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Full Length Research Paper

Coagulation efficiency of *Moringa oleifera* for removal of turbidity and reduction of total coliform as compared to aluminum sulfate

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The use of *Moringa oleifera* seed extract as a primary coagulant for a local river water source was studied with respect to turbidity removal and total coliform reduction. Aqueous solutions of powdered *M. oleifera* seeds and conventional aluminium sulfate (alum) were evaluated. The quality of the treated water was analyzed using a standard jar test procedure and compared with that achieved using alum. Based on these exploratory experiments, an equivalency dose ($mg_{Moringa\ oleifera}/mg_{aluminum\ sulfate}$) was established and tested. At the estimated equivalency dose turbidity removal was virtually the same between the two coagulants; however, the *M. oleifera* extract was not as efficient as alum for Total Coliform reduction. The use of this natural coagulant did not affect the pH and conductivity of the treated water at the dosage used. Aqueous sodium chloride solutions of powdered *M. oleifera* seeds showed a marked improvement in coagulation efficiency; however, salt extraction at the levels explored would increase the salinity of the source water considerably.

Key words: *oleifera*, coagulation, alum, total coliform, turbidity.

INTRODUCTION

Drinking water is a basic human need, including food, shelter and clothing. The lack of safe drinking water is a leading cause of morbidity and mortality, especially in local communities where waterborne diseases are prevalent and persistent due to low quality surface source waters. Appropriate treatment technology can render this poor water resource into safe potable water; however, conventional technology may not be appropriate for those communities in terms of economics, availability, and operational constraints. This paper examines and compares the efficiency of using seeds from the *Moringa oleifera* tree as an effective coagulant to traditional alum in removal of turbidity and improving bacterial quality in the finished water.

LITERATURE REVIEW

Waterborne disease is a persistent health problem throughout the world. According to Schwarz (2000) an estimated 1.6 million people in developing countries are compelled to use contaminated water resources for drinking and food preparation. Yet, in many rural communities of these countries water clarification methods like flocculation, coagulation, and sedimentation are often impractical because of the high cost of equipment and low availability of chemical coagulants.

The use of natural materials to clarify water has been practiced for centuries. Extracts of seeds from the *M. oleifera* tree have been found to be one of the most effective clarifiers. Studies to test its effectiveness for treating water have been conducted since the early 1970's (Beth, 2005). These early investigations established its effectiveness as a coagulant for treatment of water with high levels of turbidity. Other plant extracts, such as from the seeds of *Prosopis juliflora* tree, have also been shown to be good coagulants (Forster et al., 1999). Of equal importance to coagulation efficiency is the human health issue in the use of such coagulants for potable water production. Toxicological assessments by Berger et al. (1984) and Grabow et al. (1985) indicate that use of *M. oleifera* as a primary coagulant does not pose a

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human health threat. The use of non-toxic natural coaglants obtained from local resources would lessen the economic hardship in developing countries of procuring conventional chemical coagulants. Several in-depth studies have confirmed that *M. oleifera* seeds possess effective coagulation properties (Jahn 1986, 1988; Muyibi and Okuofo 1995; Muyibi and Evison 1996; Ndacigengesere et al. 1998; and Amagloh and Benang, 2009).Treatment efficiency for this alternate natural coagulant is high. For example, Muyibi and Evison (1996) reported turbidity removals by *M. oleifera* used as a primary coagulant as high as 99% for river waters with initial turbidities ranging from 105 to 350 nephelometric turbidity units (NTU). These studies have also revealed that a crude water extract of *M. oleifera* compares quite positively with aluminum sulfate and, as such, its use has been suggested for use as a water treatment agent in developing countries (Jahn 1986, 1988; Ndacigengesere et al., 1995).

