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Uses of Extract Moringa Oleifera Seed in Treatment of Surface Water in UYO

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***ABSTRACT :** The research aimed to test the viability of using Moriga oleifera (MO) seed extract as a coagulant to replace alum, (aluminum sulphate) and other commercially used chemical coagulant for thickening of wasted activated sludge from a sewage treatment plant. Other studies have confirmed that MO has some coagulant properties that increase the setting rate of the sludge when compared settling rate of untreated sludge. However the data available is limited. This study uses Zone settling Rate *ZSR(and Jar test methods to assess the affect of treating Waste Activated Sludge (WAS) with Moringa seed extra and liquid alum. The Zone Settling Rate experiment is performed to obtain the percentage reduction in solid-liquid interface height from the top of the liquid surface in a settling column. This reflects the efficiency of settling process taking place in treated and untreated samples. Similarly, a Jar tester was used to conduct gravity settling study but with continuous stirring mechanism in place. The percentage of reduction in interface height is obtained at regular intervals such that settling velocity of the particles could be calculated. These two experiments were aimed to identify the affect of coagulant treatment on waste activated sludge. In addition, a batch type anaerobic digester was setup to monitor the difference in biogas production among sludge treated with different coagulants.*

***KEYWORDS:** Moringa Oleifera Seed; Treatment; Surface Water; Uyo*

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I. INTRODUCTION

The management of biosolids and residuals produced by wastewater treatment processes is one of the most difficult and expensive problems in the field of wastewater engineering (Metcalf & Eddy, 2002). Treatment methods used, vary not only between countries, but also between rural and urban regions (Michiel R. J. Doorn, 2006). Water treatment techniques used in the developed countries are incompatible in developing countries owing to the costs associated with water treatment plants. Moreover skills and technology required are also minimal in developing countries. Hence it is time to focus research on providing sustainable and cost effective solutions by predominantly investigating natural sources. Solutions which require less or no use of chemicals for water treatment, such that all nations can have accesses to better treatment facilities despite socio economic inequalities. (Ghebremichael, 2004). The main concern of wastewater treatment facilities these says is the lack of space for, and efficient handling of, solid wastes. Better waste management along with low cost production forms a critical part of the new strategies to be implemented by wastewater treatment facilities.

During the course of the water treatment, suspended particles from the raw effluent are extracted while the treated water is either reused or released in the environment. Material extracted from the effluent contains particles of dissolved organic or inorganic matter, bacteria, viruses algae and so on (Bratby, 2006). All these particles are suspended in more or less concentrated forms and the resulting liquid is termed sludge (Floerger, 2003). Sludge generally settles at the bottom of the tanks during primary, secondary and advanced treatment processes in a liquid or semisolid liquid form, with 0.25 to 12 percent solids by weight (Metcalf & Eddy 2002). It contains large quantities of negatively charged colloidal matter which causes electrostatic repulsion. Hence sludge has greater water content as the particles are evenly dispersed due to the repulsive forces (Watanabe et al., 1999). The problem in dealing with this sludge is (1) the presence of high water content which makes it difficult to handle and dispose of the sludge and (2) the presence of unwanted chemical and organic matter which requires chemical treatment of the sludge (Metcalf & Eddy, 2002) prior to landfill or land applications. Therefore, successful waste management (i.e. disposal of sludge) depends on the efficiency of solids/liquid separation of the sludge and the rate at it which occurs.

Sludge management can be expensive as the costs involved in disposing of the sludge are high due to its impact of the environment. Hence it is desirable to provide a cost-effective solution, which also increases the amount of water extracted prior to disposal, by thickening the sludge, reducing the disposal costs.

TREATMENT PROCESS AND DEFINITION	EFFECT ON BIOSOLIDS	EFFECT ON LAND APLLICATION PRACTICES
Thickening: Low force separation of water and solids by gravity, floatation, or ceninfugation	Increase solids contact by removing water	Lower transportation costs
Digestion lanaerobic and aerobic: Biological stabilization drough conversion of organic mater to carbondioxide water and methane	Reduces the biodegradable content (stabilization) by conversion to soluble material and gas. Reduces pathogen level and odor.	Reduces the quantity of biosolids.
Alkaline stabilization: Stabilization through the addition of alkaline materials (e.g lime kiln dust)	Raises pH. Temporary deveases biological activity. Reduces pathogen levels and controls putresciblity and oder	High pH immobilizes metals as long as pH levels are maintained
Conditioning: processes that biosolids to coagulate to aid in the separation of water	Improves sludge dewatering characteristics. May increase dry solids mass and improve stabilization.	The case of spreading may be reduced by treating biosolids with polymes
Dewatering: High force separation water and solids. Methods include vacuum filters ceunfuges. Filter and belt presses etc.	Increases solids concentration to 15% to 45%. Lowers introgen and potassium concentrations improves ease of handling	Reduces land requirements and lowers transportation costs
Composting: Aerobic thermophilic, biological stabilization in a window aerated static pile or vessel	Lowers biological activity, destroys pathogens and converts sludge to humus-like material.	Excellent soil conditioning properties contains less plant available nitrogen than other biosolide
Heat Drying: Use of beat to kill pathogens and eliminate most of the water content	Disinfects sludge destroys most pathogens and lowers oder and biological activity	Greatly reduces sludge volume

Figure 1: A Summary of Sludge Treatment Processes (Evanylo 1999)

There are various sludge treatment processes that are used in the industry today which include thickening, anaerobic and aerobic digestion, dewatering, figure 1 summarizes the treatment process and their effect on land applications (Evanylo, 1999). However the area of focus for this research project is on gravity thickening and anaerobic digestion treatment processes.

Aims and Objectives

Study Aim

The purpose of this project is to investigate the technical feasibility of using a natural product to replace the chemical coagulants currently used for wastewater treatment in the water industry. The aim of this research is to investigate the use of MO seed extract as a natural coagulant to potentially replace alum (Aluminium sulphate) in thickening of Waste Activated Sludge (WAS).

Outcomes

The outcomes of this project include finding the reduction in solid-liquid interface of sludge samples treated with natural (MO) and chemical (alum) coagulants and the settling velocity of the suspended sludge particles. In addition, monitoring the amount of biogas produced due to anaerobic digestion on daily basis.

