OPTIMISATION OF PHYSICAL PARAMETERS OF 
COAGULATION-FLOCCULATION PROCESS 
IN WATER TREATMENT

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ABSTRACT

Moringa oleifera is a plant coagulant, which has a potential for use on a large-scale, for treatment of turbid waters in developing countries. In this study, the results of laboratory based investigations into the effects of various forms of Moringa oleifera coagulant on its coagulation effectiveness using low, medium and high turbidity water samples are presented. The paper presents results of optimisation studies on coagulant dose, container geometry/jar configuration, Rapid Mix Velocity Gradient (RMVG), and Slow Mix Velocity Gradient (SMVG) by using various forms of M.O. coagulant on low, medium and high turbidity water suspensions. In this study, Bentonite clay and Kaolin clay suspensions were used. It was observed that optimum dose of coagulant varies with the form of coagulant, type of jar and type of turbidity suspension. The circular baffle showed better performance in turbidity removal.

Key Words: Moringa oleifera, Coagulant, Rapid mix, Slow mix, Velocity gradient, Optimisation

INTRODUCTION

The presence of unsettleable organic and mineral substances causes some problems in obtaining drinking water. Generally, these systems are in colloid systems. The very significant surface area of the particles and the existence of the surface charge removes any possibility of elimination by spontaneous settling\(^1,2\). Coagulation-flocculation followed by sedimentation, filtration and disinfection, often by chlorine, is used worldwide in the water treatment industry before the distribution of treated water to consumers. Aluminium salts are by far the mostly widely used coagulants in water and wastewater treatment. However, recent studies have pointed out several serious drawbacks of using Aluminium salts, such as Alzheimer’s disease and similar health related problems associated with residual Aluminium in treated waters\(^3,4\), besides production of large sludge volumes. There is also the problem of reaction of alum with natural alkalinity present in the water, leading to a reduction of pH, and low efficiency in coagulation of cold waters. A significant economic factor is that many developing countries can hardly afford the high costs of imported chemicals for water and wastewater treatment\(^5,6\). By using natural coagulants, considerable savings in chemicals and sludge handling cost can be achieved. Around 50% to 90% of alum requirement can be saved\(^7\). Ferric salts and synthetic polymers have also been used as coagulant but with limited success, because of same disadvantages as in the case of Aluminium salts. Therefore, it is desirable that other cost effective and more environmentally acceptable alternative coagulants be developed to supplement if not replace alum, Ferric salts and synthetic polymers. In this context, natural coagulants present a viable alternative.

Natural coagulants of vegetable and mineral origin were used in water and wastewater treatment before the advent of synthetic chemicals like

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Aluminium and Ferric salts, but they have not been able to compete effectively because of the fact that a scientific understanding of their effectiveness and mechanism of action was lacking. Thus, use of natural coagulants has been discouraged without any scientific evaluation. They have succumbed progressively under modernization and survived only in remote areas of some developing countries. Recently however, there has been resurgence of interest in natural coagulants for water treatment in developing countries. There are very few reports where the crude extract from MO has been used.

Except in traditional use and in some laboratory or pilot studies, no large exploitation of Moringa oleifera in water treatment has been reported so far. This rejection may be explained by the presentation of Moringa as a low technology appropriate only to developing countries. One way to improve acceptance of Moringa as a coagulant all over the world is to show clearly its advantages over conventional coagulants and apply modern technology to supply it to water and wastewater treatment industry at cheaper cost. Reports in the literature describe uses of natural coagulants at household level.

In all the investigations carried out so far parameters used in conventional jar test have been used to evaluate the coagulation efficiency of Moringa oleifera in the treatment of surface waters and synthetic waters. In all such studies, the physical parameters like slow mixing velocity gradient and time, rapid mixing velocity gradient and time were fixed according to standard jar test values for alum coagulation. The only parameter varied in most of the cases was doses of Moringa oleifera. Furthermore, studies into the interaction between physical parameters affecting coagulation like type of turbidity, type of coagulant, slow mix; rapid mix rates and times, container geometry are not documented.

