be influenced in the removal of turbidity to some extent from the groundwater and synthetic water.

Keywords: Coagulation; Isotherms; *Moringa oleifera*; NTU; Turbidity

1. Introduction

Coagulation has remained the most widely used method of removing particulate and organic matter in water treatment. The turbidity in water is due to the presence of colloidal particles. Turbidity removal is one of the important steps in water treatment process, which is generally achieved using coagulant [1–3]. Many coagulants are widely used in conventional

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water treatment processes based on their chemical characteristics. These coagulants are classified into inorganic, synthetic organic polymer, and natural coagulants [4]. An inorganic polymer, poly aluminum chloride and inorganic salt, "Alum" are the most widely used coagulants in water treatment. However, some studies have reported that the aluminum, which is the major component of alum and PVC, may induce Alzheimer's disease [5–8]. It was also reported that the monomers of some synthetic organic polymers such as acrylamide have neurotoxicity and strong carcinogenic properties [9–11]. Also, there is a problem of low efficiency coagulation in cold water and the reaction of alum with natural alkalinity in water which leads to the reduction of pH of the water stream [12].

Moringa oleifera is the most widely cultivated species of the genus Moringa, which is the only genus in the family Moringaceae. The Moringa tree is grown mainly in semi-arid, tropical and sub-tropical areas; grows best in dry sandy soils, tolerates poor soil, including coastal area. It is a fast growing, drought resistant tree that is native to the foot hills of the Himalayas in North Western India. It is considered as one of the world's most useful trees because almost every part of the tree is used for one or the other beneficial property [13–16]. Among many found in nature, the simple species *M. oleifera* exhibits excellent properties of treating water [17–19], besides having many medicinal and nutritional values within. *M. oleifera* seeds have anti-microbial activity and are utilized for wastewater treatment in Sudan by rural women to treat highly turbid Nile water [20]. The seeds of *M. oleifera* are considered to be antipyretic, acrid, and bitter. Moringa seed kernels contain oil that is commercially known as "Ben oil" or "Behen oil" which is used by watchmakers for illumination and lubrication of delicate mechanisms [21]. Toxicology studies conducted so far reported that *M. oleifera* seeds do not constitute a serious health hazard [22]. The active components in Moringa seeds were found to be soluble cationic proteins having molecular weight of about 13 kDa and isoelectric pH value of 10 and 11 [23].

In the present study, the *M. oleifera* seeds have been prepared and tested for the removal of turbidity from the groundwater as well as from the synthetic water. The characterization of the *M. oleifera* seeds have been done with Fourier transform infrared spectroscopy (FT-IR) and scanning electron microscopy (SEM) analyses. The effects of operating variables such as initial turbidity, *M. oleifera* dosage, and pH on the removal of turbidity were also reported in this report. The experimental data was fitted to the Langmuir and Freundlich sorption isotherm models to check the influence of sorption in the removal of turbidity from the solutions.

2. Experimental

2.1. Preparation of M. oleifera seed powder

Dry *M. oleifera* seed powder was used as the coagulant in this study. The seeds were obtained from Erode district, Tamil Nadu, India. The pods were allowed to mature and dry to a brown color on the tree. The seeds were then removed from the harvested pods and were stored with winged seed covers at room temperature. The winged seed cover was manually removed, good quality seeds were selected, and the kernel was ground to a fine powder using an electric blender. The powder was subjected to mesh analysis to determine the average particle size. The mesh analysis was done in a sieve shaker. The sized down powder was then stored in an airtight container. The surface morphology studies of the Moringa powder was studied using SEM analysis. This test was done to check the influence of sorption in this process, being a solid–liquid system; there are high chances of the solid material getting sorbed on the surface. The SEM analysis was done to check the irregularities in the surface, which in turn gives a good amount of information about the magnitude of sorption. The FT-IR analysis was carried out to check the nature of the charge present in the *M. oleifera* seed powder. The predominant functional groups present in the *M. oleifera* powder were also found out. The FT-IR analysis was done at the Chennai industrial co-operative analytical laboratory Ltd. and the SEM analysis at University of Madras, Guindy Campus, 600 025, Chennai.

2.2. Screen size analysis of M. oleifera seed powder

The size distribution is of critical importance to the way the material performs in use. In this study, after grinding the *M. oleifera* seeds, it was subjected to mesh size analysis in a mechanical sieve shaker following the horizontal and tapping sieving method. The obtained weight fraction values were presented in Tables 1 and 2. The particle size distribution graph was plotted between mass fraction (and cumulative mass fraction) in y axis and particle size in x axis (Figs. 1 and 2).