Scope

This research differs from previous studies as the coagulant property of MO seed has mostly been tested on water samples rather than on WAS. The significance of the project is that if the initial results are positive from this study, it will open up further intensive research on aspects such as surface chemistry, dynamics of sedimentation and thickening with MO, biogas yield of sludge settled with MO, sustainability (biodiesel generation potential of MO residuals) and modeling on the use of MO for water treatment industry.

II. LITERATURE REVIEW

Water Treatment

Wastewater originates from variety of domestic, commercial and industrial sources (Michael R. J. Doorn, 2006). It comprises of suspended and/or dissolved organic and inorganic matter, various biological forms such as algae, viruses, bacteria. Much of the suspended material in wastewater is in the microscopic to submicroscopic size range. Particles smaller than approximately 10-5 mm are referred to a colloids. Colloidal material includes mineral substances, small aggregates of precipitated and flocculated matter, silt, bacteria, plankton, viruses, biopolymers and macromolecules (Bratby, 2006). These particles form the constituents of sludge during wastewater treatment.

Wastewater is either treated on site (collected), sewered to a centralized plant (collected) or disposed untreated via an outfall. Wastewater treatment and discharge systems can greatly differ between countries and between rural and urban regions. The most common wastewater treatment plants and lagoons for both domestic and industrial wastewater. Centralized wastewater treatment methods consist of primary, secondary and tertiary treatment.

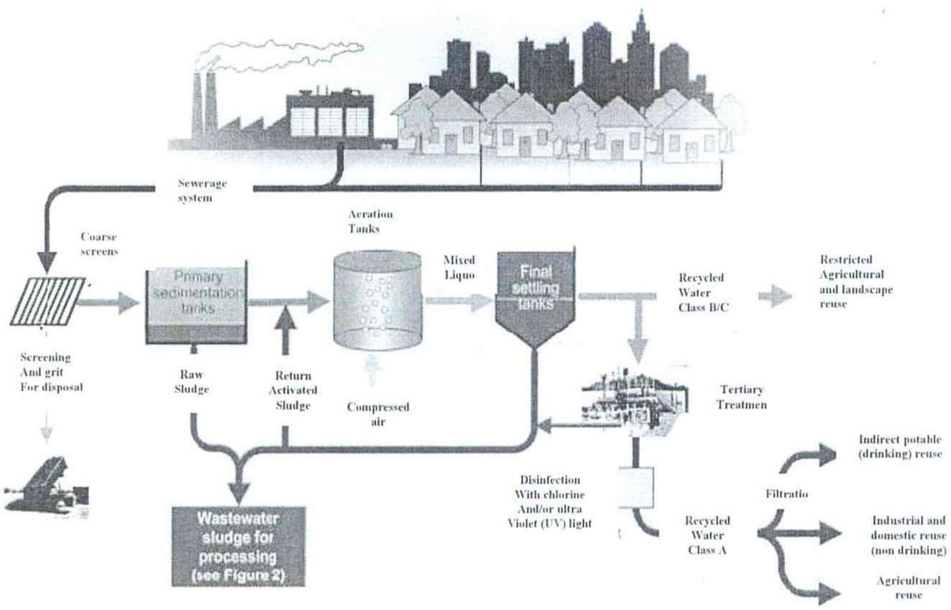


Figure 1: Processes in a Typical Wastewater Treatment Plant (Biosolids 2009).

In primary treatment while physical barriers are used to remove larger solids, smaller particles are allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation by micro-organism. This includes aerobic stabilization ponds, trickling filters and activated sludge processes, and anaerobic reactors. Tertiary treatment processes are used to purify wastewater from pathogens, contaminants and remaining nutrients such as nitrogen and phosphorus compounds (Michiel R.J. Doorn, 2006). Figure 2 shows typical processes in wastewater treatment facilities.

Sludge

During the course of the water treatment, products coming fron the raw effluent are extracted while the treated water is either reused or released in the environment. Amongst these products from the raw effluent are particles that decant naturally or come from either the physiochemical treatment; microorganism from dissolved organic matter treatment; and/or mineral matter that is non biodegradable. All these products are suspended in more or less concentrated forms and the resulting liquid is termed sludge (Floerger, 2003). It contains large quantities of negatively charged colloidal matter with electrostatic repulsion. Hence sludge contains large amount of water molecules as the sludge particles are evenly dispersed to withstand the repulsive forces (Watanabe et al., 1999).

There are different types of sludge generated depending on which part of the treatment process sludge is obtained from (Floerger, 2003). This includes: primary sludge, sludge from chemical precipitation, activated sludge, and trickling-filter sludge. Sludge from primary settling tanks is usually grey and slimy and in most cases has extremely offensive odor. It can be readily digested under suitable conditions of operation. Activated sludge generally has a brown appearance and is assumed that when the color is dark the sludge is approaching a septic condition. If the colour is lighter than usual there may have been under aeration with a tendency for the solids to settle slowly. Sludge in good condition has an inoffensive earthy odor and tends to become septic rapidly producing a disagreeable odor. Activated sludge readily digests either by itself or when mixed with primary sludge (Metcalf & Eddy, 2002). This is also known as biological sludge as it comes from the biological treatment of the wastewater. Only part of the settled sludge is sent for further treatment such as dewatering or Dissolved Air Flotation (DAF) and part of it may be recirculated to maintain the bacterial population in the reactor. Hence this type of sludge is termed waste activated sludge or reactivated sludge. A portion of the sludge drawn from the secondary settlement tank which is wasted due to the continuous growth of new micro-organisms during the activated sludge process is termed waste activated sludge. Waste activated sludge has been evaluated in this project.

Thickening

Drinking water treatment sludge consists of 90-99.9% water giving it a greater volume (Ghebremichael, 2004). Sludge management involves thickening, conditioning, dewatering and safe disposal of the dewatered waste. In order to reduce the volume of the sludge, water content has to be removed from it. Solid-liquid separation processes in sludge treatment include thickening and dewatering. Thickening is defined as the capacity of sludge to increase its concentration of solids by 2-3 times, through filtration and gravitation/centrifugal acceleration. The ability to thicken is commonly evaluated by allowing sludge to settle in graduated cylinders. This forms the basis for the experimental work undertaken for this research project (Spinosa, 1997). Therefore it is established that removal of liquid from solids/suspended particles present in sludge by gravity thickening is the area of focus.

