Nigerian Journal of Engineering,Vol. 30, No. 3, December 2023, ISSN (print): 0794 – 4756, ISSN(online):2705-3954.

Nigerian Journal of Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
journal homepage: www.njeabu.com.ng

A Comparison of the Ability of Bio-Coagulants to Treat Turbid Water

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Research Article

Abstract

This study was carried out to compare bio-coagulants' ability to treat wastewater. Moringa oleifera seed and watermelon seed extracts were tested and proffered in this research. Synthetic turbid water was prepared using a clay suspension and a high correlation coefficient of 0.9967 was obtained between clay suspension dosage and turbidity lending credence to its use for the simulation. Jar tests were carried out to determine the optimum dosage of the bio-coagulants and alum as the control. In the settling column tests, it was observed that the removal efficiencies increased with time and decreased with the depth of the column. Alum had the highest average removal efficiency (97%), followed by Moringa oleifera seed extract with 84.5% removal. While watermelon seed extract had the least removal of 70.75%. Finally, the detention time and overflow rates were found to be within acceptable limits showing that these natural coagulants are potential alternatives to alum, which is presently the most common, coagulant in water treatment.

doi: 10.5455/nje.2023.30.03.15

Keywords
Moringa, watermelon, coagulation, overflow rate, detention, alum

Article History
Received: – November, 2021 **Accepted: – October**, 2023
Reviewed: – , July 2022 **Published: –**, December 2023

1. Introduction

Synthetic coagulants, such as alum, are used to treat the water in the waterworks. These synthetic coagulants have a negative impact on the environment and health (Serasinghe et al. 2022). For example, aluminum ion concentrations above 50μg/L are potentially toxic to aquatic organisms; and polyacrylamide residues (acryl amide) are neurotoxic and possess strong carcinogenic properties (Ghebremichaelet al. 2005; Mohd-Sallehet al. 2019).
Furthermore, coagulation is one of the most vital operations in water treatment employed in destabilizing suspended particles and reacting with organic materials in raw water. Organic matter removal by coagulation could be determined by the creation of insoluble compounds between organic matter and coagulants, as well as adsorption on freshly created hydroxide precipitate (Yanget al. 2008). Due to the detrimental consequences of synthetic coagulants, natural coagulants have gained popularity due to their abundance, low cost, nontoxicity, and biodegradability. Natural coagulants derived from plant extracts such as *Moringa oleifera seeds, Cactus latifaria,* and *Prosopisjuliflora* are now utilized in the treatment of drinking water for humans (Zhang et al. 2006). Several investigations have also confirmed that active coagulant agents in plant extracts are proteins due to their ability to firmly interact with other components (Zhang *et al*., 2006; Chew *et al.,*2018). The high protein content of watermelon (*citrulluslanatus*) seed has also been validated as having promising abilities as natural coagulant for water treatment in recent studies (Muhammad et al. 2015).

Moringa oleifera seeds have been used as a primary coagulant in drinking water clarification and wastewater treatment due to the presence of a water-soluble cationic coagulant protein which is able to reduce the turbidity of raw water (Mangale et al. 2012; Mogboet al. 2020).
A study carried out by Nand et al. (2012) showed that *Moringa* seeds were also effective in water purification in terms of the adsorption of metals. Laboratory investigations confirm the seed to be highly effective in the removal of suspended solids which contributes to its ability to clean both low and high-turbidity water (Berger et al., 1984; Saulawaet al. 2013). Nhut et al. (2021) evaluate the effectiveness of surface water treatment using *Moringa oleifera* seeds by-products as bio-coagulant to remove turbidity and natural organic matter. They found that the optimum bio-coagulant dosage was 0.15 ml L^{-1} for the water samples in both rainy and dry seasons. Furthermore, the paired t-tests used to compare the pre-treatment and post-treatment datasets for COD and turbidity removal efficiencies were significant ($p < 0.05$) in the three studied sites. Thus, results indicated that Moringa oleifera extract was a promising material that is environmentally friendly and low-cost to treat surface water.
When watermelon seed cake was used in combination with a chemical coagulant such as alum higher colour and turbidity removal of as high as 100% clarification of colour were observed. However, the recommended ratio for the combined coagulant dose was 80% watermelon seed powder, and 20% alum at which the best water treatment was obtained (Muhammad et al., 2015). This, therefore,

