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Comparative Study of Clarification Efficiencies of Alum and Moringa Oleifera Coagulants

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Abstract:
Background: *Many communities live deplorably in extreme poverty in some poor countries of the world. Majority rely upon traditional sources of highly turbid and untreated surface waters for their domestic needs. These surface waters can be treated with coagulants to remove the turbidity thereby making them suitable for consumption. Therefore, this study compared the efficiencies of Alum and Moringa oleifera coagulants in removal of turbidity from water.*
Materials and Methods*: One-Factor-At-A-Time (OFAT) experimental approach was adopted in this study. This entails carrying out the experiments by varying one factor at a time when others are kept constant. The factors considered in this study are dosing, pH and impeller rotational speed respectively, which involved three stages of experiments. A 20 litre sample of turbid water was prepared by mixing 60 g weight of clay soil particles (0.020 mm - 0.0020 mm grain size) in 20 litres of distilled water to give 3000 mg/l concentration of turbid water. Required doses of Alum and Moringa oleifera coagulants were introduced in 500 ml samples of turbid water stored in beakers in accordance with the number of trials for each variable.*
Results*: Though Moringa oleifera proved to be a better coagulant than Alum, the result is not significant at 5% level of significance for dosing, impeller rotational speed and pH at short-term period of clarification of 15 minutes. For long-term clarification, there is significant difference between turbidity removal at 15 minutes and turbidity removal at 60 minutes when Alum coagulant was used. The same result was noted when turbidity removal using Moringa oleifera was studied at 15 minutes and 60 minutes, but the result of Moringa oleifera is more critical than alum because computed t-value for Alum was 12.755 and that for Moringa oleifera was 33.843 which indicate that the result is significant at 5% level.*
Conclusion*: Moringa oleifera is a better coagulant than Alum but the difference is insignificant, though 100% clarification could be attained if both supernatant water were to be allowed for clarification to last for a long time.*

Key Word*: Comparative, Alum, Moringa oleifera, Clarification, Study*

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I. Introduction

In poor countries throughout Africa, Asia, and Latin America, approximately 1.4 billion rural and peri-urban people live deplorably in extreme poverty (< $1.25 U.S. per day), struggling day-to-day to survive. The majority rely almost exclusively upon traditional sources of highly turbid and untreated pathogenic (viral and bacterial) surface water for their domestic water needs [1]. Since time immemorial, the indigenous method employing crushed seed powder from the pan-tropical *Moringa oleifera* Lam. (*M. oleifera*) tree has resulted in an effective natural flocculating agent, providing a low-cost household solution to the critical need for potable water in rural riparian communities.

A literature review indicates that *M. oleifera* seeds coagulate 80.0% to 99.5% [2] of turbidity (surrogate for suspended fine particles) and colour (surrogate for natural organic material). *M. oleifera* seeds contain 35% to 40% oil by weight [3], and can first be processed to yield a high-quality edible vegetable oil "high in oleic acid" [4] that resists rancidity [5]. Of particular importance, the seed cake (press cake) remaining after oil extraction still retains the active flocculating properties for removing turbidity without diminished efficacy. As a general rule of thumb, one shelled seed ($\sim 200\ mg$) is used to treat 1 litre of very turbid surface water [6].

As a clarifying agent, there is an important limitation with *Moringa oleifera* seed extract, i.e., the crude extract is unsuitable for low turbidity waters [7]. "This may be due to the low molecular weight of the coagulant and the patch mechanism of charge neutralization and floc formation that forms smaller light flocs" [8]. This is an important consideration, for example, if one is contemplating using *M. oleifera* as a turbidity-removing agent before the SODIS disinfection method [9].

The seed kernels of *Moringa oleifera* contain significant quantities of a series of low molecular weight, water-soluble proteins which, in solution, carry an overall positive charge. The proteins are considered to act similarly to synthetic, positively charged polymer coagulants. When added to raw water the proteins bind to the predominantly negatively charged particulates that make raw waters turbid (silt, clay, bacteria etc.). under proper agitation these bound particulates then grow in size to form flocs, which may be left to settle by gravity or be removed by filtration [10,11]. *Moringa oleifera* powder has been reported to have the capability of reducing low and high turbidity values in surface water [12-18]. *Moringa oleifera* was used as a natural coagulant in a full-scale treatment trial at the water treatment works in Malawi. Turbidity values as high as 270-380 NTU were reduced to around 04 NTU, which are within the WHO (2006) guideline value with the addition of the powder [19].