Moringa oleifera (MO) : MO is a tree native to North India and it is drought resistant. It grows in hot, semi-arid regions with annual rainfall of 250–1500 mm as well as in humid area with annual rain fall in excess of 3000 mm. MO is a multi-purpose tree, with most of its parts being used for a number of applications. The seeds contain carbohydrates, proteins and fats. The MO seeds either as it is or after extraction of fats and carbohydrates can be used as coagulant. The protein content of the seed has a coagulation property. By using MO as a coagulant, considerable savings in chemicals and sludge handling cost may be achieved. Apart from being less expensive, it produces readily biodegradable and less voluminous sludge.

In this study, laboratory investigations were carried out to determine the multiple effects of physical parameters like slow mixing and rapid mixing time and velocity gradient, doses of coagulant, container geometry and initial particulate concentration (turbidity) on coagulation of turbid water with Moringa oleifera. These parameters were varied while the other parameters were kept constant and optimization was carried out for optimum values of doses of Moringa oleifera and other parameters.

MATERIAL AND METHODS
The collected seeds were analyzed in the laboratory or its contents the results of seed analysis are shown in Table 1.

The parameters which affect the coagulation-flocculation process are initial turbidity, dosage of coagulant, physical and chemical characteristics of coagulant, rapid mix velocity gradient, rapid mix time, slow mix velocity gradient, slow mixing time, settling time, jar configuration/container geometry. Amongst listed variables, the study was limited to the optimization of coagulant dosage, jar configuration/container geometry, rapid mix velocity gradient, rapid mix time, slow mix velocity gradient and slow mixing time.

The entire study was divided into four different stages for three coagulants viz. Moringa oleifera shelled blended, Moringa oleifera shelled blended oil extracted and alum. A series of experiments were conducted on three synthetic raw water turbidities viz. 50, 150, and 450 NTU representing low, medium and moderately high range of turbidity. The complete experiment comprised of rapid mixing, followed by slow mixing and sedimentation. Residual turbidity was used as the parameter to judge the performance of the process. All care was taken throughout the course of experiments to ensure accuracy.
and reproducibility of the results. In the present study, the experiments were designed using the single factor method of optimization.

**Stage-I**

In stage-I, optimum doses of *Moringa oleifera* shelled blended, *Moringa oleifera* shelled blended oil extracted and alum, for three different initial turbidities, were determined by keeping other parameters constant. Dose of coagulant, which was found to be optimum during the stage-I, was used in stage-II, stage-III and stage IV.

**Stage-II**

The effect of different container geometry/jar configurations like Circular Non-Baffled (CNB), Circular Baffled (CB), Square Non-Baffled (SNB) and Square Baffled (SB) was studied while other parameters were kept constant. The details of the container geometry/jar configurations are mentioned in Table 2. Dosage of coagulant obtained from stage I was used and again optimized with respect to different container geometry/jar configurations.

**Stage-III**

The dose and the jars optimized in stage I and II were used in the stage III. Stage-III dealt with different slow mixing rpms (velocity gradients) like 20 rpm, 30 rpm, 40 rpm and 50 rpm while other parameters were kept constant. The rapid mixing and slow mixing time was 1 min and 15 min respectively. In the stage-III, only CB, CNB and SB jars were used as they were found to be most effective during stage-II.

**Stage-IV**

The different rapid mixing rpms (velocity gradients) like 100 rpm, 120 rpm, 140 rpm and 160 rpm were studied while other parameters were kept constant. The rpms and corresponding

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### Table 1: Results of seed analysis

<table>
<thead>
<tr>
<th>S/N</th>
<th>Sample name</th>
<th>Parameters</th>
<th>Results</th>
<th>Units</th>
<th>Test methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Moringa</td>
<td>Protein</td>
<td>36.90</td>
<td>%</td>
<td>AOAC 920.152</td>
</tr>
<tr>
<td>2.</td>
<td><em>oleifera</em></td>
<td>Fat</td>
<td>37.25</td>
<td>%</td>
<td>Ranganna</td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td>Crude Fiber</td>
<td>12.85</td>
<td>%</td>
<td>SP-18 (P-IX) 1984</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td>Moisture</td>
<td>6.41</td>
<td>%</td>
<td>Ranganna</td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td>Ash</td>
<td>3.06</td>
<td>%</td>
<td>AOAC 940.26</td>
</tr>
</tbody>
</table>