establishes that watermelon seed powder as a natural coagulant can be more effective when used with 20% alum as a coagulant mix, thus identifying it as a potential natural coagulant for water treatment. Abiram and Rohini (2017) investigated the coagulation performance of some natural and synthetic materials to remove the suspended particles in contaminated surface water. The result shows about 70 and 75% removal efficiency for moringa and alum respectively with respect to their varying parameters. Thus, the authors concluded that Moringa oleifera shows high turbidity removal efficiency when compared to the other coagulants, in which both alum and Moringa were observed to play an equal role in the water treatment process. Shakhawathalam and Imdadul Islam (2020) focused on the evaluation of plant-based natural coagulant sources, processes, effectiveness, and relevant coagulating mechanisms for the treatment of river and pond water and they concluded that the turbidity and color removal efficiencies were satisfactory for the coagulant which was significant for use as a coagulant in water treatment purpose.

Having viewed the above literature, it was discovered that the existing study only focused on the use of jar tests in the determination of the dosage required to treat turbid water. However, it failed to elaborate more on the detention settling column. As such, this study was carried out to assess and compare the removal efficiencies of biocoagulants (*Moringa oleifera* and watermelon seed extracts) when used for water treatment in detention settling columns, using clay suspensions to simulate the turbid water for this study.

2. Materials and Methods

2.1 Preparation and Determination of Optimum Clay Suspension

Clay obtained from HayinDogo, Zaria was sieved and crushed to a fine powder with mortar and pestle. Then, 5g, 10g, and 15g of the resulting powder were then weighed and each was added to 1 liter of distilled water after which the three suspensions were stirred continuously until uniformly mixed. The suspensions were then allowed to stand for 1 hour after which each suspension was decanted, and their settling properties analyzed.

2.2 Preparation of Alum Solution

Alum solution was prepared by dissolving 1 g Aluminum sulphate ($Al_2(SO_4)_3$) in 100ml of distilled water and then stirring with a magnetic stirrer for 10 minutes

2.3 Preparation of the Bioagulant Solutions

2.4 *Moringa oleifera*

Dried Moringa oleifera seeds were obtained and shelled. The shelled seeds were ground to a fine powder using a blender. Thereafter, 2g of grinded Moringa oleifera was weighed and dissolved in 100 ml of distilled water to make a solution (Ali et al. 2010). The solution was stirred at low speed for 5 minutes and at high speed for 10 minutes to achieve a uniform mixing and then filtered through a muslin cloth and Whatman no.1 filter paper.

2.5 Watermelon Seed

Dried watermelon seeds were obtained and shelled; the shelled seeds were ground using a mortar and pestle. After that, 10g of ground watermelon seeds were weighed and dissolved in 100ml of distilled water to make a solution (Muhammad et al. 2015). The solution was then stirred using a magnetic stirrer at low speed for 5 minutes and at high speed for 10 minutes to achieve a uniform mixing and then filtered through a sieve and then Whatman no. 1 filter paper.

2.6 Jar Tests

Jar tests were carried out according to the procedure outlined by EPA (1998). This was to determine the optimum dosages of the coagulants for use in the settling column tests. Jar tests were carried out by using a jar tester (Phipps and Bird, Model 300) to evaluate coagulation activity at several dose levels of coagulants. Four 500-ml beakers were filled with 500 ml of synthetic water and placed in the slots of the jar tester(See Figure 1). The synthetic waters samples were agitated at 100 rpm and 10rpm. During this agitation, various dosages of coagulants were added to each beaker (between 1ml to 3ml for *Moringa oleifera* seed extract; 1ml to 8ml for watermelon seed extract; and 1ml to 6ml for alum) and agitated for 2 min at 100 rpm. The mixing speed was reduced to 10rpm for 15 minutes for slow mixing. After sedimentation for 1 h; 5 ml of the sample was collected from about 1 cm below the surface of the water and the residual turbidity of each coagulated water sample was measured using a turbidity meter to obtain the optimum dosage of the coagulants. This procedure was repeated for each coagulant.