Early studies focused on the quality of water treated by coagulation using two forms of the moringa seed shelled *versus* unshelled seeds (Ndacigengesere et al., 1995, 1998). Extracts prepared from powdered unshelled seed were less effective in coagulation and removal of turbidity. Additionally, according to Amagloh and Benang (2009) mature seed extracts are more effective in turbid waters than immature seed extracts. These studies indirectly addressed the level of active ingredient in *M. oleifera* preparations, which have been purified and isolated as dimeric cationic proteins. A disadvantage of its use is that the concentration of organic matter in treated water increases with coagulant dose, which may pose water quality problems with storage of treated water (Ndacigengesere et al., 1995). In addition, coagulation efficiency of *M. oleifera* decreases with an increase in storage duration because it is highly biodegradable with a short shelf life (Katayon et al., 2004, 2006a and 2006b). Other studies have also shown that the coagulation efficiency can be increased by extracting its active component using a salt (Tsatsuji et al., 1999, 2001).

MATERIALS AND METHODS

Coagulants: Certified ACS aluminum sulfate hydrate ($Al_2(SO_4)_3$:18 H_2O) obtained from Fisher Scientific was used as the reference coagulant. A stock solution of alum was prepared as needed by dissolving 0.5 g into 200 ml of de-ionized water. *M. oleifera* pods were purchased from Hendry Creek Hideaway, LLC. The *M. oleifera* pods were split open to obtain the seed kernels, which were allowed to air-dry. A working stock solution was prepared fresh for each experiment. Dried seed kernels were ground into a fine powder using a laboratory mortar and pestle. After grinding, 1.0 g of powder was added to 100 ml of de-ionized water and then stirred for 15 min using a magnetic stirrer. This milky solution was then filtered through a 47 mm glass microfiber filter (Whitman International, Ltd) to separate residual seed particles from the solution.

Source water: Samples of river water were obtained as needed from the Rio Grande near Socorro, New Mexico, USA.

Experimental design: Flocculation/coagulation experiments were conducted using a range of coagulant dosing from the respective stock solutions and a control without coagulant addition. For repeatability, each experimental set-up was repeated 3 times. A laboratory jar test apparatus (ECE Compact Laboratory Mixer) was used with 1000 ml beakers as the flocculation/coagulation reactor volume. Depending on the particular experimental set-up, dosing was set at 5, 10, or 20 ml for the moringa stock solution and 2, 3, or 5 ml of alum stock solution. For a given dose of either coagulant, 4 beakers were in use (3 at the applied dose and 1 control). Turbidity and total coliform count were measured for the initial condition (raw river sample) prior to the coagulation. Immediately following coagulant dosing, the beaker contents were mixed rapidly for 20 sec at 352 RPM; this was followed by 40 min of gentle mixing at 20 RPM to aid in floc formation. The flocculated suspensions were allowed to stand without disturbance for 40 min to simulate settling. The supernatants thus formed were sampled and measured for turbidity and Total Coliform count. For a few selected runs, pH and total dissolved solids (TDS) measurements were added to the experimental regiment. In addition, salt extraction of the active component of *M. oleifera* was briefly explored to confirm the enhanced coagulation efficiency as reported by Tsatsuji et al. (1999, 2001). 1.0 g of powdered *M. oleifera* seed was added to 100 ml of 0.0, 0.25, 0.50, 0.75 and 1.0 mol/L NaCl solutions. The solution was magnetically stirred, allowed to extract for 15 min, and then filtered as described above.

Turbidity measurement: Initial and final turbidity was measured using a portable turbidimeter (Hach Model 2100P) calibrated with StablCal™ stabilized formazin primary standards of 0.01, 20, 100 and 800 nephelometric turbidity units (NTU). Manufacturer's recommendations and procedures for turbidimeter calibration, sample preparation, and sample measurement were followed. The sample turbidity was expressed as NTU.

Total coliform: Total Coliform counts were quantified using the Membrane Filtration method with m-coliBlue24 culture media and a portable microbiological incubator (Hach Model 25699). Due to the potential high count of Total Coliform in the source water, a serial dilution technique was adopted based on the manufacturer's recommendation for a raw river source. Samples were incubated for 24 h at 35°C. The resultant red-colored colonies were counted and the results expressed as colony forming units (CFU) per 100 ml.

pH and TDS: For a few experiments pH and TDS were evaluated using calibrated handheld test meters (pHTestr2 and TDSTestr40, respectively). For pH measurements, a three-point calibration was performed using pH 4, 7 and 10 phosphate buffers (Fisher Scientific). For TDS, a single point calibration was conducted using a 1413 µS/cm (942 mg/L) sodium chloride conductivity reference standard (Fisher Scientific).