### Table 2: Type of jars with dimensions

<table>
<thead>
<tr>
<th>S/N</th>
<th>Type of jars</th>
<th>No. of jars</th>
<th>Dimensions (Internal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Circular Non-Baffled (CNB)</td>
<td>6</td>
<td>10 cm (dia. in Plan) × 14 cm (H)</td>
</tr>
<tr>
<td>2.</td>
<td>Circular Baffled (CB)</td>
<td>3</td>
<td>10 cm (dia. in Plan) × 14 cm (H) With 4 baffles(one at each quadrant point) of 1.1 cm × 0.2 cm all along the height</td>
</tr>
<tr>
<td>3.</td>
<td>Square Non-baffled (SNB)</td>
<td>3</td>
<td>9.1 cm(L) × 9.1 cm (B) × 14 cm (H)</td>
</tr>
<tr>
<td>4.</td>
<td>Square Baffled (SB)</td>
<td>3</td>
<td>9.1 cm(L) × 9.1 cm (B) × 14 cm (H) With 4 baffles(one on each side) of 1.1 cm × 0.2 cm all along the height</td>
</tr>
</tbody>
</table>
velocity gradient values are given in Table 3. In the stage-IV, only CB, CNB and SB jars were used as they were found to be most effective during stage-II.

Table 3: RPM and its corresponding velocity gradients

<table>
<thead>
<tr>
<th>rpm</th>
<th>Velocity gradient (s⁻¹)</th>
<th>RPM</th>
<th>Velocity gradient (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>22</td>
<td>100</td>
<td>251</td>
</tr>
<tr>
<td>30</td>
<td>41</td>
<td>120</td>
<td>330</td>
</tr>
<tr>
<td>40</td>
<td>65</td>
<td>140</td>
<td>415</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>160</td>
<td>507</td>
</tr>
</tbody>
</table>

Preparation of seed extracts

Tree dried good quality *Moringa oleifera* seeds were selected and crushed to fine powder in a blender. Exactly 5 gm seed powder was added to 200 ml distilled water and kept aside for 2 minutes. The mixture was filtered through a muslin cloth. The filtrate was diluted using distilled water to make up the total volume to 500 ml resulting in stock solution having approximate concentration of 10000 mg/l (1%). Fresh stock solutions were prepared everyday to avoid the effect of storage period.

Preparation of turbid water samples

5 gm of kaolin clay was mixed to 500 ml distilled water. The mixed clay sample was allowed to soak for 24 hrs. This suspension was then stirred using the rapid stirrer so as to achieve uniform and homogeneous sample. The resulting suspension was found to be colloidal and was used as stock solution for preparation of turbid water samples. Everyday stock sample of kaolin clay was diluted using tap water to desired turbidity.

Single factor method of Optimization as proposed by Cochran and Cox (1962), was used for the study. In this method, the experimentation was carried out by keeping one parameter varying and other parameters constant.

The experiments were performed according to Bureau of Indian Standards IS 3025(PART 50): 2001.

RESULTS AND DISCUSSION

The experiments were carried out with raw water turbidities of 50 NTU, 150 NTU and 450 NTU.

Optimisation of coagulant dose

**M.O. shelled blended**: The optimum dose is found to be 70 mg/l, 130 mg/l, and 300 mg/l respectively. (Fig. 1)

**M.O. shelled blended oil extracted**: The optimum dose is found to be 50 mg/l, 100 mg/l, and 150 mg/l respectively (Fig. 2)

**Alum**: The optimum dose is found to be 30 mg/l, 40 mg/l, 50 mg/l respectively (Fig. 3).

Optimization of container geometry

It can be observed from the Fig. 4 to Fig. 6 that the residual turbidity is least in case of circular Baffled type of container.

When the paddle of flocculator rotates without baffles, the resultant flow follow linear path and create vortex at the surface of the liquid and relatively between blades and liquid is small. When baffled container was used, the liquid follows both vertical and lateral currents, which prevent vortex formation, thereby resulting in better dissipation of power applied, that cannot be accomplished in non-baffled container. A circular container with baffles gave the best performance as compared to other geometry containers like CNB, SB, and SNB.