2.7 Column Settling Test

A settling column of diameter 102mm and depth 2m with four sampling ports provided at 0.5 m, 1.0 m, 1.5 m, 2.0 m, from the bottom of the column as shown in Figure 2 was used for the settling test. The settling column was filled with the prepared turbid water solution of initial turbidity of 150NTU. This setup was repeatedly used for each of the coagulants. Each of the dosage of the coagulants obtained from the jar tests was dosed to each settling column setup. Then the samples were drawn from each sample port from top to bottom and the turbidity of each sample was measured using a turbidimeter. Subsequently, the average was taken as the initial turbidity of the sample.

Then for each setup, samples were drawn at 20 minutes intervals, for a total of 180 minutes, from each sample port from top to bottom. The turbidity and total suspended solids of each sample were measured with a turbidimeter and weighing balance respectively. Thereafter, the percentage removal of these turbidity readings were calculated from their initial turbidity values.

The graph of sampling port depth versus time of percentage removal of turbidity readings (iso-concentration settling curves) was plotted for each coagulant. Overflow rates and detention times were obtained from the graphs and used to

evaluate overall turbidity removal efficiencies. The settling curves are shown in Figure 8 below.
The detention time is given by the intersection of the settling curves with the 2 m depth line. The overflow rate was then calculated using the formula

$$V_0 = \frac{H}{ti} \quad (1)$$

Where V_o = overflow rate in m/day; H = 2m and t_i = detention time in days

The overall removal efficiencies were then calculated using the interpolation method described by Zhang et al. (2006)

Figure 1: Jar Test Apparatus

Figure2: Settling Column

3.0 Results and Discussions

Figure 3 shows the correlation between clay suspension dosage and turbidity. An increase in the clay suspension dosage showed a corresponding increase in turbidity in an approximately linear fashion. This showed that there was a strong correlation between the two and hence the turbidity could be successfully simulated using the clay suspension.
Figures 4a, b, and c show the results of the jar test from which the optimum dosages of *Moringa oleifera* and Watermelon seed extracts and Alum respectively were obtained. Among the experimental dosages adopted, an optimum dosage of 3ml was obtained (see Figure 4a), for *Moringa oleifera.* This was equivalent to a 91.6% reduction in turbidity (101NTU to 8.5NTU). With respect to watermelon seed extract, an optimum dosage of 8ml was obtained (see Figure 4b), corresponding to a 97% reduction in turbidity (98NTU to 2.75NTU). Finally, an optimum Alum dosage of 6ml resulted in a 91.6% reduction in turbidity (99NTU to 4.5NTU). The high turbidity reductions achieved by the biocoagulants, at these low concentrations, also showed preliminary evidence of their efficiency as coagulants. The established optimum dosages were then used to treat the synthetic turbid water in the settling columns.
The results of the settling column tests are given in Tables 1, 2, and 3 for the three coagulants respectively. The removal efficiencies were calculated using Equation 2 below:

$$R\ (\%) = \left(1 - \frac{T_f}{T_0}\right) \times 100 \quad (2)$$

Where R (%) is the removal efficiency and T_f and T_o are the final and initial turbidities respectively. The tables showed that alum had the highest average removal efficiency of 97%, followed by morinnga *oleifera* (84.5%) with watermelon seed extract having the least (70.75%). It could also be observed that the removal efficiencies increased with increasing time for constant depth. This could be attributed to the fact that as contact time increases, more floc particles of larger sizes are formed which leads to faster settling. The removal efficiencies decreased with increasing depth at a particular time interval. This is because of higher turbidity at greater depths due to settling flocs.
The results are summarized in Figures 5, 6, and 7. From Figure 5, the trend shows that alum had greater average removal efficiency at each time interval; while watermelon had the least average removal efficiency for each time interval.
From Figure 6, there is an overall increase in removal efficiency as the detention time increases. This is a result of increased flocculation with time. Alum showed higher removal efficiencies at shorter detention times compared to *Moringa oleifera* and watermelon seed extracts. With respect to overflow rate, there was a decrease in the removal efficiencies with an increase in overflow rate for all three coagulants. This is evident from Figure 7, which showed that *Moringa oleifera* seed extract had the sharpest decline in removal efficiency with increasing overflow rate.