Stokes Law

In order to undertake gravity thickening of sludge in an efficient matter, it is pivotal that the rate of settlement is high. This allows for the design of smaller sedimentation tanks in wastewater treatment plants. In particular those in metropolitan areas with limited space to set up new processes units or expand capacity. Most suspended particles in sludge have a negative surface charge. This charge sets up repulsion forces that reduce the tendency for the particles to agglomerate and settle. However other factors such as particles size, particle density and liquid density can also affect the settling property of the particles. Using Stokes law, the time it takes for free falling suspended particles in sludge to settle can be estimated (Pillai. J, 2004).

$$V = \frac{2xgxr^2\,(d_{1-}\,d_2)}{9 \text{ x } \eta}$$

Where V= final velocity of particle, r=radius of particle, d1 =density of particle, d2 =density of liquid, ŋ= coefficient of viscosity and g = gravitational constant. Since Stokes law assumes that the particle is settling freely, due to certain conditions in the liquid column, some particle to particle interference or hindered settling will occur further slowing down the settling rate (Pillai. J , 2004). In order to handle the same amount of effluent in a smaller settling or sedimentation pond, the settling rate has to be increased. The only parameter that can be influenced according to Stokes law, to result in an increase in settling rate, is to modify the particle size, in this case to increase its size.

Coagulation-Flocculation

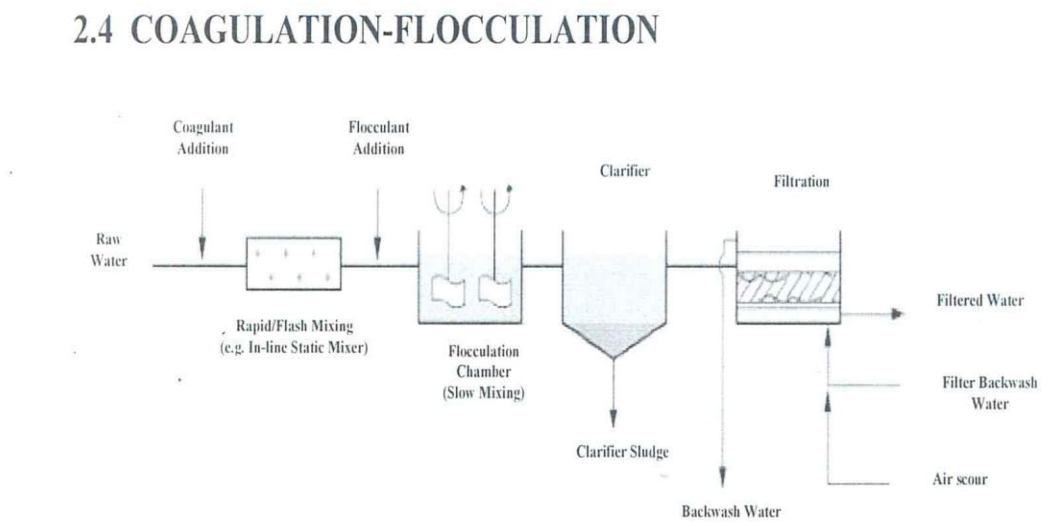


Figure 2: Conventional, Coagulation, Sedimentation and Filtration (Saadun, May 2011)

The combined processes of coagulation, flocculation and clarification aim to increase particle size for efficiency of very small particles, colloids and micro pollutants that are in the wastewater (Jarvis, 2005) (Geldreich, 1996). The processes involved in conventional treatment are illustrated in Figure 3. This project focuses on the coagulation aspect of the sludge treatment; as this process provided a greater scope for modifying the commercial methods and techniques currently used and replacing them with cost – effective and naturally sustainable solutions.

Coagulation

Coagulation is the process by which the medium is destabilized such that particles are readily agglomerated. It is the process of chemically changing colloids, allowing them to form bigger particles by particle destabilization. The transformation from stable to unstable is visible. In dispersed suspensions, floc or precipitate, formation can be observed due to destabilization whereas in more concentrated suspension dewatering of the suspension is observe. Particle destabilization is achieved by double layer compression or physical enmeshment of colloids within the coagulant precipitates or via a chemical reaction or through chemical sorption (Cornwell and Bishop, 1983).

As mentioned earlier, suspended particles have a negative surface charge. To being these particles together, the surface charges need to be neutralized. The process of charge neutralization and bonding of particles to micro-floc particles is achieved by coagulation. Generally coagulants are positively charged such that charge neutralization can be achieved. Therefore both inorganic and organic coagulants generally used in conditioning of sludge (flocculation and aggregation) are cationic (Watanabe et al., 1999). Coagulated particles are then aggregates to larger particle sizes and settled by addition of a flocculant. Figure 4 is an example of formation of microfloc upon the addition of a coagulant to clay particles in solution. This is similar to the process associated with suspended particles in waste activates sludge.

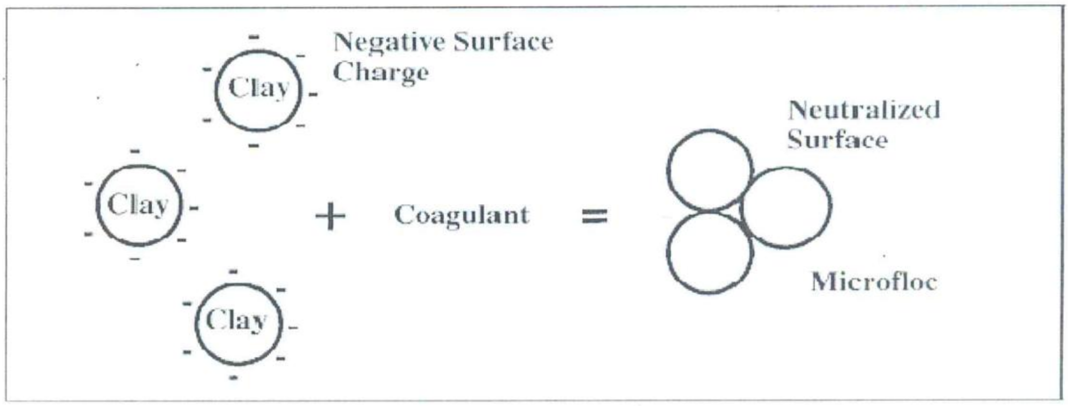


Figure 3: Formation of a Microfloc (Pillai, J. 2004)

