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Research Article

Moringa oleifera Lam. and Its Potential Association with Aluminium Sulphate in the Process of Coagulation/Flocculation and Sedimentation of Surface Water

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The present study aims to optimize the operational conditions in surface water coagulation/flocculation and sedimentation step, besides evaluating the association between seeds of *Moringa oleifera* Lam. (*M. oleifera*) and the synthetic coagulant aluminium sulphate for surface water treatment. The assays were performed in Jar Test using surface water from Pirapó River basin, Maringá, PR. It was observed that the operational conditions affect the coagulation/flocculation and sedimentation process efficiency. Optimal operational conditions for coagulants association are as follows: rapid mixing velocity (RMV) of 105 rpm, rapid mixing times (RMT) of 1 min, slow mixing velocity (SMV) of 30 rpm, slow mixing times (SMT) of 15 min, and sedimentation time (ST) of 15 min; this enables an improvement in the process, contributing to a reduction in synthetic coagulant aluminium sulphate demand of up to 30%, combined with an increase in *M. oleifera* dosage, not affecting the coagulation/flocculation and sedimentation process efficiency, considering the water pH range between 7 and 9.

1. Introduction

Currently, millions of people are exposed to dangerous levels of chemical pollutants and biological contaminants in drinking water due to the inadequate handling of urban population and industrial or agricultural wastewaters [1]. Thus, it is necessary to carry out physical, chemical, and/or microbiological processes in order to remove the impurities present in water and coagulants have been widely used in this way in conventional processes of water treatment [2].

Aluminium sulphate ($Al_2(SO_4)_3 \cdot 18H_2O$) stands out as the most used synthetic coagulant in Brazil when it comes to water treatment of public supplies as a result of its high efficiency in suspended solids removal and low cost [3]. However, its effect is strongly dependent on pH, especially in the range from 5.5 to 8 [4], and at the end of the treatment there is the possibility of a high concentration of residual aluminium remaining in water [5], which can be associated with the acceleration of degenerative processes of Alzheimer's disease [6–8]. There is also the problem of the reaction between aluminium and the natural alkalinity present in water, which leads to a pH reduction [9]. Therefore, it is interesting to propose alternatives to reduce the quantity of the synthetic coagulant, such as the utilization of natural coagulants in water treatment.

Natural coagulants are biodegradable and present low toxicity and low levels of residual sludge production [5, 10], besides being considered health-friendly [6, 11].

Seeds of *Moringa oleifera* Lam. *(M. oleifera)* stand out as a promising natural coagulant [7, 12–15] by being considered as a low-cost and safe alternative, besides having attested efficiency in water treatment [16].

Amagloh and Benang [17] assure that when seed powder of *M. oleifera* is added to turbid water, the proteins present in this coagulant produce positive charges by means of electrostatic attractions with negatively charged particles [18], such

Table 1: Operational conditions of coagulation/flocculation and sedimentation process.

ASSAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
RMV (rpm)	100	105	110	100	105	110	100	105	110	100	105	110	100	105	110	100	105	110	100	105	110	100	105	110	100	105	110
RMT (min)	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3
SMV (rpm)	15	15	15	15	15	15	15	15	15	30	30	30	30	30	30	30	30	30	45	45	45	45	45	45	45	45	45
SMT (min)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15

SMV: slow mixing velocity; RMV: rapid mixing velocity; SMT: slow mixing times; RMT: rapid mixing times.

as mud, clay, bacteria, and other toxic particles present in water. The flocculation process occurs when the proteins get bound to the negative charges of the particles, producing flakes and bringing together the impurities present in the water. However, the coagulation mechanism is not yet well defined among researchers.

Investigations into the behavior of seeds of *M. oleifera* in conjunction with aluminium salts presented promising results [11, 13, 19], attesting that *M. oleifera* is a feasible coagulant as a partial replacement of synthetic coagulants [16]. Valverde et al. [4] observed that the association of seeds of *M. oleifera* and aluminium sulphate brings about an increase in apparent color and turbidity removal efficiency of surface water. Dalen et al. [20] mention that the association of coagulants can improve water sanitation in developing countries.

Considering the operational conditions in the coagulation/flocculation process, studies carried out by Cordeiro Cardoso et al. [21] demonstrated that rapid mix, slow mix, and sedimentation do influence color and turbidity removal during the process performed with seeds of *M. oleifera*. Since these parameters affect the global efficiency of impurity removal in surface water, they do not have to be simply adopted, but operational conditions from laboratory studies must be established for the water treatability [22].