Volume-surface mean diameter is given as follows:

$$D_s = \frac{6}{\Phi_s A_w \rho_p} \tag{1}$$

Table 1
Weight distribution

Mesh no	Weight (g)
Above 42	47.3
48	29.5
60	4.7
80	1.1
Pan	0.3
Total	82.9

The specific surface area (the total surface area of a unit mass of particles) is given as follows:

$$A_w = \frac{6}{\Phi_s \rho_p} \sum_{i=1}^{n} \frac{x_i}{D_{pi}} \quad (2)$$

Volume-surface mean diameter is further given as follows:

$$D_s = \frac{1}{\sum_{i=1}^{n} \frac{x_i}{D_{pi}}} \quad (3)$$

where Φ_s is the sphericity of the particle, A_w is the specific surface area (the total surface area of a unit mass of particles), ρ_p is the particle density, D_{pi}—average particle diameter, x_i—mass fraction in a given increment, n is the number of increments, and D_s is the volume-surface mean diameter. The average particle size of the *M. oleifera* seeds powder was found out to be 0.37192 mm.

2.3. Ground water samples collection

The coagulation tests were done on real time ground water sample, collected from areas of Anna Nagar, Chennai, Tamil Nadu, India. This was done to check the efficiency of *M. oleifera* seed powder in treating the drinking water of lower turbidity as well. The residual turbidity of the collected groundwater sample was found to be 130–145 NTU.

2.4. Preparation of synthetic turbid water

The synthetic turbid water samples were prepared based on the groundwater turbidity by adding kaolin into tap water. Ten grams of kaolin was added to 1 L of tap water. The suspension was stirred slowly at 35 rpm for one hour in a magnetic stirrer for uniform dispersion of kaolin particle. The suspension was then allowed to stand for 24 h at room temperature to allow complete hydration of the kaolin. This kaolin suspension was used as a stock solution for the experiments. Small amounts of the stock solution were diluted to one liter using tap water to prepare synthetic turbid water of various turbidity levels. The initial pH of the kaolin suspension prepared just before the coagulation tests was found to be 7.5 ± 0.1. The initial turbidities of the made up solutions were measured using an electronic digital turbidimeter (SANSEL Instruments India Pvt Ltd.). The results were compared to that of groundwater and the parameters were adjusted accordingly.

2.5. Coagulation tests

The coagulation studies were performed using Jar test apparatus, which comprises six stirrers simultaneously rotating with a rotational speed which could be varied from 0 to 150 rpm.

2.5.1. Effect of initial turbidity on the removal of turbidity

Five 1 L beakers were filled with diluted kaolin test solutions (1 L) and were placed on the slots in the jar tester. The well-grounded *M. oleifera* powder with different dosage levels was added in each of the beakers and the solution was subjected to rapid mixing at 150 rpm for 2 min followed by slow mixing at 30 rpm for 30 min. The solutions were kept undisturbed for 1 h for sedimentation. After sedimentation, residual turbidity of each of the supernatant sample was measured using the turbidimeter. The final turbidity readings were tabulated for further calculations. In

Table 2
Screen analysis

Mesh no.	Standard size (mm)	Mass fraction	Avg. particle diameter, D_{pi}, (mm)	Cumulative mass fraction
35	0.500	0	–	0
42	0.3936	0.5705	0.4053	0.5705
48	0.3198	0.3558	0.3567	0.92641
60	0.25	0.05669	0.2849	0.93811
80	0.177	0.01327	0.2135	0.99638
Pan	0.149	0.00366	0.1630	1

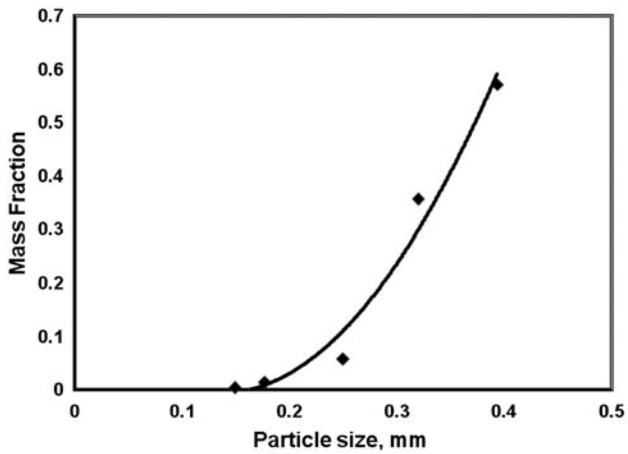

Fig. 1. Particle size distribution for *M. oleifera* seed powder: differential analysis.