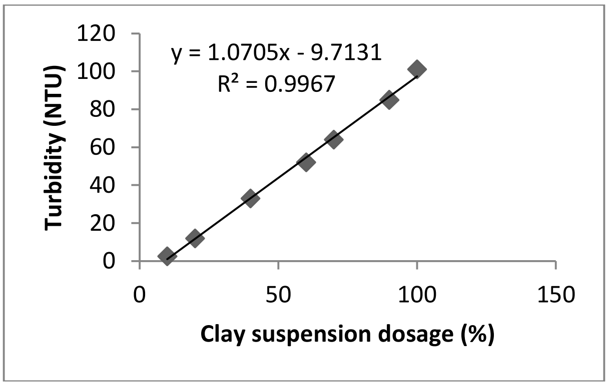

Figure 3: Regression Plot for Synthetic Turbid Water

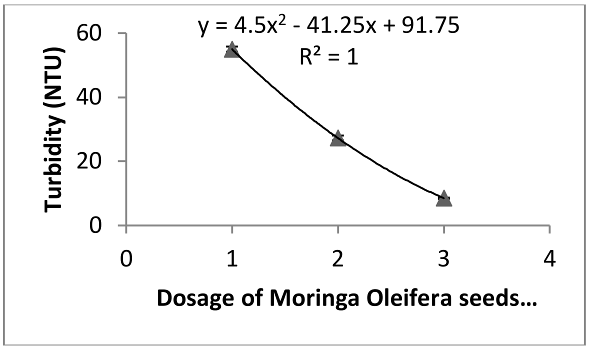

Figure 4a: Regression Plot of Turbidity against Moringa Seed Extract Dosage

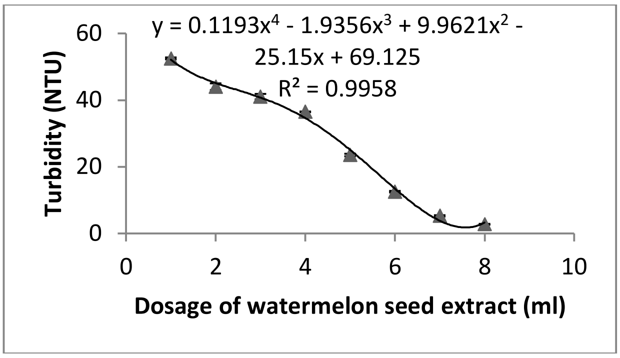

Figure 4b: Regression Plot of Turbidity against Watermelon Seed Extract Dosage

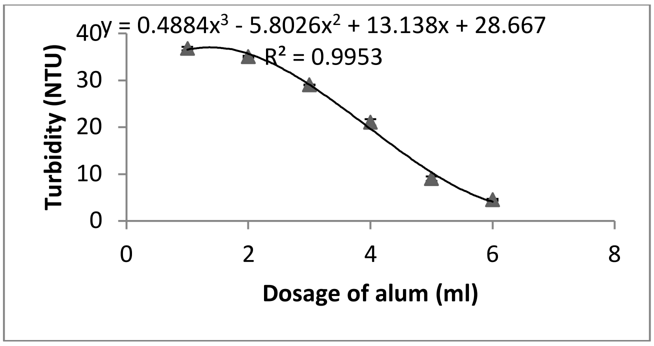

Figure 4c: Regression Plot of Turbidity against Alum Dosage

Table 1: Percentage removal Efficiency (R %) as a function of time and depth for *Moringa oleifera*

Depth (m)	Time (min) 20	40	60	80	100	120	140	160	180
0.5	47	51	55	57	56	68	81	85	90
1	38	42	45	47	52	61	74	83	86
1.5	34	37	39	41	45	56	66	76	84
2	11	17	27	35	41	47	59	70	78
Average	**33**	**37**	**42**	**45**	**49**	**58**	**70**	**79**	**85**

Table 2:Percentage removal Efficiency (R %) as a function of time and depth for watermelon seed extract