Pritchard et al. [15] assert that rapid mixing of a few seconds is important after the addition of a coagulant so as to assure a uniform dispersion and also increase the opportunity of contact between the particles [18]. In this way, in order to ensure coagulation efficiency, the occurrence of a uniform and intense mixture of the coagulant in water is necessary so that the contact probability between coagulant and particles is excellent before the completion of the reactions.

According to Vijayaraghavan et al. [7], there is a shortage of comprehensive studies that compare natural and synthetic coagulants association efficiency. In this way, the general objective of this work is to optimize the operational conditions of coagulation/flocculation and sedimentation step, besides evaluating the efficiency of natural coagulant seeds of *M. oleifera* and synthetic coagulant aluminium sulphate association in surface water treatment, by means of the alteration of coagulants dosage and coagulation pH, using coagulation diagram tools.

2. Materials and Methods

Surface water collected at the Water Treatment Plant (Sanepar) of the city, coming from Pirapó River basin, Maringá city, Paraná state, Brazil, was characterized by means of the following quality parameters: apparent color and compounds with $UV_{254\,nm}$ absorption (DR 5000 Hach spectrophotometer), turbidity (2100P Hach turbidimeter), total dissolved solids (TDS), and pH (Thermo Scientific Orion VSTAR92 Versa Star pH meter).

The coagulation/flocculation assays were carried out in Jar Test, Nova Ética, 218/LDB0 of six jars, with rotation regulator of mixer shafts, in duplicate, in 700 mL recipients of surface water.

2.1. Coagulants Preparation. For the preparation of synthetic coagulant standard solution, 1 g of aluminium sulphate hydrate (Vetec) was dissolved in distilled water and the volume was brought to 100 mL in order to obtain a 1% $w \cdot v^{-1}$ solution.

In order to obtain *M. oleifera* powdered coagulant, 15 g of seeds ordered from Aracaju, SE, were manually peeled, ground in a blender (NL-41 Mondial), and dried in a forced air buffer (Digital Timer SX CR/42) at 40°C until constant weight was observed [17].

2.2. Operational Conditions of Coagulation/Flocculation and Sedimentation Process. In this step, coagulant dosages added during the assays were adapted from values cited in the literature, namely, 25 $mg \cdot L^{-1}$ for aluminium sulphate [23, 24] and 50 $mg \cdot L^{-1}$ for seeds of *M. oleifera* [25].

Operational conditions of coagulation/flocculation and sedimentation process used in the association of seeds of *M. oleifera* and aluminium sulphate coagulants are presented on Table 1. It is worth mentioning that these values are based on optimal operational conditions of seeds of *M. oleifera*, earlier studied by Madrona et al. [10] and Cordeiro Cardoso et al. [21], and of aluminium sulphate, obtained through information at Sanepar, thus adopting real operational conditions used at the Water Treatment Plant in Maringá city.

2.3. Coagulation Diagrams. Coagulation diagrams developed on 3DField 3.5.3.0. software were created from coagulation pH variation and seeds of *M. oleifera* and aluminium sulphate association dosage by evaluating the removal efficiency of apparent color, turbidity, and compounds with $UV_{254\,nm}$ absorption.

Surface water pH used in the assays was adjusted in the range between 4 and 10 with 0.1 $mol \cdot L^{-1}$ and 1 $mol \cdot L^{-1}$ sodium hydroxide (NaOH) and 0.1 $mol \cdot L^{-1}$ and 1 $mol \cdot L^{-1}$ hydrochloric acid (HCl).

For this step of the work, coagulants dosages specified in Table 2 were used, according to adaptations from the methodology proposed by Nwaiwu and Bello [19].

Table 2: Coagulants dosage in association.

Point	% coagulant ($Al_2(SO_4)_3 \cdot 18H_2O$/ *M. oleifera*)	Coagulant dosage ($mg \cdot L^{-1}$) $Al_2(SO_4)_3 \cdot 18H_2O$	Seeds of *M. oleifera*
1	0%/100%	0	50
2	10%/90%	2.5	45
3	20%/80%	5	40
4	30%/70%	7.5	35
5	40%/60%	10	30
6	50%/50%	12.5	25
7	60%/40%	15	20
8	70%/30%	17.5	15
9	80%/20%	20	10
10	90%/10%	22.5	5
11	100%/0%	25	0