Coagulation is one of the most important physicochemical operations used in water and wastewater treatment can be achieved by chemical and electrical means [20] The coagulation experiments indicated that alum effectively removed COD (65%) and TSS (> 75%) on the average values of COD using 150 mgL^{-1} aluminum sulphate at a pH range of 5-8.

The most common and economical salt of aluminum is alum $(Al_2(SO_4).nH_2O)$ and widely used as a coagulant in water treatment. The aqueous chemistry of aluminum is complex and upon addition of an aluminum coagulant in water treatment. The mechanism by which aluminum functions depend on which aluminum species react to remove dissolved or colloidal contaminants. Destabilization involving aluminum monomers is referred to as charge neutralization or coagulation of colloidal particles in the presence of $Al(OH)_3$ is termed as enmeshment or sweep floc. Dissolved organic can be removed by adsorption on aluminum precipitation[21] . For aluminum salts, the mechanism of coagulation is controlled by the hydrolysis speciation [22]. The positively charged polyhydroxo-complexes such as $[Al_8(OH)_{20}]^{+4}$ in the pH range between 4 and 7, are the effective flocculants. Over-saturation and formation of amorphous hydroxide precipitates $[Al(OH)_3]$ enmeshes colloidal particles in a "sweep floc". Many other monomeric and polymeric species have been reported;

Monomers: $[Al(OH)_4]^{+2}$, $[Al(OH)_2]^{+}$, $[Al_2(OH)_2]^{+4}$, $[Al(OH)_4]^{-}$, *Polymers*: $[Al_6(OH)_{15}]^{+3}$, $[Al_7(OH)_{17}]^{+4}$, $[Al_8(OH)_{20}]^{+4}$, $[Al_{13}(OH)_{34}]^{+5}$.

Polyaluminum chlorides (PACl) are similar to Alum except that they contain high charge polymeric aluminum species as well as the monomer. An Al_{13} with the formula $Al_{13}O_4(OH)_{24}(H_2O)_{12}{}^{7+}$ has been shown to dominate species [23-25]

II. Materials and Methods

The equipments used in this study include turbidity meter by HANNA Instruments 1998, Model HI 93703 Portable Microprocessor Turbidity Meter) and a pocket-size pH meter (pHep®) from HANNA instruments [range 0.0 to 14.0 pH; resolution 0.1 pH; accuracy @ 20℃/68℉ of $\pm$ 0.1 pH]. Chemicals used in this study include Alum and crushed *Moringa oleifera* seed. Variation of pH for its effect on clarification was achieved by using 0.1 M hydrochloric acid (HCl) and 0.1 M sodium hydroxide (NaOH) concentrations respectively. Clay soil particles in the range of 0.020 mm to 0.0020 mm diameter were taken from sieve analysis conducted on soil sample collected from a nearby clay formation and was used to prepare the turbid water. Distilled water was purchased from the market. Turbid water sample of 3000 mg/l concentration was prepared by mixing 3 g of clay particles in one litre of distilled water. Different doses of Alum and crushed *Moringa oleifera* seed coagulants were also prepared by mixing appropriate quantities in one litre of distilled water

Experimental Procedure

One-Factor-At-A-Time (OFAT) experimental approach was used in this study. This entails carrying out the experiments by varying one factor at a time with other factors being kept constant. In conducting this experiment, separately, 25 mg/l, 40 mg/l, 55 mg/l, 70 mg/l, 85 mg/l, and 100 mg/l doses of Alum and crushed *Moringa oleifera* seed coagulants (i.e. conditioners) were dissolved in twelve beakers each containing 500 ml of turbid water samples.

At constant pH of 7 and impeller rotational speed of approximately 100 rpm, the water was initially rapidly mixed for 20 minutes and allowed to settle for 30 minutes.

Subsequently, clarification was studied at varied pH of 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0 respectively, at constant dosage of 47.5 mg/l and impeller rotational speed of 100 rpm. Next, removal efficiency was investigated at constant pH of 7 and dosage of 47.5 mg/l when rotational speeds varied from 20 rpm, 40 rpm, 60 rpm, 80 rpm and 100 rpm inclusive. The 500 ml samples in the beakers were mixed for twenty minutes and allowed to settle and samples drawn after 15 minutes and 60 minutes.