Similar trend of results was observed in both *Moringa oleifera* shelled blended, oil extracted dosage and alum as coagulant that residual turbidity was least in case of Circular Baffled geometry type of container. The residual turbidity increased with the below order of container geometry CB< CNB< SB< SNB.
Fig. 1: Optimum dosage of *Moringa oleifera* shelled blended at 50, 150 and NTU

Fig. 2: Optimum dosage of M.O. shelled blended oil extracted at 50, 150 and 450 NTU

Fig. 3: Optimum dosage of alum for 50, 150 and 450 NTU
Fig. 4: Effect of container geometry at 50 NTU

Fig. 5: Effect of container geometry using different coagulants for 150 NTU initial turbidity

Fig. 6: Effect of container geometry using different coagulants for 450 NTU initial turbid water
Optimization of slow mixing RPM/velocity gradient
The results obtained from the experiments carried out in this phase correspond to the slow mixing rpm and its velocity gradient are shown in Fig. 7 to Fig. 9. The observations are as follows.

![Diagram](image1)

**Fig. 7**: Effect of container geometry using different coagulants for 50 NTU initial turbid water

![Diagram](image2)

**Fig. 8**: Effect of container geometry using different coagulants for 450 NTU initial turbid water
M.O. Shelled Blended

For 50 NTU, 150 NTU and 450 NTU the RPM/SMVG values are 30 rpm (41 s\(^{-1}\)), 40 rpm (65 s\(^{-1}\)), 40 rpm (65 s\(^{-1}\)) respectively.

M.O. shelled blended oil extracted

For 50 NTU, 150 NTU and 450 NTU the RPM/SMVG values are 30 rpm (41 s\(^{-1}\)), 40 rpm (65 s\(^{-1}\)), 40 rpm (65 s\(^{-1}\)) respectively.

Alum

For 50 NTU, 150 NTU and 450 NTU the RPM/SMVG values are 30 rpm (41 s\(^{-1}\)), 40 rpm (65 s\(^{-1}\)), 30 rpm (65 s\(^{-1}\)) respectively.

The results are in agreement with work on natural polyelectrolyte of Bulusu et al. (1968), who noted that disturbance of floc formation occurs if speed rotation was increased to 60 rpm, and in the present study above 60 rpm, redispersion of the particles of already formed floc was noted.

The residual turbidity at the optimum slow mixing velocity gradient for the range of initial low to moderately high turbidity is less than 30 NTU. The slow mixing velocity gradient for 50 NTU turbidity is 40 S\(^{-1}\) (30 rpm), and for 150 and 450 NTU is 65 S\(^{-1}\) (40 rpm), it means that for low initial turbidity there exist less SMVG and which increased with increasing initial turbidity to medium and moderately high.

After oil extraction, although optimum dosage required was less, the same trend was observed with slow mixing velocity gradient. The least residual turbidity was observed at slow mix velocity gradient of 40 S\(^{-1}\) (30 rpm), 65 S\(^{-1}\) (40 rpm), and 65 S\(^{-1}\) (40 rpm). Similarly, when alum was used as coagulant at 40 S\(^{-1}\) (30 rpm), 65 S\(^{-1}\) (40 rpm), and 40 S\(^{-1}\) (30 rpm) SMVG values of the least residual turbidity was observed.

Optimization of Rapid Mixing Velocity Gradient

With the optimal dose established, the single factor method proposed by Cochran and Cox (1962), was used to determine the optimal values of velocity gradient for rapid mix for turbidity values for low to moderately high (50-450 NTU). The rapid mix velocity gradient which gave the least residual turbidity was designated as optimum rapid mix velocity gradient.

It is observed that there exists an optimal velocity gradient for rapid mix, for 50, 150 and 450 NTU initial turbidity, of (329.59 S\(^{-1}\)) 120 rpm, (415.52 S\(^{-1}\)) 140 rpm and (415.52 S\(^{-1}\)) 140 rpm respectively.

These results are in agreement with work Suleyman A. Muyibi (1995), in which it was established that residual turbidity is a function of the rapid mix velocity in combination with coagulant dosages.

However in the present study, it was found that at optimum dosage of 50 -100- 150 mg/l for 50 NTU (Low) to 450 NTU (Moderately high) turbidity, the optimum rapid mix velocity gradient is (329 S\(^{-1}\)) 120 rpm for 50 NTU and (415 S\(^{-1}\)) 140 rpm for both 150 and 450 NTU.