Flocculation

Flocculation is the process that follows on from destabilization and forms aggregates (i.e. flocs). Flocculation is the process of linking coagulates colloids in to contact with each other to form larger aggregates (Gregor et al., 1997). This is generally considered to be a two stage process of particle transport and particle attachment (Amirtharajah and O'Melia, 1990). In fact flocculation occurs as soon as a coagulating agent is added (Brathy, 2006). Figure 5 shows a pictorial representation of aggregated formation in clay particles. The aggregates are formed due to flocculation and they can't be removed by clarification. Clarification is the process by which the flocs/aggregates settle out die to sedimentation. (Batancourt and Rose, 2004).

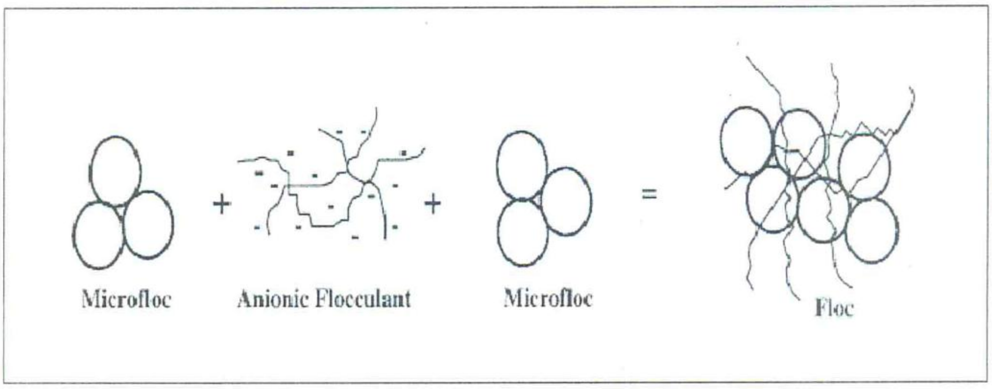


Figure 4: Formation of a FLoc from Microfloc (Pillai, J. 2004)

Coagulants
Chemical Coagulant

There are many commercially available chemical coagulants in the industry. Alum, Ferric chloride, and lime are commonly used for sludge thickening. There are two groups of chemical coagulants (Table 1). (i) Aluminum based coagulants which include aluminum sulphate, chloride and sodium aluminates and (ii) Iron based coagulants which include ferric sulphate, chloride, and ferrous sulphate and cationic polyelectrolyte perform the same function of suppressing the zeta potential of the colloidal system to a significantly low value such that colloidal particles will collide and then coalesce under the influence of slow stirring (Woodard and Curren, 2006).

Despite being commercially used, chemical coagulants do have drawbacks, for example studies suggest an association with residual aluminum in treated water and Alzheimer's disease (Vieira et al., 2010). In addition, sludge that has been thickened with chemical coagulants and polymers is believed to pose a threat to the environment as the leaching of chemicals from the deposition in to the ground can contaminate the ground water system (Kaggwa et, al., 2001). The costs associated with chemical conditioning exceed half of the sludge management and handling costs (Ghebremichael and Hultman, 2004). Therefore, investigating the viability of using a natural coagulant to thicken the wastewater sludge is a worthwhile prospect as it has a great potential to replace chemical conditioners in the industry if it is proven to be viable, ultimately providing a cheaper and sustainable solution.

Table 1: A list of Typically Used Inorganic Coagulants (Ge Water and Process Technologies, 2021).

Name	Typical Formula	Typical Strength	Typical Forms Used in Water Treatment	Density	Typical Uses
Aluminum coagulant Sulphate	$Al_2(SO_4)_3$ 14 to 18 H_2O	17%Al203	Lump granular or Powder	60-70Ib/ft^3	Primary
Alum		8.25% Al203	Liquid	11.1 Ib/gal	
Aluminum coagulant Chloride	$AlCl_3$ $6H_2O$	35% $AlCl_3$	Liquid	12.5 Ib/gal	Primary
Ferric coagulant Sulphate	$Fe_2(SO_4)_3$ $9H_2O$	68%Fe_2 $(SO_4)_3$	Granular	70-72 Ib/ft^3	Primary
Ferric – Floc Coagulant Sulphate	$Fe_2(SO_4)_3$ $9H_2O$	41%Fe_2 $(SO_4)_3$	Solution	12-3 Ib/gal	Primary
Ferric Coagulant Chloride	$FeCl_3$	60%$FeCl_3$ 35-45% $FeCl_3$	Crystal solution	60-64Ib/ft^2 112 – 124 Ib/gal	Primary
Sodium coagulant Bluminate	$Na2Al_2O_4$	38-46% $Na2Al_2O_4$	Liquid	123-129 Ib/gal	Primary Cold/hot precipitation softening

Natural Coagulant

Use of natural coagulants have been documented for over 100 years (Pillai. J, 2004) and have been used in the past before chemical coagulants were discovered (Bratby, 2006). Natural coagulants were present in form of polymers – molecules consisting of repeating chemical units held together by covalent bonds. Polymers with certain type of functional group attached to them are known as polyelectrolyte. Depending on the functional group present they are referred to as cationic or anionic polyelectrolyte and all of the polyelectrolyte are typical hydrophilic colloids. Similar to chemical coagulants, there are several natural polyelectrolyte such as nuts of Nirmali (*Strychnos potatorum linn*), seed of Red Sorrela plant (*Hibiscus sabdariffa),* and seeds of drumstick tree *(Moringa oleifera)*. However these natural polymers may not be as effective as chemical coagulants (Bratby, 2006).