RESULTS AND DISCUSSION

The experimental results on the effectiveness of *M. oleifera* extract as a coagulant as compared to alum are presented in Figures 1 through 6. At the coagulant dosages examined for *M. oleifera*, no change in solution pH and conductivity was observed with the treated water. This agrees with the findings of Ndacigengesere et al. (1995) and Katayon et al. (2006), but is in contrast with those of Amagloh and Benang (2009).

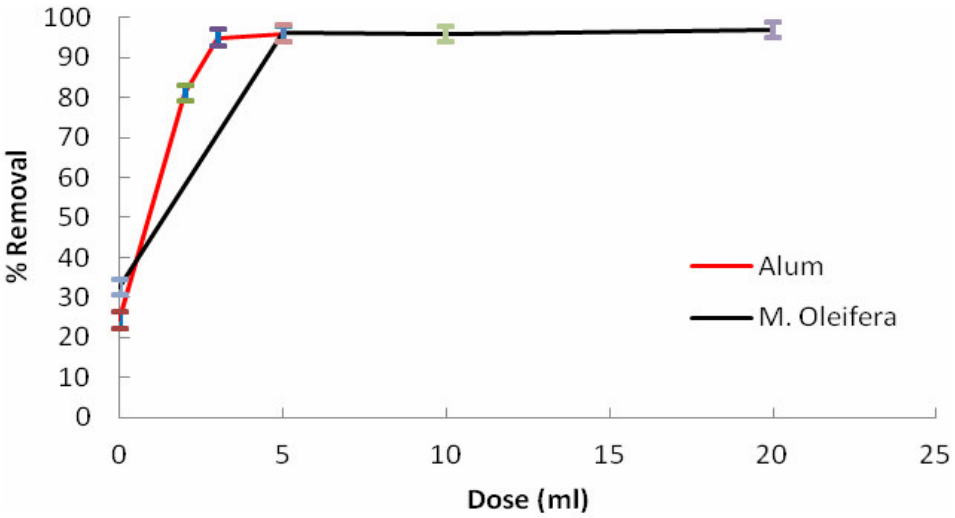

Figure 1. Turbidity removal with alum and *M. oleifera*.

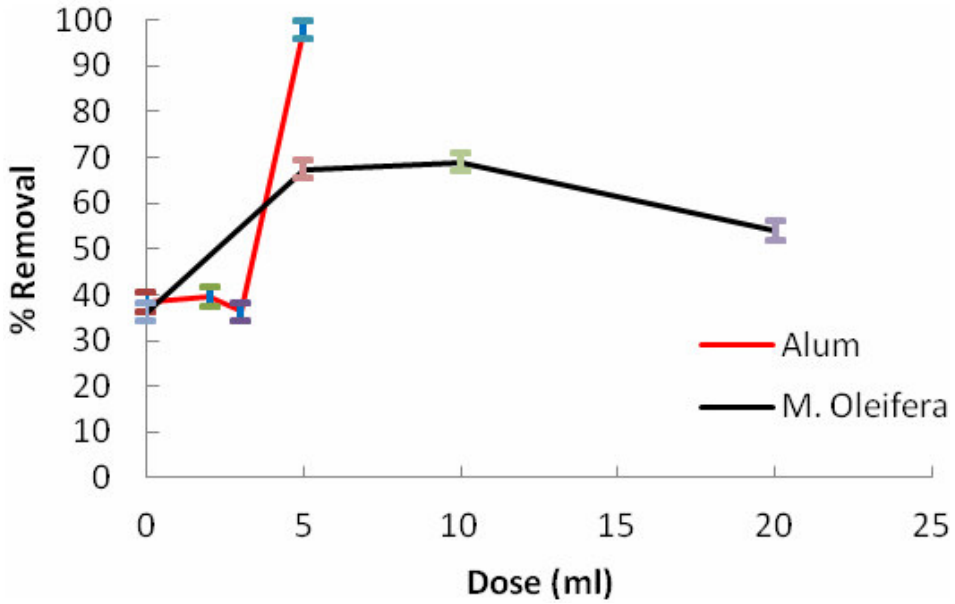

Figure 2. Total coliform reduction with aluminum sulfate and *Moringa oleifera*.