The findings are in agreement with the work of Mashelkar et al. (1991), which mentions that optimum values of rapid mix velocity gradient are dependent on initial raw water turbidity and which is less at low turbidity of 50 NTU and high for both moderate and high turbidity.

It is evident from the study that the rapid mix resulted in a decrease in total number of particle count, while the relative number and size of floc increased progressively. This increase in particle size is attribute to growth of floc from single particle that were present in synthetic raw water with increase in velocity gradient up to optimization and further increase in rapid mix rpm, the re-dispersion of the aggregates of already formed flocs took place.

Similarly, when the de-oiled coagulant was used, for 50, 150 and 450 NTU initial raw water turbidity, optimum rapid mix velocity gradient of (329.59 S\(^{-1}\)) 120 rpm, (415.52 S\(^{-1}\)) 140 rpm and (415.52 S\(^{-1}\)) 140 rpm gave the least residual turbidity. (Fig. 10 to Fig. 12)
Fig. 9: Effect of slow mix velocity gradient USINT different coagulants at 450 NTU

Fig. 10: Effect of slow mix velocity gradient USINT different coagulants at 50 NTU
Fig. 11: Effect of slow mix velocity gradient USINT different coagulants at 150 NTU

Fig. 12: Effect of slow mix velocity gradient USINT different coagulants at 450 NTU
CONCLUSION

*Moringa oleifera* seeds present a viable alternative to alum, not only in developing countries, but also worldwide. *Moringa oleifera* has a great potential in water treatment. The oil content in the seed will form an emulsion or film coating, which may inhibit the contact with the surface of reaction and thus reduce floc formation. Shelled blend oil extracted *Moringa oleifera* has been found to be more effective than the shelled blended seeds as a primary coagulant for turbid water. Shelled blended *Moringa oleifera* was able to achieve 64 % turbidity removal at an optimum dosage of 70 mg/l for 50 NTU initial turbidity, while for 150 and 450 NTU turbidity, at the dose of 130 mg/l and 300 mg/l the turbidity removal was 85 % and 93 % respectively.

Shelled blended oil extracted *Moringa oleifera* was able to achieve 78.7 % turbidity removal at an optimum dosage of 50 mg/l for 50 NTU while for 150 and 450 NTU turbidity, at the dose of 100 mg/l and 150 mg/l, % turbidity removal was 83 % and 94% respectively.

Alum was able to achieve 92 % turbidity removal at an optimum dosage of 30 mg/l for 50 NTU, while for 150 and 450 NTU turbidity at the doses of 40 mg/l and 50 mg/l, the percentage turbidity removal was 96.24 % and 98% respectively. At optimum dosage, the percent turbidity removal is found to increase with increase in initial turbidity in case of all three type of coagulants. Requirement of dose for *Moringa oleifera* for both shelled blended and shelled blended oil extracted was higher than alum for all the turbidities. Increasing dosage of *Moringa oleifera* lead to decrease in turbidity up to the optimum dosage, after which the residual turbidity increased due to floc restabilization.

Shelled blend oil extracted *Moringa oleifera* has been found to be more effective than the shelled blended seeds as a primary coagulant for turbid water.

Results showed that the circular baffled jars are best suitable for water purification with both *Moringa oleifera* shelled blend oil extracted and shelled blended seeds as well as Alum too.

The study has conclusively established that the physical parameter such as velocity gradient and container geometry, have great influence on the flocculation process. The slow mixing velocity gradient for low initial turbidity is $40 \text{ S}^{-1}$ (30 rpm), and for 150 and 450 NTU is $65 \text{ S}^{-1}$ (40 rpm), which means that for low initial turbidity, there exists less SMVG, and it increased with increasing initial turbidity to medium and moderately high. The rapid mix velocity gradient for low initial turbidity is 120 rpm ($329.59 \text{ S}^{-1}$) and for 150-450 NTU, it is 140 rpm ($415.52 \text{ S}^{-1}$), it may be concluded that for low initial turbidity, there exists less rapid mix velocity gradient and it increases with increasing initial turbidity to medium and moderately high.

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REFERENCES


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