Moringa Oleifera

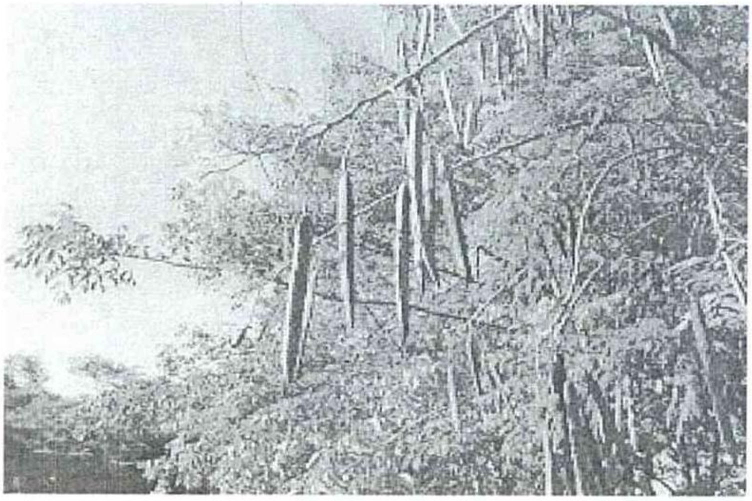


Figure 5: Moringa Oleifera Tree (Picture from Wikipedia)

The natural polyelectrolyte that is tested for this project is Moringa oleifera. Moringa is a native plant of Northern India belonging to the family of Moringaceae (Figure 6). It is now wisely spread throughout tropical countries and in few parts if Western Australia. Approximately 14 species have been identified, all possessing different coagulant properties depending on the local geomorphologic conditions in which they are grown (Ndabigengesere, Narasiah et al, 1995). The seed contains up to 40% by weight in oil. The tree is easy to cultivate and can provide multiple harvests in a year (Bratby 2006).

A Study conducted by Department of Agricultural and Food in Western Australia, in to production of bio-diesel from *Moringa oleifera* states that these plant species are tolerant to high salinity levels, water logging, frost and drought. Only their pods are harvested, while the trees keep growing using water and reducing the high watertable whilst sequestrating carbon (Brockman 2008). Earlier studies found the plant to be non-toxic which provided the precursor for further investigations and finally resulting in many developing countries using the plant extract as a viable coagulant to treat water. Earlier studies reasoned the presence of active components called cationic peptides of molecular weight of 6 to 16 KDa and isolectric pH value of 10 for its coagulating property. Since most of the impurities are negatively charged. *Moringa oleifera* with its high cationic property is expected to be efficient in adsorbing the particles and neutralizing the negative charge on the surface of sludge materials thus resulting in effective water treatment (Yin 2010).

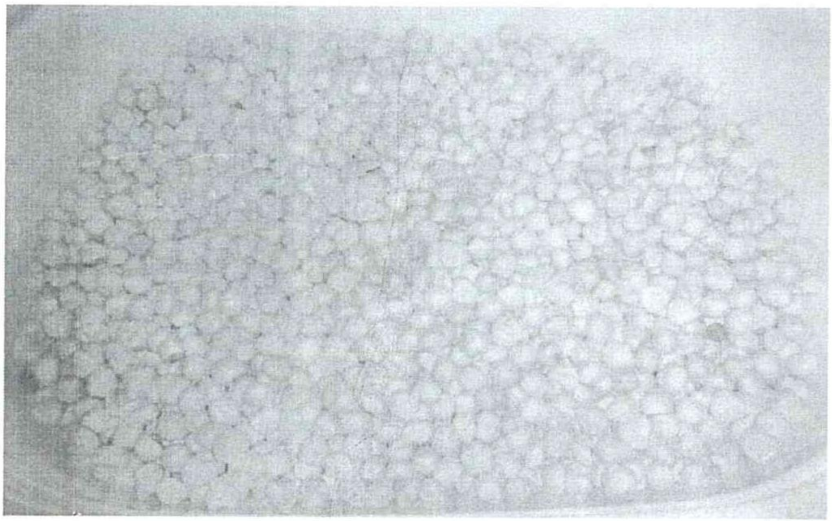


Figure 6: Moringa Oleifera seed kernels (Picture from Wikipedia)

Previous studies conducted on *Moringa oleifera* seeds (figure 7) have yielded positive results for use as a coagulating agent, suggesting a potential for alum (Pritchard, Craven et al, 2010). A review of the literature indicated that the *Moringa oleifera* seed in diverse, extracted and purified forms, has proved to be effective in removing suspended particles, and generated a reduced volume of sludge compared to alum. It also softens hard waters and acts as effective absorber of cadmium (Bhuptawat, Folkard et al, 2007). *Moringa oleifera* powder has been reported to have he capability of reducing low and high turbidity values in surface water (Muyibe and Okuofu, 1995) and has a bacterial removal range of 90-99% (Madsen, Schlundt et al, 1987). It was also used as a natural coagulant in a full scale treatment trial at the Thyolo treatment works in Malawi during the wet season of 1992. Additions of Mo powder has reduced turbidity values as high as 270-380 NTU (Nephometric Turbidity Units) to around four NTU complying with WHO (World Health Organization) water quality guidelines (Sutherland, Folkard et al, 1994).

Results from a study conducted by Ghebremichael and Hultman in Sweden that used MO as a conditioner to treat chemical condition effect as alum and it was concluded that MO alone or in combination could be effectively used and replace alum for dewatering of chemical sludge (Ghebremichael and Hultman 2004). Research conducted by Muyibi on using Moringa seeds as a floccuclant in waste sludge treatment yielded positive results for sludge volume reduction. A reduction of up to 67% was achieved using gravity settling compared to the control (no Moringa applied) sludge (Muyibi, Noor et al, 2001). Although investigations on using MO to treat sludge are limited, the findings from this research studies suggest that there is potential for using MO sees extract in treating sludge.