At the end of each section of the experiments, some samples were drawn from the supernatant water samples and subjected to turbidity test using Portable Microprocessor Turbidity Meter. Samples drawn from the

beakers after 15 minutes and 60 minutes were meant to assess the short- and long-term effects of clarification resulting from different mixing speeds.
Performance comparison of Alum and crushed *Moringa oleifera* seed coagulants was carried out by test of hypothesis using the statistical t-test on paired comparisons at 5% level of significance.
Hypothesis:
$H_0 : \mu_{1i} = \mu_{2i}$ (for all i), and there is no significant difference in the removal efficiencies between the two coagulants, any difference may have arisen by chance.
$H_1 : \mu_{1i} \neq \mu_{2i}$ (for all i) and there is significant difference in the removal efficiencies between the coagulants.
The variance and t-statistic are calculated as:

$$s_d^2 = \sum_{i=1}^{N} \frac{(d_i - \bar{d})^2}{N-1}$$

$$t = \frac{\bar{d}}{s_d/\sqrt{N}}$$

Where d_i is the difference between turbidity values of samples clarified with Alum and the ones clarified with crushed *Moringa oleifera* seed coagulants.
$\bar{d}$ is the average difference between turbidity values of samples clarified with Alum and the ones clarified with crushed *Moringa oleifera* seed coagulants.
s_d is the standard deviation
N is the number of observations.

Decision:
If the computed $|t|$ is smaller than the tabulated t, (i.e. $|t| < t_{0.95,\ df}$), the result is not significant at 5% level of significance so that the null hypothesis will be accepted that no significant difference exist between the clarification potentials of Alum and *Moringa oleifera* coagulants. On the other hand, if computed $|t| > t_{0.95,\ df}$ the null hypothesis is rejected and the alternative hypothesis that significant difference exist between the clarification potentials of Alum and *Moringa oleifera* coagulants will be accepted.

III. Results

Table no 1 shows the final turbidity after clarification with Alum and crushed *Moringa oleifera* seed coagulants. The experimental conditions was an initial turbidity value of 877 NTU, a pH of 7 and impeller rotational speed of approximately 100 rpm. Result showed that optimum removal efficiency of Alum is slightly higher than removal efficiency of *Moringa oleifera* with values of 39.7% for Alum at a dose of 70 mg/l and 36.2% for *Moringa oleifera* at a dose of 55 mg/l, and overall results show that turbidity is in the range of 50 - 100 mg/l [26]. Also, [27] achieved turbidity removal of 93.13% at 40 mg/l dosing using poly-aluminum-silicate-chloride in pulp and paper industry.

Table no 1: Final turbidity after clarification with Alumand *Moringa oleifera* coagulants

Dose (mg/l)	Final turbidity (NTU)	
	Alum	*Moringa oleifera*
25	111	91
40	131	146
55	181	317
70	348	275
85	301	259
100	264	161

Initial turbidity = 877 (NTU); Impeller Rot. Speed =100 rpm
pH = 7

Figure 1 is a plot of the relationship between coagulant doses and turbidity removal efficiencies of the two coagulants. The plot shows that at 25 mg/l and 40 mg/l, there is no sharp contrast between turbidity removal for both coagulants, though variation was much at dose of 100 mg/l with values of 30.1% for Alum and 18.4% for *Moringa oleifera* coagulants. Test of hypothesis at 5% level of significance indicated that there is no significant difference in the removal efficiencies of both coagulants. This is shown in Table no 4 and it was observed that computed t-value of 0.185 is less than tabulated value of 2.57, this is an indication that the result is not significant at 5% level and rejection of the alternative hypothesis, H_1.