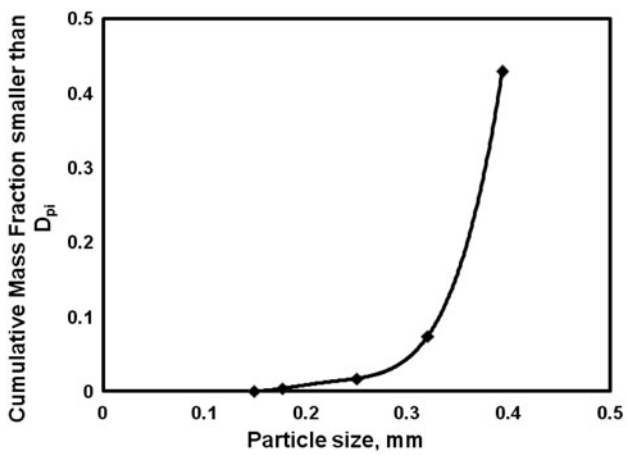

Fig. 2. Particle size distribution of *M. oleifera* seed powder: cumulative analysis.

this study, the *M. oleifera* dosage and pH was kept at constant of 1.0 g and 6–7, respectively. Five different initial turbidities such as 50, 75, 100, 120, and 135 NTU were studied in this experiment.

The coagulation tests were conducted in groundwater samples, so as to check the efficiency of *M. oleifera* in treating drinking water as well. The residual turbidity of the collected groundwater sample was found to be 135 NTU. The same procedure was followed for groundwater. The beakers were filled with 1 L groundwater, same amount of Moringa powder was added, and the solutions were subjected to same timings of mixing. The initial turbidities considered in this case were 50, 75, 100, 120, and 135 NTU. The percentage of turbidity removal was calculated from the following relationship:

$$\% \text{ Removal} = \frac{\text{Initial turbidity} - \text{Final turbidity}}{\text{Initial turbidity}} \times 100 \quad (4)$$

2.5.2. Effect of M. oleifera *dosage on the removal of turbidity*

In order to investigate the optimum *M. oleifera* dosage for the turbidity removal, dosages in the range 0.5–2.5 g were added to the different beakers containing 50–135 NTU of test solutions. This experimental study was carried out, which is similar to the previous experimental procedures.

2.5.3. Effect of pH on the removal of turbidity

pH studies were carried out to find the optimum pH level at which *M. oleifera* seed powder provides the maximum removal efficiency. To examine the effect of pH on the turbidity removal, several experiments were performed at different pH ranges from 5.0 to 9.0 and other parameters such as initial turbidity and *M. oleifera* dosage were kept at constant. The initial pH of the kaolin test solution was measured using a pH meter (ENICO instruments Ltd.). Buffer solutions were used in small amounts to adjust the pH of the test solutions. After the adjustment of pH, the *M. oleifera* seed powder was added in each solution, at the same dosage levels as before. The same procedure was repeated with same timings for mixing. After sedimentation, the final pH of the solution was measured before the turbidity measurements. The initial and final residual turbidities of the test solutions were estimated.

2.6. Sorption isotherms

The experimental data obtained from the effect of initial turbidity studies were fitted to the different sorption isotherms. In this study, the Langmuir (1918) and Freundlich (1906) sorption isotherm models were applied to check the influence of sorption in the removal of turbidity using *M. oleifera* seed powder. According to Langmuir isotherm model (1918), the sorption of sorbate occurs uniformly on the active sites of the *M. oleifera* seed powder and once an adsorbate occupies an active site, no further sorption can take place at this site. Langmuir isotherm model can be represented as follows:

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \quad (5)$$

The linear form of Langmuir isotherm model can be represented as follows:

$$\frac{1}{q_e} = \frac{1}{q_m K_L}\frac{1}{C_e} + \frac{1}{q_m} \tag{6}$$

where q_e is the equilibrium sorption capacity (mg/g), q_m is the maximum monolayer sorption capacity (mg/g), K_L is the Langmuir equilibrium constant (L/g), and C_e is the equilibrium concentration or final concentration of suspended solids (mg/L). To determine the sorption process, a dimensionless constant called separation factor R_L is used. The separation factor is expressed as follows:

$$R_L = \frac{1}{1 + K_L C_o} \tag{7}$$

where C_o is the initial concentration of suspended solids (mg/L). The value of R_L gives information about the nature of sorption ($0 < R_L < 1$—favorable sorption, $R_L > 1$—unfavorable sorption, and $R_L = 0$—irreversible sorption).