Anaerobic Digestion

Biological method such as aerobic digestion are widely used for sludge stabilization as they not only reduce the volume of sludge to be disposed off but also produce methane gas (during anaerobic digestion). In addition, these processes also result in high quality biosolids for land application and as a carbon source for gentrification. However aerobic digestion is not economically viable to treat large volume of sludge due to the operational costs associated with high energy consumption of aerators in aerobic digesters. Hence it is preferred to use anaerobic digestion with biogas as by product (Table 2) in most wastewater treatment plants and is generally applied to primary and secondary (waste-activated) sludge (Navaneethan, 2007). The proportion of methane in the biogas is about 69 to 75% (Sialve et al., 2009)

Table 2: Gas Production Using Primary and Activated Sludge(Navaneethan, 2007).

REFERENCES	**GAS PRODUCTION ML/GVS**	
	Primary sludge	Activated sludge
Sato et al. (2001)	612	380
Speece (2001)	362	281
Ritmann and McCarty(2000)	375	275

Anaerobic digestion (AD) plays an important role in transforming organic matter into biogas thereby reducing the amount of final sludge solids for disposal while destroying most of the pathogens present in sludge; and by limiting odour problems associated with digested solids (Appels et al., 2008). AD involves microbial degrading of organic matter without using oxygen. Biodegradable organic matters are converted in to carbon-dioxide, methane and water (Banjade, 2008) The main features of anaerobic digestion process are mass reduction, biogas production and improved dewatering properties of the treated sludge. There are four key biological and chemical steps of anaerobic digestion process: hydrolysis, acidogenesis, acteogenesis and methanogenesis summarized in Figure 9. A wide range of microorganisms, such as prokaryotic bacteria and methanogens are involved in the digestion process. The four primary bacteria which convert the complex organic matter in simple matter include hydrolytic bacteria, fermentative acidogenic bacteria, acetogenic bacteria and methanogens (Archer and Kirsop, 1990).

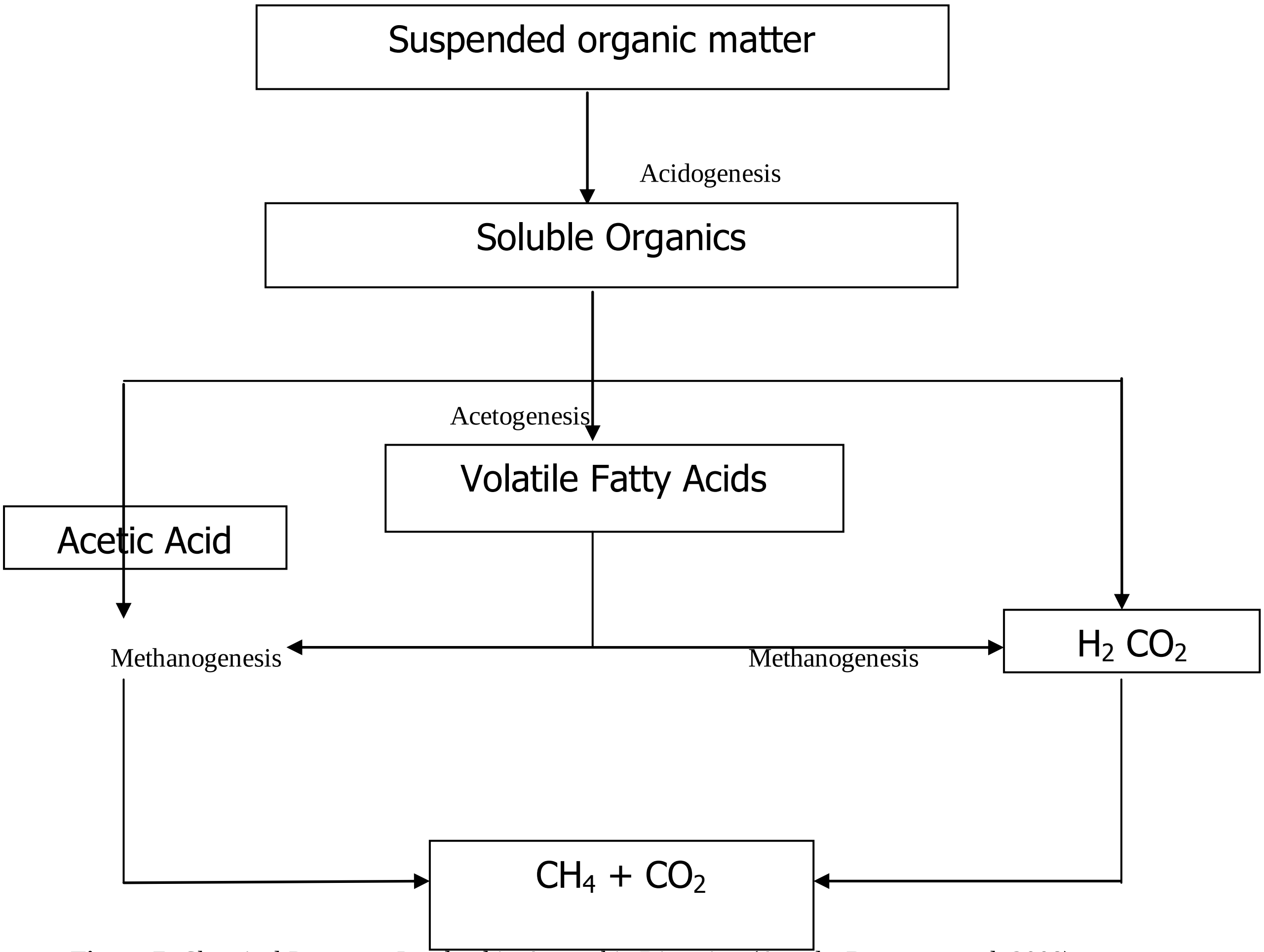


Figure 7: Chemical Processes Involved in Anaerobic Digestion (Appels, Baeyense et al, 2008)

Anaerobic Digestion is a complex process and requires strict anaerobic conditions such as oxidation reduction potential (OPR) < -200 mV to proceed and depends on the activity if a microbial association to transform organic material. Various parameters affect rates of different steps of the digestion process. Such factors include ph, alkalinity, temperature and retention times (Gyhoot and Cerstraete, 1997).Each group of micro-organisms has a different optimum pH range any slight change in pH can affect the digestion process. Similarly temperature has important effects on the physiochemical properties of the components found in the digestion substrate. It influences the growth rate and metabolism of micro-organisms and hence the population dynamics in the anaerobic reactor. Therefore it is important to maintain a stable operating temperature in the digester as any slight fluctuations in temperature can significantly affect the bacterial activity (Appels et al., 2008).