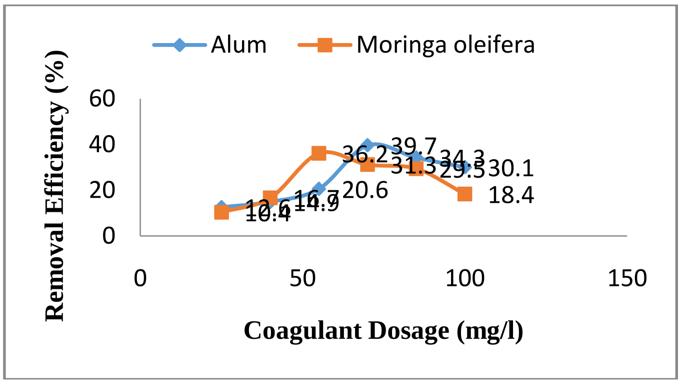


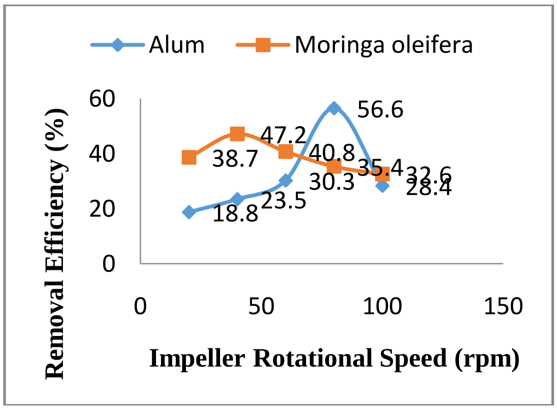
Figure 1: Variation of coagulant dose with removal efficiency Experimental conditions: Initial turbidity - 877 NTU; pH-7; Impeller rotational speed- 100 rpm

Table no 2 presented the short- and long-term effects of clarification by Alum and *Moringa. oleifera* coagulants. Turbidity were measured at 15 minutes and 60 minutes after stirring and at varied rotational speeds ranging from 20 rpm to 100 rpm. Results showed that clarification is faster with *Moringa oleifera* coagulant and optimum removal of 47.2% was observed at rotational speed of 60 rpm. Though the overall performance favour *Moringa oleifera*, Alum demonstrated optimum removal of 56.6% at 80 rpm. At 5% level of significance, $t_{0.025,\ 4} = 2.780$ as compared with the computed t-value of 0.935 for short-term effect in which clarification took place for 15 minutes for comparison between Alum and *Moringa oleifera* coagulants (see Table no 4). On the basis of long-term effect where clarification occurred for 60 minutes, $t_{0.025,\ 4} = 2.780$ while the computed t-value was 1.566 and despite *Moringa oleifera* being a better clarifier, computed t-values were less than tabulated t-values for both short- and long-term considerations so that the results are not significant at 5% level of significance and is inferred that there is no significant difference (see Table no 4). The results are also presented in Figures 2 and 3 which are plots that compared clarification potentials of the two coagulants, and they indicate that *Moringa oleifera* is better than Alum. In Figure 3, it can be seen that if more time is allowed 100% clarification may be reached by the two coagulants. Similar result of 98.7% turbidity removal was obtained by [28].

Table no 2: Final turbidity for Alum and *Moringa oleifera* coagulants for different rotational speeds

Impeller rotational speed (rpm)	Alum		*Moringa oleifera*	
	Final turbidity (15 mins)	Final turbidity (60 mins)	Final turbidity (15 mins)	Final turbidity (60 mins)
20	165	709	339	872
40	206	837	414	877
60	266	848	358	877
80	496	877	854	845
100	249	877	839	839

Initial turbidity = 877 NTU; pH = 7; Dosage = 62.5 mg/l



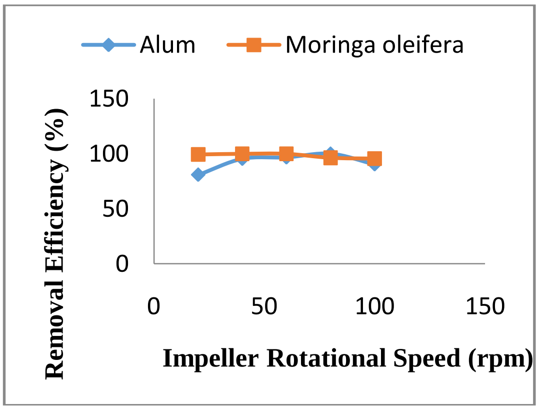
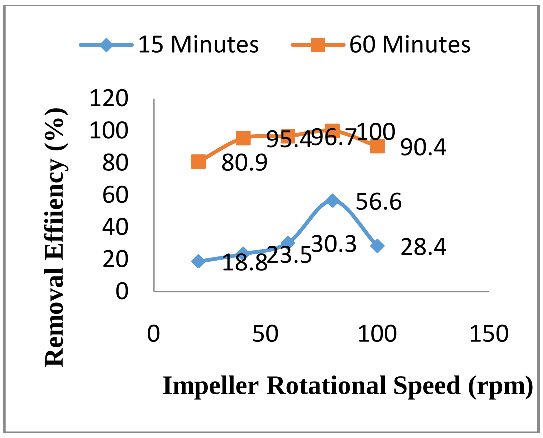