Freundlich sorption isotherm model (1906) assumes that multilayer sorption takes place onto a heterogeneous surface. Freundlich isotherm model can be written as follows:

$$q_e = K_F C_e^{1/n} \tag{8}$$

The Linear form of Freundlich isotherm model can be represented as follows:

$$\log q_e = \frac{1}{n}\log C_e + \log K_F \tag{9}$$

where K_F is the Freundlich constant ((mg/g)(L/mg)$^{(1/n)}$) related to the bonding energy and n is a measure of the deviation from linearity of sorption. Value of n indicates the degree of non-linearity between solution concentration and sorption ($n = 1$, sorption is linear; $n < 1$, sorption is chemical process, and $n > 1$, sorption is favorable physical process). The magnitude of the influence of sorption, nature, either monolayer or multilayer, and its connectivity with coagulation was identified from these isotherm studies.

3. Results and discussion

3.1. FT-IR analysis

The vibrational spectrum of a molecule is considered to be a unique physical property and is a characteristic of the molecule. As such, the infrared spectrum can be used as a fingerprint for the identification by the comparison of the spectrum from an unknown with previously recorded reference spectra. In this case, the FT-IR studies were carried out to deduce the specific functional groups present in the sample and the nature of charge in the sample. The functional group data would give an insight into the sorption capability of *M. oleifera* seed powder and knowledge about the charge gives the amount of extent of coagulation in this process. Fig. 3 gives the FT-IR spectra of *M. oleifera* seed powder sample. The interpretation of infrared spectra involves the correlation of absorption bands in the spectrum of an

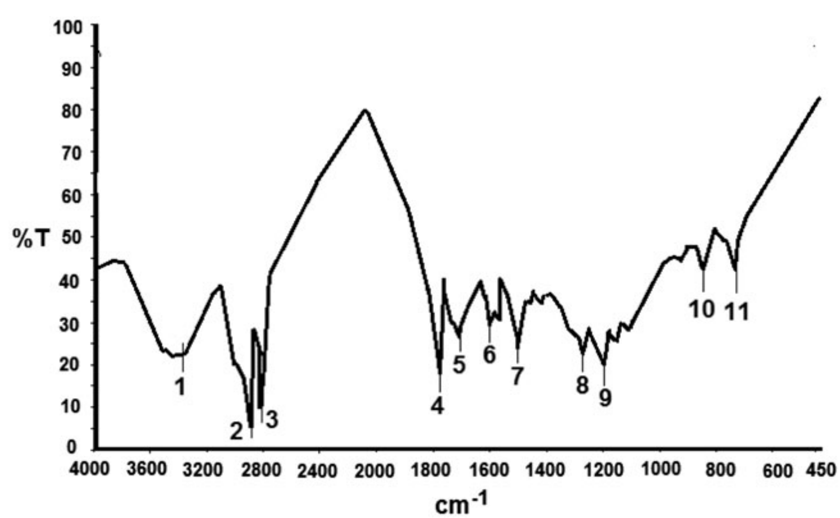

Fig. 3. FT-IR spectra of *M. oleifera* seed powder.

Table 3
Peak positions of FTIR spectra

Peak no.	Position (cm^{-1})	Functional group
1	3317.93	Hydroxyl group, H—bonded OH stretch
2	2927.41	Methylene C–H asym. stretch
3	2853.17	Methylene C–H sym. stretch
4	1746.23	Ester (C–O–C)
5	1656.55	Amide (C–N or N–H)
6	1536.02	Aliphatic nitro compound
7	1463.71	Aromatic ring (aryl group) stretch
8	1234.22	Aromatic ether group
9	1161.9	Secondary amine, CN stretch
10	794.528	Aromatic 1, 3-di substitution (meta)
11	722.211	Aromatic 1, 2-di substitution (ortho)

unknown compound with the known absorption frequencies for types of bonds. A total of 19 peaks were observed in the spectra, indicating a variety of functional groups within the range. Several bands can be distinguished in the region of 4,000–1,000 cm^{-1}. The moderately intense band at 3,317.93 cm^{-1} indicates alkynes C–H stretch while the band at 1,161.9 cm^{-1} shows either C–N stretch or O–CN stretch; the intense peak at 1,746.23 cm^{-1} indicates either alkyl carbonate or ester stretch. Table 3 gives the peak positions of the infrared spectra [24]. From the Fig. 3, the peak at 2,927 cm^{-1} was attributed to C–H group and the peak at 1,656.53 cm^{-1} to C=O group. The peak at 1,234.22 cm^{-1} indicated amines stretch while the ones at 476.33 cm^{-1} and 466.689 cm^{-1} indicated the presence of poly sulfide [24].