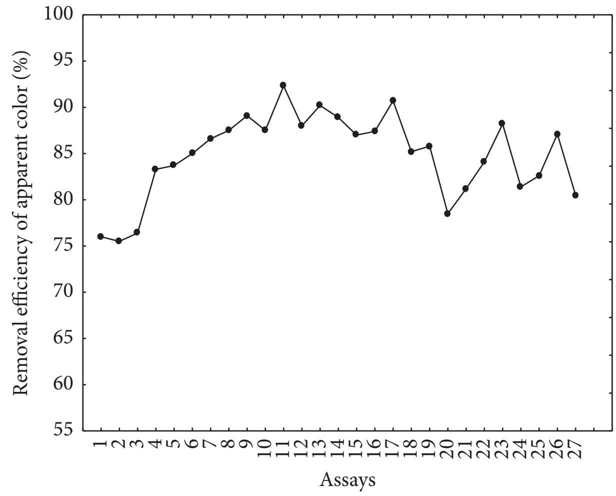

Figure 1: Removal efficiency of *M. oleifera* and aluminium sulphate for apparent color.

2.4. Coagulation/Flocculation and Sedimentation Process Evaluation. After completing the coagulation/flocculation and sedimentation process, 15 mL of treated water was collected for results evaluation, which was carried out on the basis of percentage reduction in apparent color, turbidity, and compounds with $UV_{254\,nm}$ absorption.

2.5. Statistical Analysis. For the purpose of comparing the results obtained in the coagulation/flocculation and sedimentation assays, Analysis of Variance (ANOVA) and multiple comparison of means, or Tukey's Test, were carried out, using confidence interval of 95%, for significant p values < 0.05, in order to verify significant differences by means of SISVAR version 5.3 statistical program [26].

In order to assess the removal efficiency of quality parameters after the water clarification process, a 27 × 4 factorial delineation was used, whose factors were as follows: assays (27 variations for slow and rapid mixing velocity (SMV and RMV) and slow and rapid mixing times (SMT and RMT) and sedimentation times (four ST), with two replications [18].

3. Results and Discussions

Table 3 presents the characterization of surface water.

3.1. Operational Conditions: Optimization Step of the Coagulation/Flocculation and Sedimentation Process. By evaluating the results obtained by means of Tukey's Test, it is possible to observe that there was no significant statistical difference concerning operational conditions presented in Table 4.

Earlier studies [2, 4] have shown results of apparent color and turbidity removal with 60 min and 120 min sedimentation time (ST), using saline and aqueous extract of *M. oleifera*, respectively, as the sole coagulant in the coagulation/flocculation and sedimentation process. The elapsed time required for sedimentation when using *M. oleifera* powdered seed as the sole coagulant is higher than that of *M. oleifera* and aluminium sulphate association [8, 19]. Bongiovani et al. [27] confirm that the utilization of a polymer along with seeds of *M. oleifera* improves removal efficiency of quality parameters and it increases the size of flocs, thus diminishing significantly the overall sedimentation time.

Several results are presented in Table 4. However, ST lies in the range from 30 min to 60 min. Since 15 min is the standard elapsed time used at Water Treatment Plants [27], optimal operational conditions for seeds of *M. oleifera* and aluminium sulphate association are as follows: rapid mixing velocity (RMV) of 105 rpm, rapid mixing time (RMT) of 1 min, slow mixing velocity (SMV) of 30 rpm, slow mixing time (SMT) of 15 min, and sedimentation time (ST) of 15 min.

Figures 1, 2, and 3 present assay results for 15 min ST concerning efficiency removal of apparent color, turbidity, and compounds with $UV_{254\,nm}$ absorption.

By evaluating the results obtained for the three quality parameters studied, one can conclude that the optimal operational conditions for seeds of *M. oleifera* and aluminium sulphate association are: RMV of 105 rpm, RMT of 1 min, SMV of 30 rpm, SMT of 15 min, and ST of 15 min.

3.2. Coagulation Diagrams Construction Step. Coagulation diagrams are constructed from removal efficiency of the quality parameters evaluated, considering that the best results are identified by dark-colored regions.

Figures 4, 5, and 6 show coagulation diagrams that evaluate removal efficiency of apparent color, turbidity, and compounds with $UV_{254\,nm}$ absorption, respectively.

As for coagulants association, in a general way, it is possible to observe in the coagulation diagrams that as the aluminium sulphate dosage increases, the coagulation effect is enhanced.