III. METHODOLOGY

A series of laboratory tests have been carried out to investigate the effectiveness of the organic *coagulant Moring oleifera* and *Strychnoc potatorum* (Nirmali) in comparison to chemical coagulants in thickening of sludge. The experimental methods were predominantly based on the standard methods (APHA, 1998), which included:

- ❖ Three rounds of Zone settling rate and jar tests, and;
- ❖ Batch type anaerobic digestion study of sludge in order to monitor production of biogas in a daily basis.

Material Preparation

Sludge – Natural

The sludge used or the experiments was the Waste Activated Sludge supplied by Water Board Wastewater Treatment Plant of Water Corporation of Uyo. The sludge was collected from the secondary sedimentation tank and was free of any chemicals. The sludge was collected from the treatment plant in plastic containers and stored in a refrigerator until it was used for the experiments. The sludge was left open for it to reach room temperature before it was used for any experiments. The concentration of sludge used has a range of 5550-8500mg/L of total solids depending on the day it was acquired from the treatment plant. This because the concentration of the sludge varied depending on the treatment conditions in the wastewater treatment plant.

Sludge-Synthetic

Synthetic sludge was used during the jar test experiments to test the effectiveness of the coagulant. The desired turbidity level was achieved by using distilled water and kaolin clay. Eight point five grams of kaolin was added to 1L of distilled water in order to prepare an artificial sludge sample that had similar concentration as natural sludge with total solids of 8500mg/L. The mixture was stirred for 30 minutes before it was left overnight for the dissolution of clay particles to take place. Jar test apparatus was used to perform the mixing process set at a speed of 120 rpm.

Coagulant

Chemical coagulant

Alum

Liquid alum (Aluminium Sulphate) from de-best Chemicals. WA was used as the chemical coagulant during the experiments of this research. The amount of liquid alum used in the initial round was 10mL/L whereas for the remainder of the laboratory investigations 8mL/L was used. These doses were found to be optimum in treating this particular waste activated sludge when few individual trials were conducted to find the optimum dose of alum that yielded in better settling of the sludge. The liquid alum used consisted of sulphuric acid, water and aluminum sulphate at <0.1%,>60% and 25% respectively. The liquid had a pH range of 1.5-2.5 with the solution being odourless and colourless liquid.

Organic Coagulant

Moringa oleifera

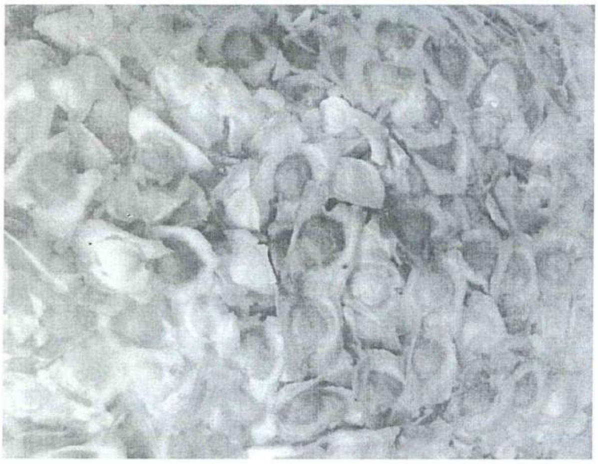


Figure 8: Moringa Oleifera seeds used for experiments

Dried *Moringa oleifera* seeds were used for the experimental purposes. Mo seeds were order from market. Seeds from the pods were removed and good quality seeds selected for the study. The winged seeds were shelled to extract kernels which were ground into a fine powder using a blender. A stock solution was made using the powder which was used during initial trials. MO powder was applied directly to the sludge for the remainder of the experiments. Figure 10 shows Moringa seeds that need to be dehusked and made into a fine powder for application. A blender was used to finely grind the kernels. Grinded materials was passed through a sieve in order to obtain very fine Moringa powder.

The powder from the dried seeds was used to make a stock suspension, which acted as coagulant when added to water samples. Five different concentrations of stock suspension of the seed extract was prepared by adding various mass of seed powder to each of the five 300mL of distilled water samples, similar to the method used in a previous study (Okuda et al., 1999). The concentration of the stock was determined by the mass of MO powder added to the water sample. A mass of 4.5g of MO seed powder added to 300mL of distilled water resulted in a concentration of 15,000mg/L. The ranges of concentrations prepared were between 15000 mg/L and 35,000mg/L as presented in Table 3. Upon addition of the MO seed powder to each water sample, the mixture was stirred for approximately 30 minutes and allowed to settle, similar to the method used in (Arnoldsson et al., 2008). This solution was used as the coagulant to treat the sludge in the first round of experiments. To avoid any ageing effects, the stock solution was prepared just before the experiment. However for rest of the experiments, the ground powder was applied directly to the sludge instead of preparing the stock solution to observe any change in settling process.

Table 3: Concentration of Various Moringa Stock Solutions for experiment

Concentration	15,000mg/L	20,000mg/L	25,000mg/L	30,000mg/L	35,000mg/L
Mass of MO used	4.5 g	6g	7.5g	9g	10.5g
Volume of Distilled water	300mL	300mL	300mL	300mL	300mL

EXPERIMENTAL TESTS

Zone Settling Rate

Zone settling rate (ZSR) was the core experimental procedure of this research project. The effectiveness of the coagulant was determined by measuring the amount of sludge settled and the rate at which it settled. This experiment was chosen as the previous studies conducted on conditioning sludge with different chemicals had used this method. The effectiveness of the coagulant was found in terms of reduction of suspension of solids particles in the supernatant fluid. It was calculated based on the percentage reduction of the solid/liquid interface height.