Depth (m)	Time (min) 20	40	60	80	100	120	140	160	180
0.5	22	32	41	48	60	63	65	70	80
1	17	25	36	42	49	51	57	67	75
1.5	11	17	25	37	43	45	51	58	69
2	6	10	20	31	38	41	47	54	59
Average	**14**	**21**	**31**	**40**	**48**	**50**	**55**	**62**	**71**

Table 3: Percentage removal Efficiency (R %) as a function of time and depth for Alum

Depth (m)	Time (min) 20	40	60	80	100	120	140	160	180
0.5	71	72	78	91	95	98	99	-	-
1	48	52	77	90	93	96	98	99	-
1.5	42	47	74	76	89	94	96	97	98
2	33	44	52	65	80	90	93	94	96
Average	**49**	**54**	**70**	**81**	**89**	**95**	**97**	**97**	**97**

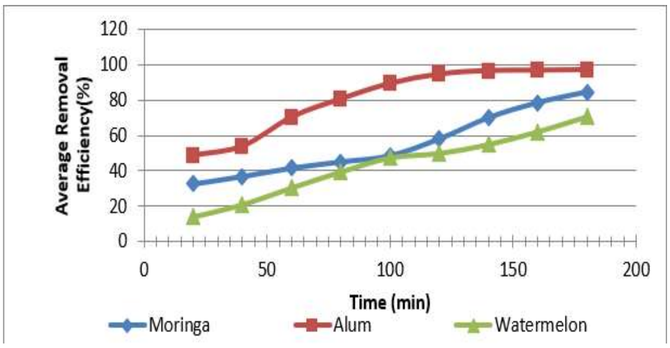

Figure 5: Average Removal Efficiency against Time for the three Coagulants

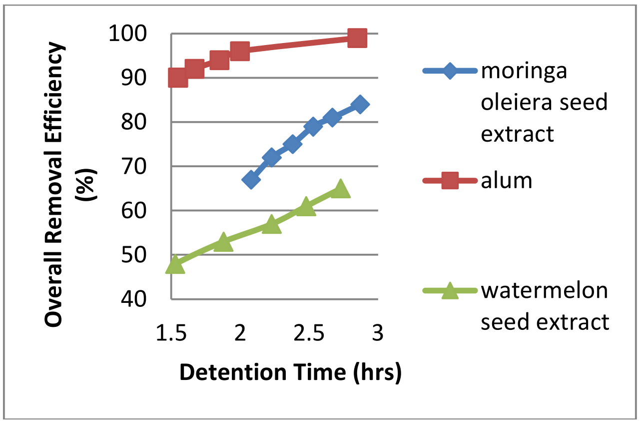

Figure 6: Average Removal Efficiency against detention time for the three Coagulants

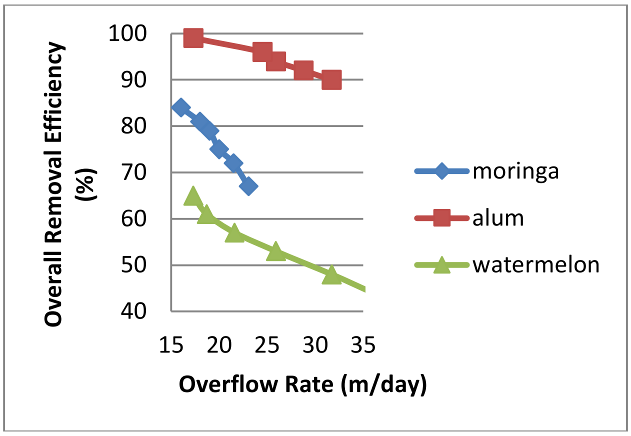

Figure 7: Average Removal Efficiency against overflow rate for the three Coagulants