3.2. SEM analysis

Fig. 4 shows the SEM analysis of *M. oleifera* seed powder sample at a size range of 500 microns. The surface of the coagulant seems to be irregular and rough at some places and smooth at others. Small pores were found around the edges, indicating the possibility of sorption at a smaller magnitude.

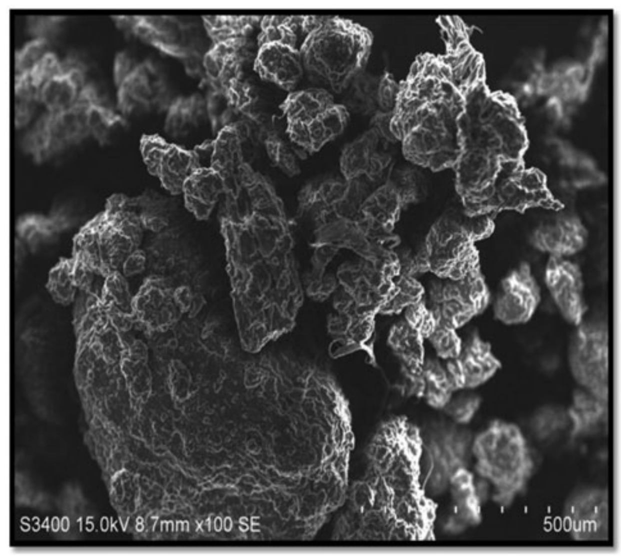

Fig. 4. SEM image of *M. oleifera* seed powder.

3.3. Effect of initial turbidity on the removal of turbidity

Synthetic turbid water consisting of kaolin suspensions was prepared and it was subjected to coagulation tests. The initial turbidities were varied in each trial as 50, 75, 100, 120, and 135 NTU at a constant *M. oleifera* dosage of 1.0 g and at a constant pH of 6.0. Fig. 5 shows the effect of initial turbidity on the removal of turbidity from the synthetic water. From Fig. 5, it can be observed that the percentage removal of turbidity was increased from 54.67 to 74.28% with increase in the initial turbidity from 50 to 135 NTU, respectively. At higher concentration of turbidity, more number of colloidal particles will be present and this initiates more interaction between the colloidal particles. But at the lower concentration, the less number of colloidal particles will be present and also the interactions between the particles are not that much as compared to that of the higher concentration of turbidity.

The coagulation tests were also conducted in sample groundwater, so as to check the efficiency of *M. oleifera* seed powder in treating drinking waters as well. The residual turbidity of the collected sample groundwater was found to be 135 NTU. The original groundwater was used as a stock solution (135 NTU) and this water was diluted with tap water to provide the different turbid water samples such as 50, 75, 100, 120, and 135 NTU. The results of the coagulation tests

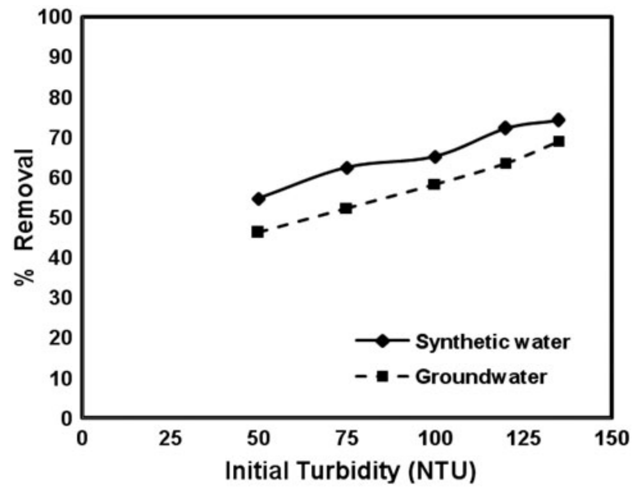

Fig. 5. Effect of initial turbidity on the removal of turbidity. (Initial turbidity = 50–135 NTU, pH = 6.0, and *M. oleifera* dose = 1.0 g.)