Figure 2: Comparison of removal efficiencies based on short-term effect. (Experimental conditions: pH - 7; Time - 15 mins; Initial turbidity - 877 NTU; Dosage - 62.5 mg/l)

Figure 3: Comparison of removal efficiencies based on long-term effect. (Experimental conditions: pH - 7; Time - 60 mins: Initial turbidity - 877 NTU; Dosage - 62.5 mg/l



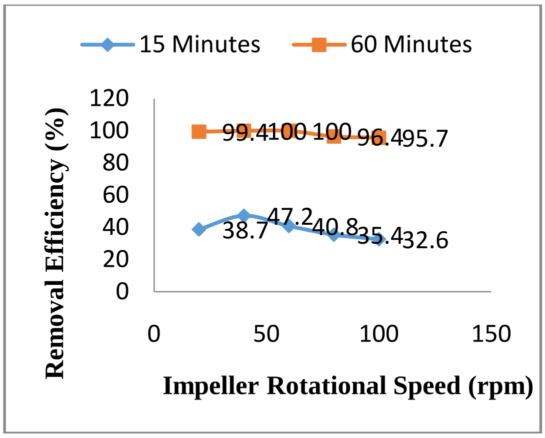


Figure 4: Comparison of removal efficiencies for short- and long-term effects for Alum (Experimental conditions: pH - 7; Dosage - 62.5 mg/l. Initial turbidity - 877 NTU;

Figure 5: Comparison of removal efficiencies for short- and long-term effects for *Moringa oleifera.* (Experimental conditions: pH - 7; Dosage - 62.5 mg/l. Initial turbidity - 877 NTU;

Figure 4 show the plot of comparison of removal efficiencies for short- and long-term for Alum. An investigation was done to understand what happened during the removal of turbidity on application of Alum in the turbid water between 15 minutes and 60 minutes. Turbidity removed after 15 minutes was compared with turbidity removed after 60 minutes. Also, figure 5 show the plot of comparison of removal efficiencies for short- and long-term for *Moringa oleifera*. An investigation was also done to understand what happened during the removal of turbidity on application of *Moringa oleifera* in the turbid water between 15 minutes and 60 minutes respectively. Turbidity removed after 15 minutes was compared with turbidity removed after 60 minutes. Comparison of the results of test of hypothesis for both Alum and Moringa oleifera was conducted at 5% level of significance. This will help in making decision and inference as in which of the coagulants is better in turbid water clarification. Results showed that at 5% level of significance, tabulated t-value is given as $t_{0.025,\ 4} = 2.780$ when the computed t-value for Alum was 12.755 and computed t-value for *Moringa oleifera* was 33.843

The higher the computed t-value, the stronger the disagreement between the two parameters compared. *Moringa oleifera* coagulant with a computed t-value of 33.843 is farther away from the critical tabulated t-value of 2.780 than Alum coagulant which has 12.755 as computed t-value. Therefore, this study affirmed that *Moringa oleifera* is a better coagulant than Alum.

Table no 3: Final turbidity for Alum and *Moringa oleifera* coagulants for different pH values

pH	Final turbidity (NTU)	
	Alum	*Moringa oleifera*
4.0	514	267
4.5	433	458
5.0	564	497
5.5	585	532
6.0	606	577
6.5	776	442
7.0	476	645
7.5	449	615
8.0	446	610

Initial turbidity = 877 NTU; Impeller speed = 100 rpm
Dosage = 62.5 mg/l

Table no 4: Results of test of hypothesis for various parameters at 5% level of significance