Valverde et al. [4] ascertained that the association of natural and synthetic coagulants enables an increase in the removal efficiency of apparent color and turbidity of the water under scrutiny, thus corroborating the study of Dalen et al. [20], which suggests that aluminium sulphate and powdered *M. oleifera* present better synergic characteristics than

Table 3: Characterization of surface water.

Quality parameter	Apparent color	Turbidity	$UV_{254\,nm}$	TDS	pH
Surface water	406 uH	73.9 NTU	0.285 cm^{-1}	115.33 $mg{\cdot}L^{-1}$	7.817

Table 4: Values of removal efficiency for the best operating conditions in association of seeds of *M. oleifera* and aluminium sulphate.

Parameters					Removal efficiency (%)		
RMV (rpm)	RMT (min)	SMV (rpm)	SMT (min)	ST (min)	Apparent color	Turbidity	$UV_{254\,nm}$
105	1	30	15	15–45	92.3–93.6	91.0–92.0	75.5–76.3
110	1	30	15	45	90.9	90.0	72.4
100	2	30	15	30–45	91.2–92.5	92.2–92.9	74.3–75.2
105	3	30	15	45–60	93.8–95.4	92.8 – 94.1	77.2
110	3	30	15	60	92.9	92.6	79.0
110	1	45	15	60	92.8	91.2	76.1
105	2	45	15	45–60	93.1–93.3	92.9–93.3	75.3–75.8
100	3	45	15	45	91.0	91.0	74.0
105	3	45	15	45–60	92.9–93.2	92.9–93.0	78.6

SMV: slow mixing velocity; RMV: rapid mixing velocity; SMT: slow mixing times; RMT: rapid mixing times; ST: sedimentation times.

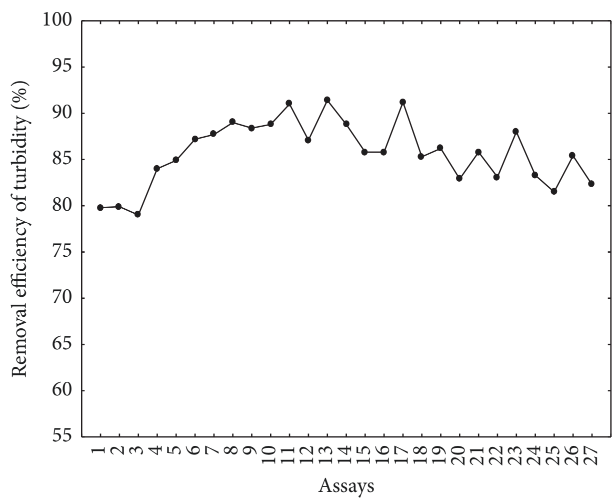

Figure 2: Removal efficiency of *M. oleifera* and aluminium sulphate for turbidity.

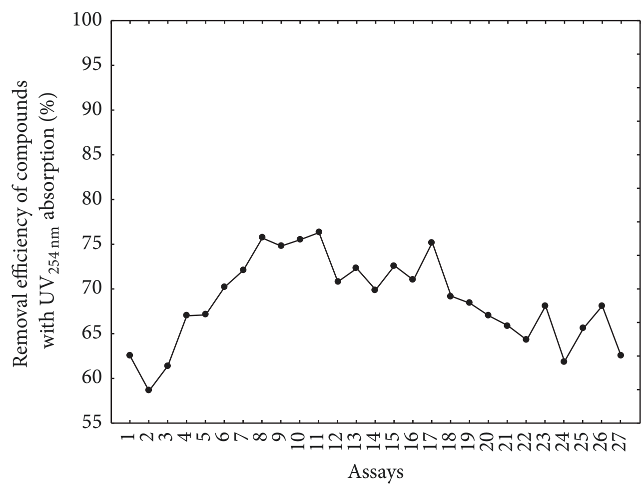

Figure 3: Removal efficiency of *M. oleifera* and aluminium sulphate for compounds with $UV_{254\,nm}$ absorption.

the ones described in the utilization of *M. oleifera* as the sole coagulant. This occurrence can be evidenced in the coagulation diagrams presented.

Considering the water pH range between 7 and 9, it can be asserted that coagulation addition with dosages higher than 17.5 $mg{\cdot}L^{-1}$ aluminium sulphate/15 $mg{\cdot}L^{-1}$ seeds of *M. oleifera* (point 8) would be interesting for the attainment of removal efficiency of about 75.0% for color and turbidity and 70.0% for compounds with $UV_{254\,nm}$ absorption.