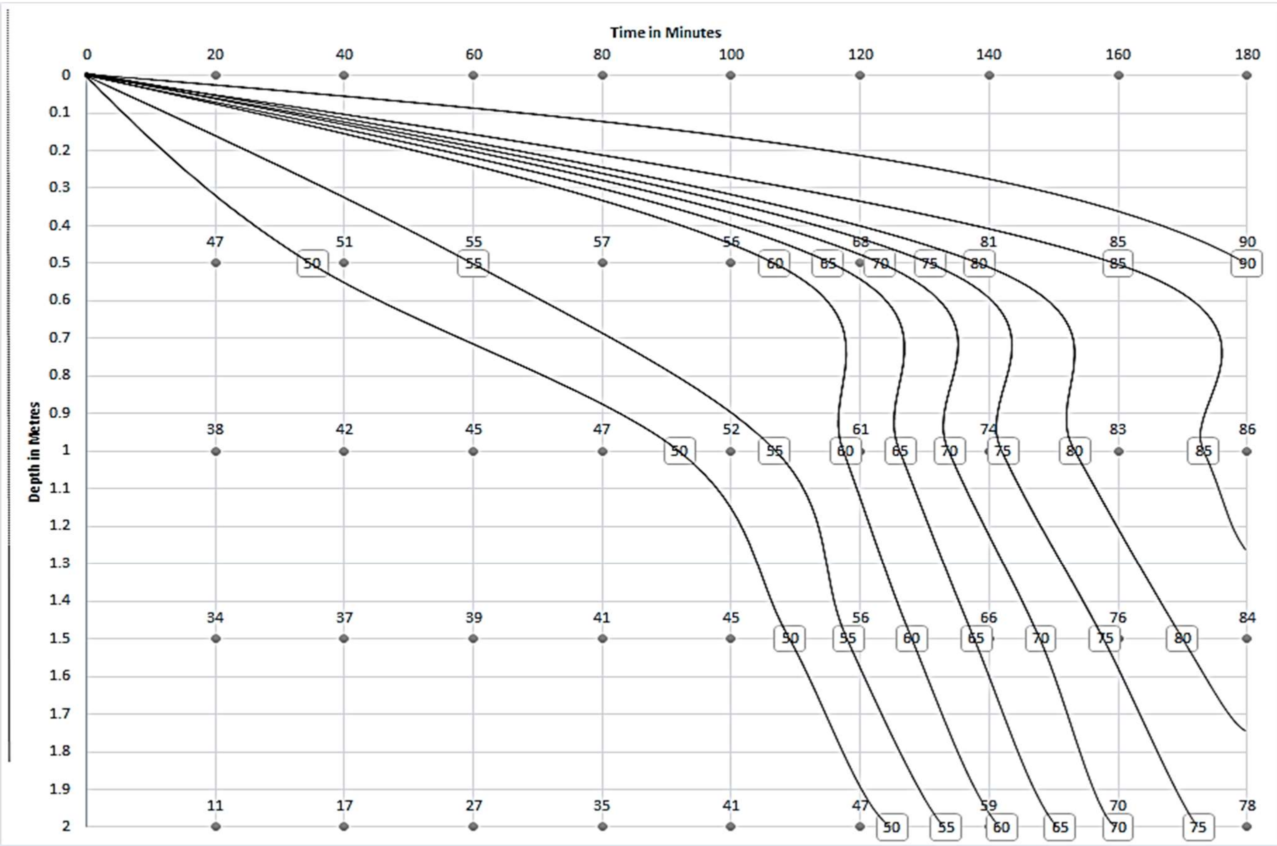

Figure 8a: A plot of percentage removal Efficiency as a function of time and depth of the settling column using *Moringa oleifera* seed extract as coagulant