Parameter varied	pH	Dosage	Alum/*M. oleifera* 100 rpm (15mins)	Alum/*M. oleifera* 100 rpm(60 mins)	Alum (15mins/60mins)	*M. oleifera* (15mins/60mins)
Degree of freedom	8	5	4	4	4	4
t-calculated	-0.379	0.185	0.935	1.566	12.755	33.843
t-tabulated	2.310	2.570	2.780	2.780	2.780	2.780

Table no 3 show turbidity values of Alum and Moringa oleifera studied at various pH values. For Alum, turbidity value decreased from 514 NTU at pH of 4.0 to 433 NTU at pH of 4.5, it further increased to optimum value of 776 NTU at pH of 6.5 followed by a consistent decrease to 446 NTU at pH of 8.0

Moringa oleifera showed a consistent increase in turbidity removal of 577 NTU up to pH of 6.0, decreased to a value of 442 NTU at pH of 6.5 at which point Alum displayed the best performance and rose to 645 NTU at pH of 7.0 which is the optimum point.

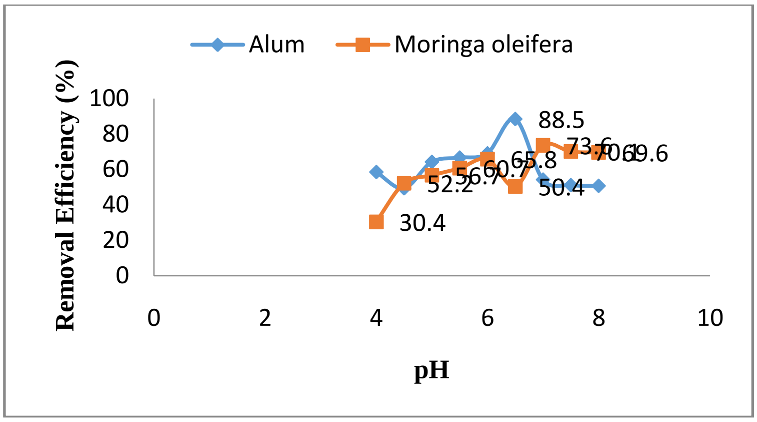


Figure 6: Comparison of removal efficiencies of Alum and *Moringa oleifera* coagulants at various pH values. (Experimental conditions: Dosage = 62.5 mg/l; Initial turbidity = 877 NTU; Impeller Rotational Speed = 100 rpm.

Figure 6 present the plot of comparison of turbidity removal efficiencies of Alum and *Moringa oleifera* at various pH values. Results show that slightly acidic conditions favour clarification by both Alum and *Moringa oleifera* coagulants which support the work of [29]. Optimum turbidity removal of 88.5% was observed in Alum at pH of 6.5 while *Moringa oleifera* indicated optimum turbidity removal of 73.6% at pH 7.0. The result is not significant at 5% level of significance as computed $|t|$ is less than $t_{0.025,\ 8}$ = 2.310 as in Table no 4, which implies accepting the null hypothesis that there is no significant difference between clarification capacities of Alum and *Moringa oleifera* coagulants.

IV. Discussion

Coagulation is an essential process in water and industrial wastewater treatment. In the area of potable water treatment, clarification of water with coagulating agents has been practiced since ancient times, using a variety of substances the most notable among them being crushed seeds. The Egyptians, as early as 2000 BC, used almonds smeared around a vessel to clarify river water. The early Romans were also familiar with alum, though it may not have been for water treatment [30]. Removal of turbidity, suspended solids (SS) and natural organic matter (NOM) using coagulation are well known because of the ability of the process in destabilizing the colloids particles and reducing the repulsion force between the particles.

In the present study, it was observed that crushed *Moringa oleifera* seed solution as coagulant removed 100% of impurities after a period of 60minutes of clarification. This is in agreement with the work of [31]. The same result was seen in Alum, though clarification was faster with Moringa oleifera. It was observed that turbidity removal increased with increase in pH a condition which agree with the work of [32]. Tests of hypothesis at 5% level of significance showed that there exist no significant difference between Alum and Moringa oleifera in turbidity removal, though overall performance indicated that Moringa oleifera is better than Alum in turbid water clarification.

V. Conclusion

Moringa oleifera is a better coagulant but the difference is not significant at 5% level of significance. Clarification on long-term duration of 60 minutes for Alum indicated significant difference in clarification and similar result was observed in *Moringa oleifera* but faster when compared with Alum.

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