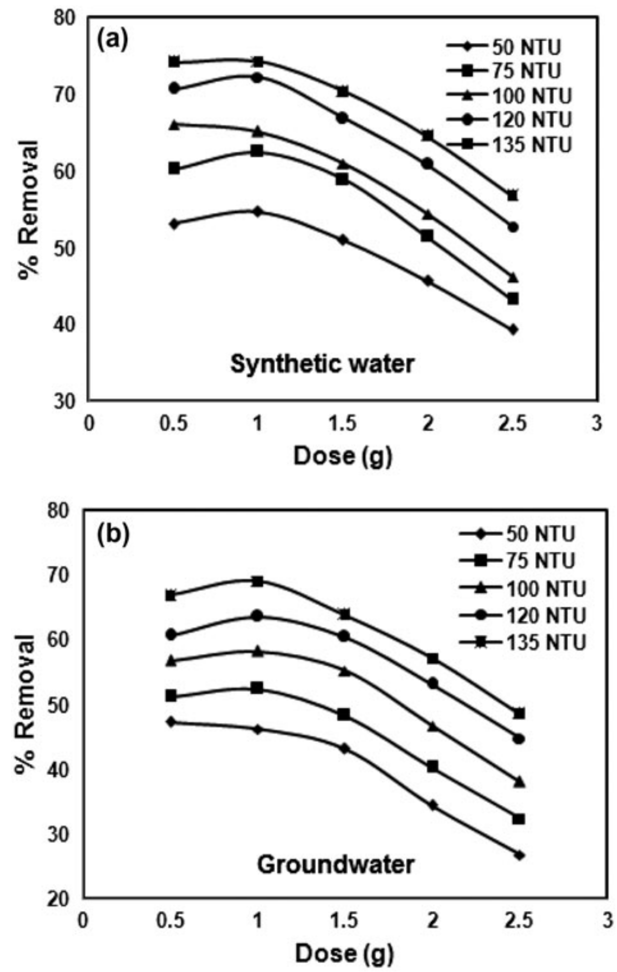

Fig. 6. Effect of *M. oleifera* dose on the removal of turbidity. (Initial turbidity = 50–135 NTU, *M. oleifera* dose = 0.5–2.5 g, and pH = 6.0.)

conducted in this groundwater were given in Fig. 5. It can be seen that the removal efficiencies were not as high as the case in synthetic water. This can be attributed to the fact that it is a low turbid solution or based on the nature of the test solution. The same results were observed as similar to the previous discussion (synthetic turbid water).

3.4. *Effect of* M. oleifera *dose on the removal of turbidity*

M. oleifera dose is also an important operating parameter with respect to the turbidity removal studies as it examines the potential of the material to remove the turbidity for given initial turbidities. The effect of *M. oleifera* dose on the removal of turbidity was shown in Fig. 6. The removal of turbidity was studied at different *M. oleifera* dosages (0.5–2.5 g) for the initial turbidities of 50, 75, 100, 120, and 135 NTU. The experimental results revealed that the removal of turbidity was increased with increase in *M. oleifera* dosage and the maximum removal of turbidity was observed at 1.0 g. This may be due to the increase in the *M. oleifera* dose which provides a greater surface area for fixed turbidities. After 1.0 g of *M. oleifera* dosage, the percentage of turbidity removal was decreased with the increase in the *M. oleifera* dosage. This may be due to the fact that the *M. oleifera* seed powder may provide the turbidity to the exiting turbidity solution. The overdosing of the *M. oleifera* seed powder resulted in the saturation of the polymer bridge sites and which causes the restabilization of the destabilized particles due to the inadequate number of the particles to form more interparticle bridges [1,25,26]. Therefore, the optimum *M. oleifera* dosage was fixed as 1.0 g and was applied to all further experimental studies.