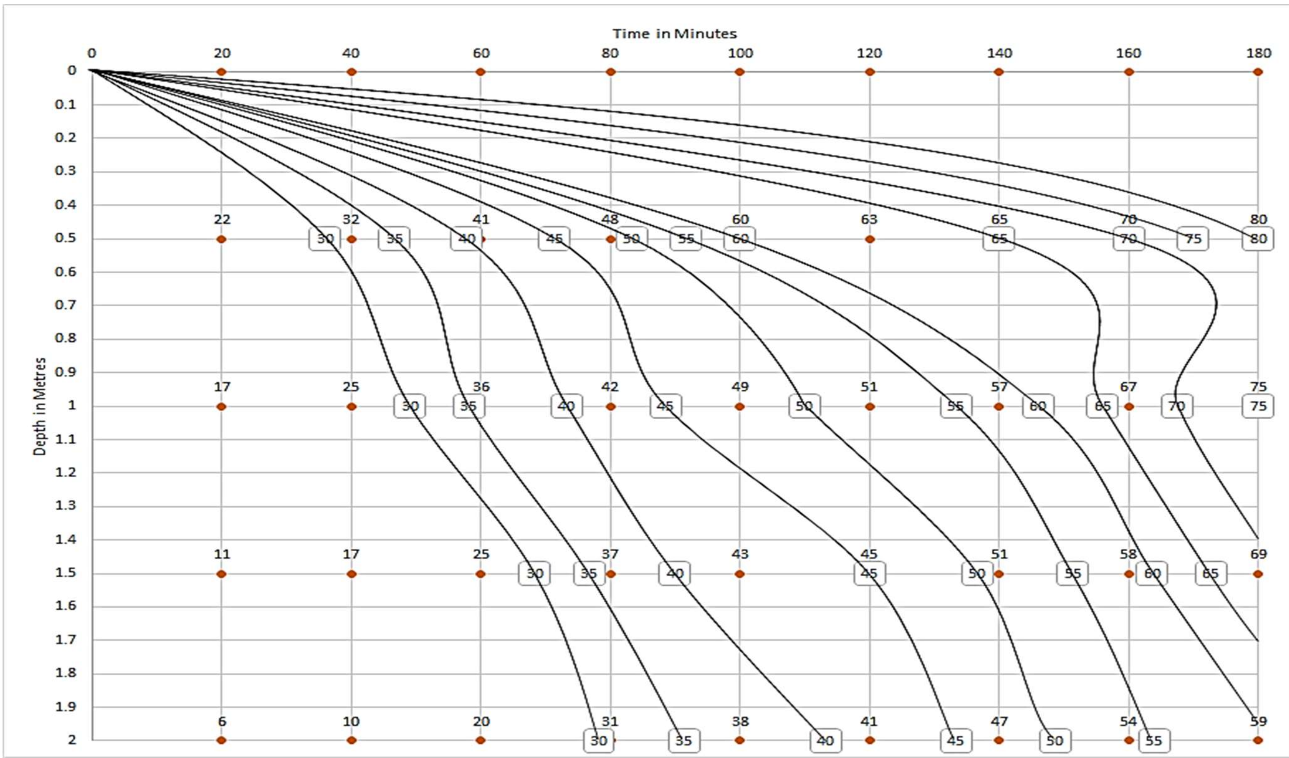

Figure 8b: A plot of percentage removal efficiency as a function of time and depth of the settling column using watermelon seed extract as a coagulant