It is possible to achieve a 30% reduction in the consumption of synthetic coagulant aluminium sulphate combined with an increase in *M. oleifera* dosage without affecting the efficiency of the process. Therefore, research in this area must continue in order to obtain water that meets the required potability standard.

4. Conclusions

It was observed that the operational conditions affect the efficiency of the coagulation/flocculation and sedimentation process. Coagulant aluminium sulphate, applied in combination with seeds of *M. oleifera,* enables an improvement in

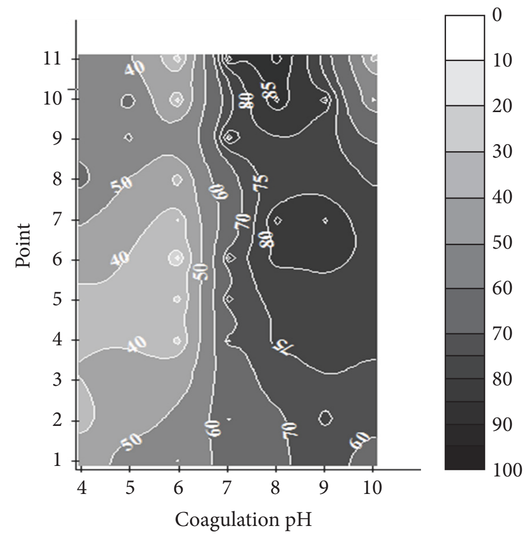

Figure 4: Coagulation diagrams with curves of apparent color removal in percentage (%).

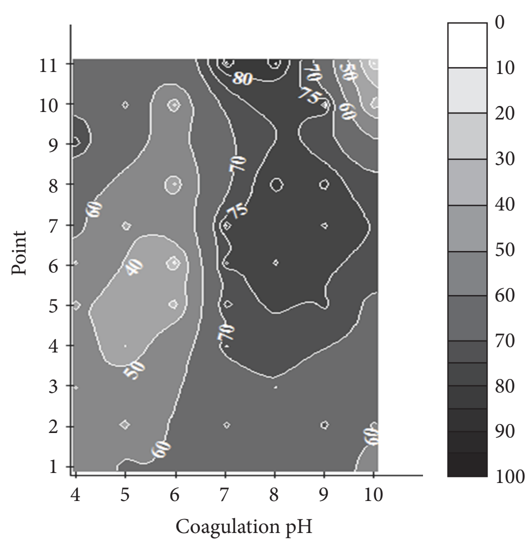

Figure 5: Coagulation diagrams with curves of turbidity removal in percentage (%).

sedimentation time of the overall process, so that 15 min are enough. Optimal operational conditions for coagulants association are as follows: RMV of 105 rpm, RMT of 1 min, SMV of 30 rpm, and SMT of 15 min.

For the water pH range between 7 and 9, the association of natural and synthetic coagulants with dosages higher than 17.5 mg·L^{-1} aluminium sulphate/15 mg·L^{-1} seeds of *M. oleifera* presents synergic characteristics, and removal efficiency of about 75.0% for color and turbidity and of 70.0% for compounds with UV$_{254\,\mathrm{nm}}$ absorption is obtained.

The use of seeds of *M. oleifera* contributes to a reduction of up to 30% in the required demand of aluminium sulphate, without affecting the efficiency of coagulation/flocculation and sedimentation process, besides being an interesting environmental option nowadays.

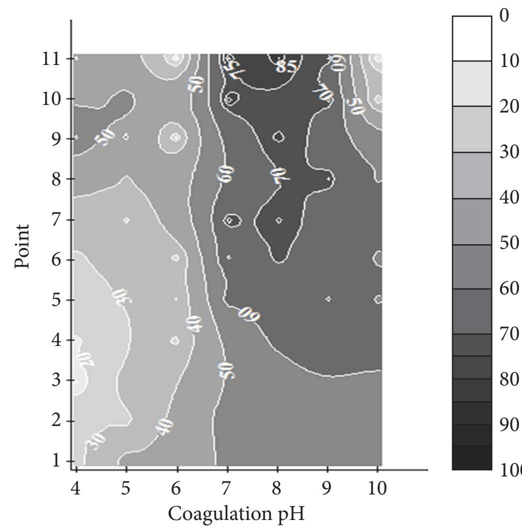

Figure 6: Coagulation diagrams with curves of compounds with UV$_{254\,\mathrm{nm}}$ absorption removal in percentage (%).

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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