3.5. *Effect of pH on the removal of turbidity*

The solution pH plays an important role in the removal of turbidities from the test solution (both synthetic water and groundwater) using *M. oleifera* seed powder. The effect of pH on the removal of turbidity was investigated by varying the solution pH from 5.0 to 9.0 for an initial turbidity of 100 NTU and the *M. oleifera* dosage was kept constant at 1.0 g (Fig. 7). From Fig. 7, it can be seen that the removal of turbidity was increased with the increase in pH value and the maximum turbidity removal was observed at a pH of 6.0–7.0 and then it started to decrease. This may be due to the fact that the decrease in the competition

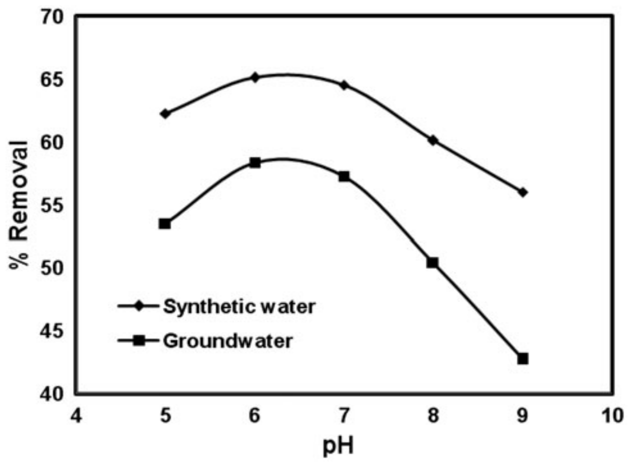

Fig. 7. Effect of pH on the removal of turbidity. (Initial turbidity = 100 NTU and *M. oleifera* dose = 1.0 g.)

between the H^+, H_3O^+, and ions in the turbidity solution for the same functional group on the surface of the *M. oleifera* seed powder. Meanwhile, as the solution pH was increased, the number of negatively charged groups on the *M. oleifera* seed powder increased which enhances the removal of turbidity. The optimum pH for the removal of turbidity was observed at a pH of 6.0 and this was used for the experimental studies.

3.6. Sorption isotherms

Even though the SEM and FT-IR analysis provided the sufficient results for determining sorption capacity of the *M. oleifera* seed powder, this was further analyzed by fitting the effect of initial turbidity data to the two main sorption isotherms namely Langmuir [27] and Freundlich [28] sorption isotherms.