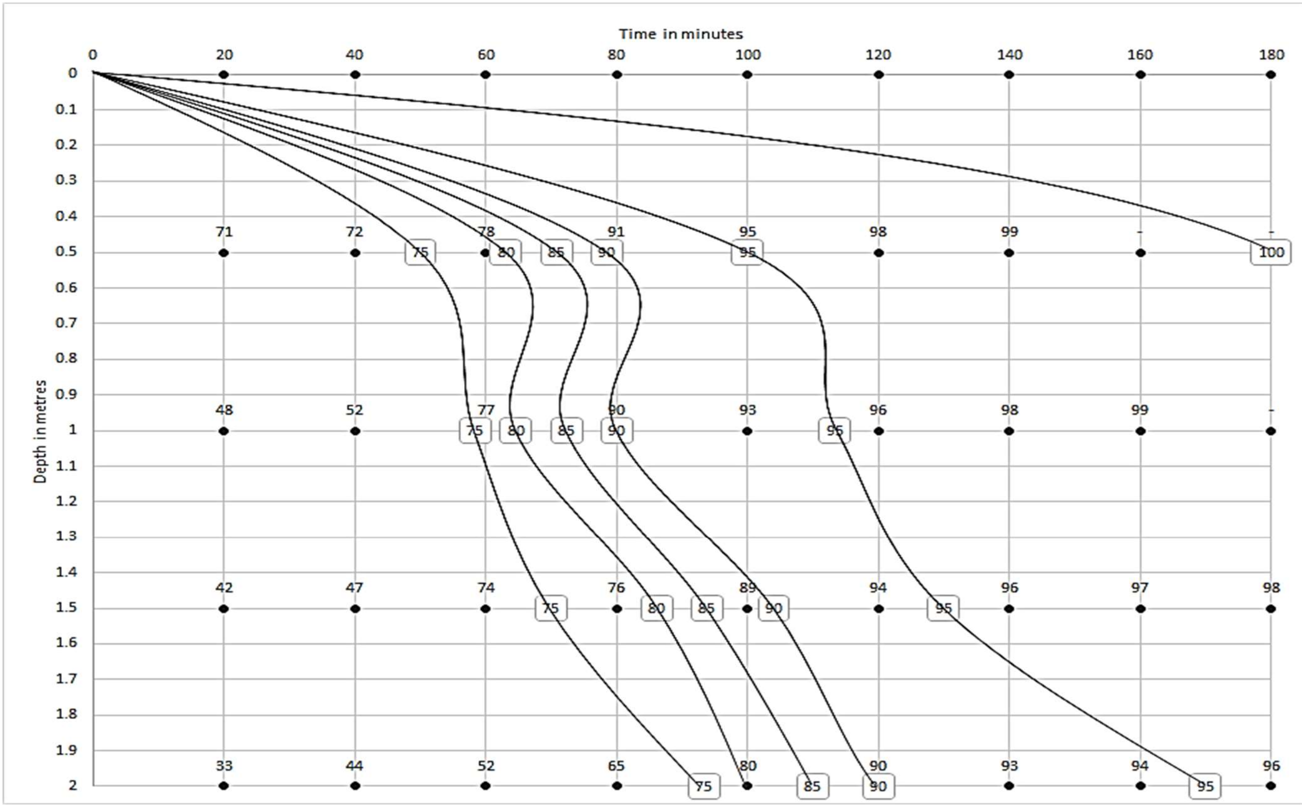

Figure 8c: A plot of Percentage Removal Efficiency as a function of time and depth of the settling column using Alum as a coagulant

Baidhani (2009) reported that a surface overflow rate of greater than $22m^3/day.m^2$ and a detention time of 2-4 hours is ideal for more effective coagulation. The three coagulants were tested within this range which implies that the bio-coagulants (*Moringa oleifera* and Watermelon seed extracts) performed well under the ideal conditions and hence are suitable for use as coagulants in water treatment.

3.1 Comparison of the present study with the existing literature

The comparison between this present study with the research conducted by Muhammad et al. (2015), showed few differences. For instance, the water sample used in this study had a higher initial turbidity of 150NTU compared to theirs which was 0.8NTU. Also, they were able to achieve 80% removal efficiency after the addition of watermelon seed extract then alum was later added to their sample, which resulted in 100% removal efficiency. On the other hand, this study achieved a 70.7% removal efficiency after 180 minutes at a depth of 2 meters.

Furthermore, comparing the turbidity removal percentage for moringa in the work of Ali et al. (2010), to this present study, this study had a higher initial turbidity of 150NTU compared to their 10.62NTU. This study achieved 84.5% turbidity removal percentage at a depth of 2 meters, whereas they obtained 64%. Thus, it was observed that they used surface water as their source while in the present research, three different experiments were run for three coagulants which led to the use of synthetic turbid water because there will be variation in the turbidity.

4.0 Conclusion

This study compares the potentials of *Moringa oleifera* and Watermelon seed extracts as coagulants in raw water treatment and also seeks to determine which of the natural coagulant (Moringa oleifera and watermelon) has the best removal efficiency to replace alum in water treatment. Alum, which is the most common commercially available coagulant, was used as a control and basis of comparison during the experiment. The study revealed that clay could successfully simulate turbidity in water, thus lending credence to its use for this study.

Alum had the highest average turbidity removal efficiency(97%) followed by *Moringa oleifera at* 84.5%, while watermelon seed extract had the lowest of 70.75% removal. These are acceptable levels for the coagulation section of water treatment and hence show that these bio-coagulants have strong coagulation strengths.

Finally, the ranges of detention time and overflow rates were within acceptable limits which further shows that *Moringa oleifera* and watermelon seed extracts can be potentially used as viable alternatives to coagulants in commercial use.

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