Turbidity removal

The initial turbidity of the source water ranged from 88 to 195 NTU. Efficiency of turbidity removal for *M. oleifera* expressed as a percentage and normalized to the untreated control is given in Figure 1. The 5, 10, and 20 ml dose of stock solution per 1000 ml sample volume corresponds to a concentration of 50, 100, and 200 mg/L of powdered coagulant, respectively. Removal by physical flocculation and sedimentation in the control was approximately 33%. Above a coagulant dose of 5 ml per 1000 ml sample volume, efficiency was high at 94% or greater removal. Also, Figure 1 shows the comparative results obtained for alum. The 2, 3, and 5 ml dose of stock solution corresponds to a concentration of 5.0, 7.5, and 12.5 mg/L of coagulant, respectively.

Total coliform reduction

Total Coliform for the source water ranged from 8 to 28 CFU per 100 ml. Total Coliform reduction for *M. oleifera* expressed as a percentage and normalized to the untreated control is given in Figure 2. Removal of turbi-

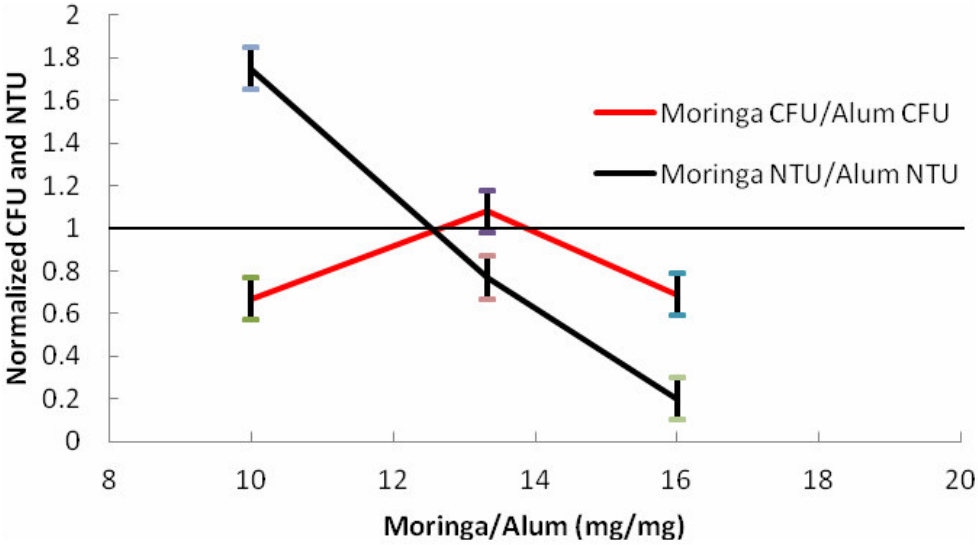

Figure 3. Normalized total coliform reduction and turbidity removal for both *M. oleifera* and alum.