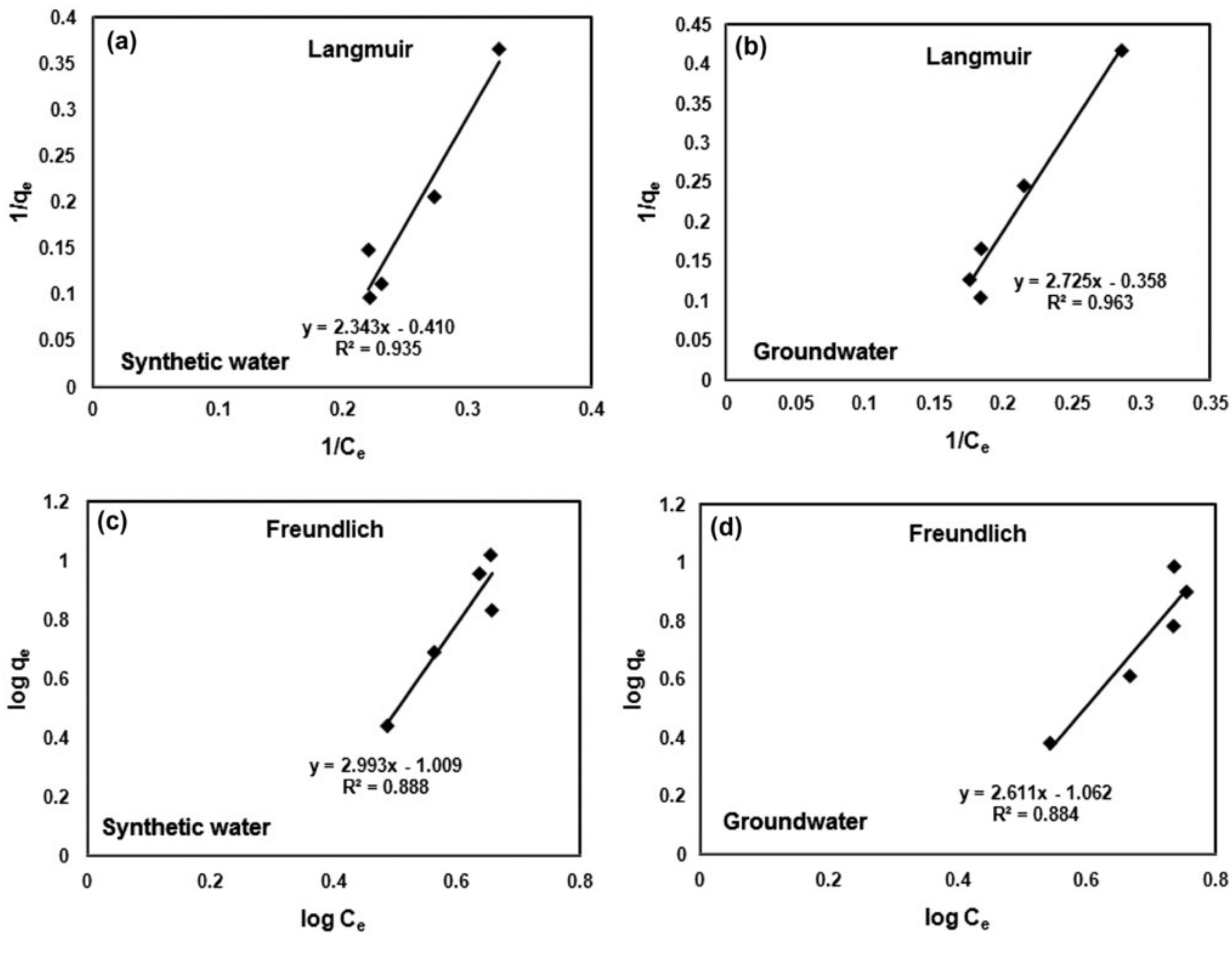

Fig. 8. Sorption isotherms for the removal of turbidity by *M. oleifera*. (Initial turbidity = 50–135 NTU, *M. oleifera* dose = 1.0 g, and pH = 6.0.)

Table 4
Estimated isotherm model parameters for the removal of turbidity using *M. oleifera* seed powder

Isotherm model	Parameters	Synthetic water	Groundwater
Langmuir	q_m (mg/g)	−2.439	−2.793
	K_L (L/g)	−0.175	−0.131
	R^2	0.935	0.963
	Equation	$\frac{1}{q_e} = \frac{2.343}{C_e} - 0.41$	$\frac{1}{q_e} = \frac{2.725}{C_e} - 0.358$
Freundlich	K_F ((mg/g)(L/mg)$^{(1/n)}$)	0.098	0.087
	n	0.334	0.383
	R^2	0.888	0.884
	Equation	$\log q_e = 2.993 \log C_e - 1.009$	$\log q_e = 2.611 \log C_e - 1.062$

Fig. 8(a)–(d) illustrates the linear isotherm models for the Langmuir (Fig. 8(a) and (b)) and Freundlich (Fig. 8(c) and (d)) isotherms regarding the sorption of particles from the test solution (synthetic water and groundwater) onto the *M. oleifera* seed powder. The parameters studied using the Eqs. (6) and (9) such as q_m, K_L, K_F, n, and coefficient of determination (R^2) values were estimated from the respective linear plots and are listed in Table 4. Considering the R^2 values for the Langmuir and Freundlich sorption isotherm models, one may infer that the experimental results for the sorption of particles onto the *M. oleifera* seed powder fit the Langmuir sorption isotherm model better than the Freundlich sorption isotherm model due to better linearity of the curves. The negative values of the separation parameter (R_L) were observed for the different initial turbidity values. The n values for synthetic water and ground water were found to be 0.334 and 0.384, respectively. From the Table 4, it was observed that the negative maximum monolayer sorption capacity (q_m) values were observed and this may give an idea that the sorption of turbidity onto the *M. oleifera* seed powder is not that much influenced in the removal of turbidity from the test solutions. And also, this directly indicates that the removal of turbidity from the test solutions using the *M. oleifera* seed powders is mainly due to the coagulation principle.

4. Conclusion

This study focused on the removal of turbidity from the groundwater and synthetic water using *M. oleifera* seed powder. The operating parameters such as initial turbidity, solution pH, and *M. oleifera* dosage affected the removal of turbidity. From the above results, the following conclusions were made:

(1) The maximum removal of turbidity for the synthetic water and groundwater were found to be 55–75% (50–135 NTU) and 46–69% (50–135 NTU), respectively.
(2) Optimum *M. oleifera* dosage for the removal of turbidity was found to be of 1.0 g.
(3) Optimum solution pH for the removal of turbidity was found to be of 6.0.
(4) The sorption isotherm could be well fitted by the Langmuir sorption isotherm model.
(5) The removal of turbidity was slightly influenced by the sorption using *M. oleifera* seed powder based on the sorption isotherms.

According to these results, *M. oleifera* seed powder can be used as an effective low cost material for the removal of turbidity from the groundwater and synthetic water.

Acknowledgments

The authors are grateful for the financial support from the SSN Trust, Chennai.

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