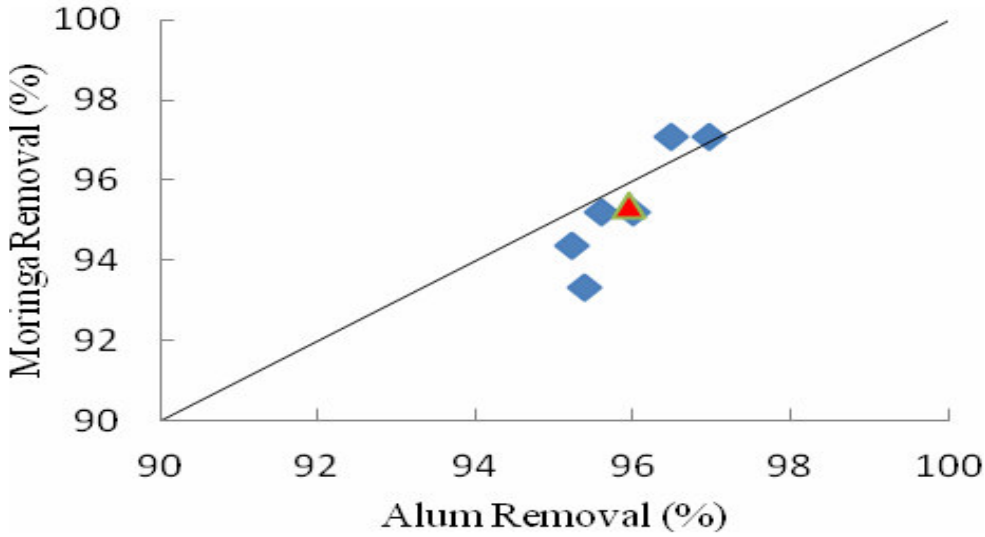

Figure 4. Comparison of turbidity removal at the equivalency dose.

dity by physical flocculation and sedimentation provides some benefit of Total Coliform reduction resulting from the attachment of bacteria to the colloidal sol. A reduction of approximately 67% is realized with dosages of 5 and 10 ml per 1000 ml sample volume; however, the higher dose was not as efficient. No plausible explanation can be given for this result as removal of turbidity was highest at the 20 ml dose. Figure 2 shows the results for alum. Total Coliform reduction was similar to the control at the low dosages examined; however, at the 5 ml dose Total Coliform counts were essentially zero, reflecting the high turbidity removal achieved concurrent with the possibility of some disinfection at the higher dose.

Normalized turbidity removal and total coliform reduction

Figures 3 provide normalized mass ratio plots of turbidity removal and Total Coliform reduction, respectively, from the previous data. The equivalency point appears to be around 12.5 mg *M. oleifera* to 1 mg alum. Using the previous concentrations of the respective stock solution, this translates to a 12.5 ml dose of *M. oleifera* as being equivalent to a 4 ml dose of alum.

Equivalent dose efficiency

Figures 4 and 5 show the results of six experiments for

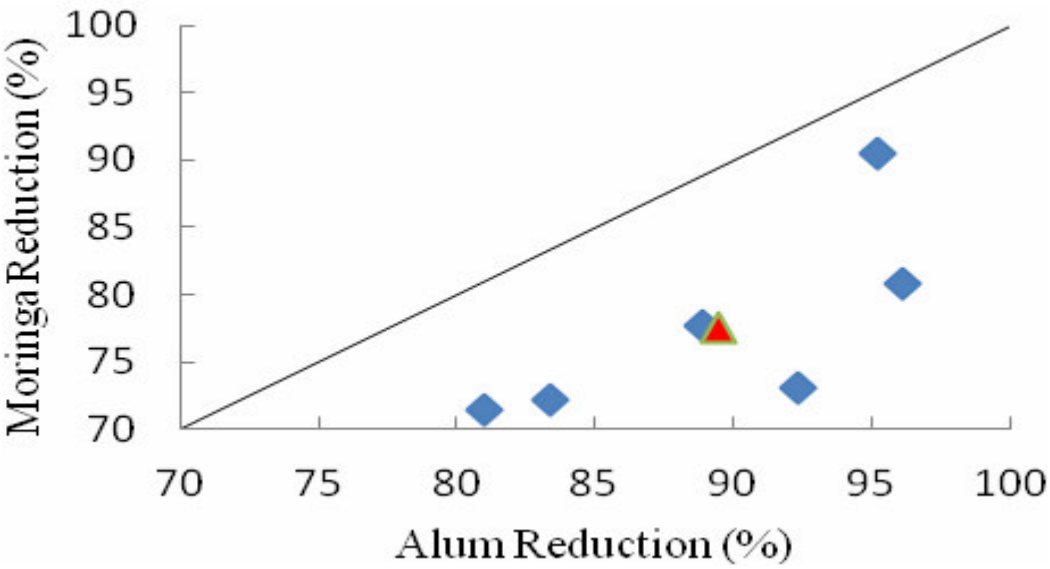

Figure 5. Comparison of total coliform reduction at the equivalency dose.

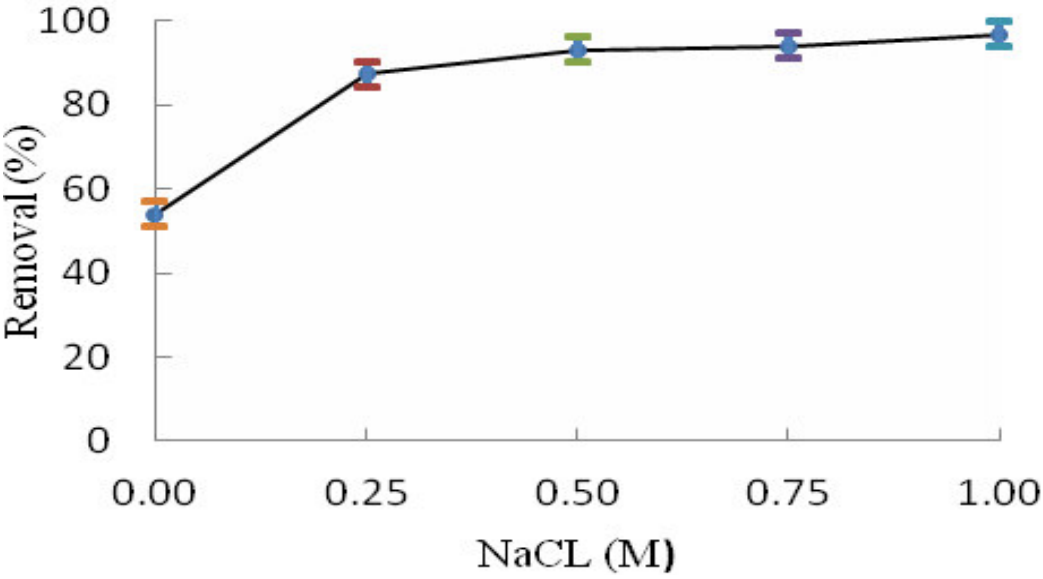

Figure 6. Improved efficiency of turbidity removal with salt extraction.

turbidity removal and Total Coliform reduction, respectively, conducted at the estimated equivalent dose. The solid line denotes a 1:1 ratio. The triangle represents the average of the data. From Figure 4, the removal efficiency of turbidity for *M. oleifera* is comparable to alum; however, Total Coliform reduction was not as efficient as alum (Figure 5). The turbidity data shows a narrow spread about the average, whereas the Total Coliform data exhibits a much wider variation. The previous figures confirm this trend by virtue of the magnitude of the respective error bars.

Salt extraction efficiency

Figure 6 demonstrates a substantial improvement in coagulation efficiency using salt extraction based on a coagulant dose of 10 ml per 1000 ml sample volume. Removal in the control was approximately 54%. With salt extraction turbidity removal was 94% or better. These results favorably compare with those of Tsatsuji et al. (1999, 2001). However, use of a salt extraction technique can result in an increase of salinity of the finished water. For example, at the coagulant dose used herein and a

0.50M salt extraction, approximately 290 mg/L of NaCl were added to the background Total Dissolved Solids (TDS) of the source water. Higher levels would impart a slight salty taste to the finished water. Use of salt extraction also places an added burden of chemical procurement for water treatment that may not be feasible in certain rural settings.

Conclusion

This preliminary investigation of the coagulation efficiency of *M. oleifera* extract shows promise with respect to overall turbidity removal and Total Coliform reduction and substantiates the findings of previous investigators. At the estimated equivalency dose based on applied coagulant mass, comparable removal of turbidity was achieved to that of alum and was on the order of 95% or greater; however, total coliform reduction was not as efficient. Both coagulants exhibited considerable variation in total coliform counts among the six experiments conducted at the equivalency dose. Average reduction was 77% versus 89%, respectively, for *M. oleifera* and alum. Additional experiments are warranted to establish a dosing equivalency for *M. oleifera* with respect to alum over a wider range of initial turbidity and total coliform counts than evaluated herein. Salt extraction of powdered *M. oleifera* seeds substantially improves overall coagulation efficiency; however, the salinity of the finished water will be increased.

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