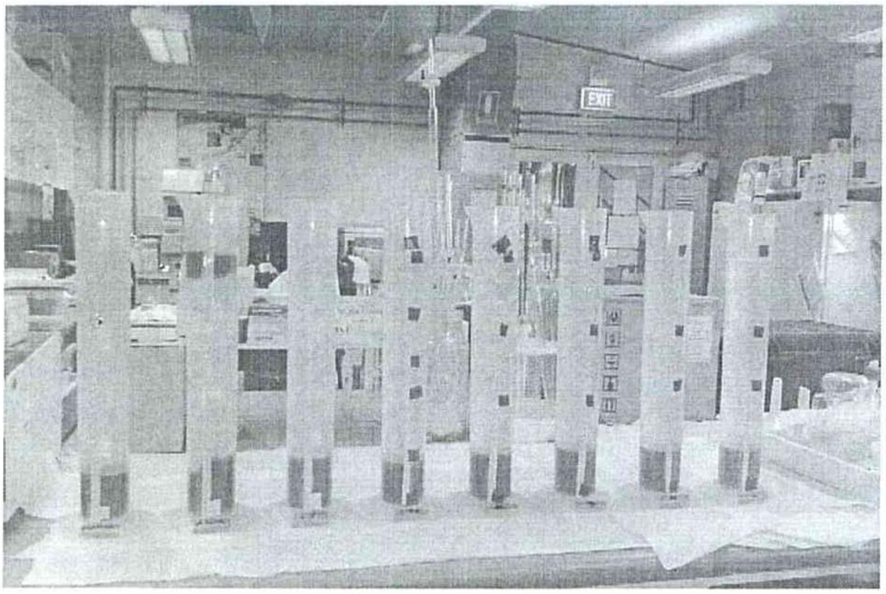


Figure 9: Shows Sedimentation of Suspended Particles during ZONE Settling Rate Test (Picture gotten from the Lab).

This method was performed in triplicate with variations in coagulant application on the sludge samples. At high concentrations of suspended solids, the solids settled in the zone settling regime. This type of settling was characterized by a distinct interface between the supernatant fluid and the settled sludge zone. The height of this distinct sludge interface was measured against time (APHA, 1998) such that; along with the rate which solids was coagulated, the reduction in sludge volume could also be obtained. This methods was employed based on the standard methods (APHA, 1998) to find the reduction in height if the sludge solid-liquid interface. However the apparatus used was different from the suggested apparatus in the standard methods due to lack of equipment availability and the occupational health and safety risks associated with handling of large amount of sludge for experimental purposes. The standard methods recommended a column of 1m height and 10ch diameter (APHA, 1998) which corresponds to a large volume of sludge whereas this experiment used IL measuring cylinders approximately 41cm in height and 6cm in diameter with a IL volume of sludge similar to method used in similar studies (Muyibi et al, 2001) (figure 11).

Round 1

For the first round of ZSR test was performed using MO stock solution prepared from fine MO powder as mentioned in the material preparation section. Fifty milliliters from each concentration of 300mL stock solution prepared earlier was used to treat 1L sludge sample. (Table 4). Upon the addition of the stock solution, the samples were stirred on a magnetic stirrer for 2 minutes at medium speed to obtain a homogenous mixture and later transferred in to 1 litre (1L) measuring cylinder for sedimentation to take place. During sedimentation solid-liquid interface in the cylinder was recorded every one minute over a 30 minutes time period. The method differed from the standard methods in terms of the apparatus, as 1L measuring cylinders with no constant rotating mechanism was used as settling vessels. The difference between initial height and final height of the interface (after 30 minutes) gave the amount of reduction, which corresponds to thickening of the sludge sample. The test had seven different sludge samples which included the control (sludge that had no additives), alum (sludge treated with aluminum sulphate) and MO treated sludge (five different dosages of Moringa) respectively. Six replicates of the test were done to obtain statistically verifiable results.

Table 4: Various dosages of MO used for ZSR Round 1 for experiment

Concentration of the stock exchange	15,000mg/L	20,000mg/L	25,000mg/L	30,000mg/L	35,000mg/L
Volume of sludge treated	IL	IL	IL	IL	IL
Volume of stock added to sludge	50m/L	50m/L	50m/L	50m/L	50m/L
Dosage of Mo used to treat sludge	750mg/L	1000 mg/L	1250 mg/L	1500 mg/L	1750 mg/L
Volume of alum	10mL	10mL	10mL	10mL	10mL

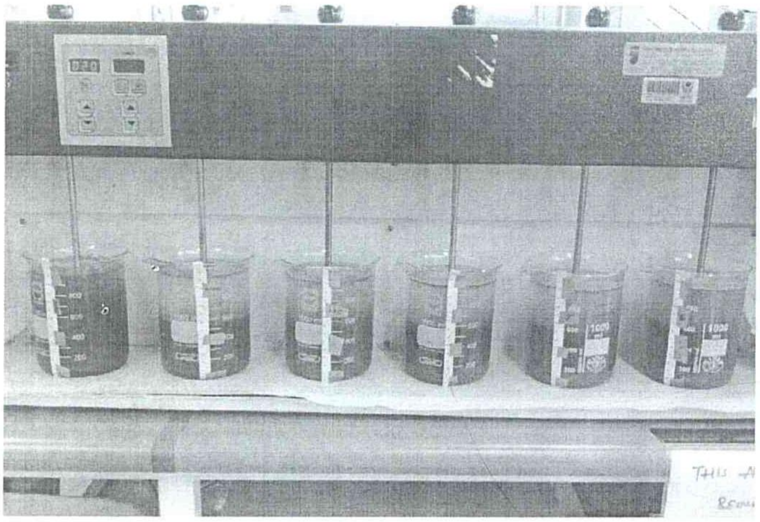
Round 2

In round 2 of the experiment, MO powder was applied directly on to the sludge in place of stock solution. A different mass of MO powder was added to each of 1L sludge samples such that the variation in dosage required to treat was achieved. Similar to the previous round, one liter samples were stirred using magnetic stirrers at medium speed to achieve a homogenous mixture. The difference in mass of the MO powder used resulted in varying dosages to treat the same amount of sludge (Table 5). Upon mixing, the samples were transferred to 1L measuring cylinders for sedimentation during which the interface height is recorded alum treated samples and a control sample were also measured for comparison purposes. Four repetitions of this test were performed. The difference from the previous round was the increase in the range of dosage used. The settling time was increased to 5 hours from 3 minutes to identify any change in trend observed.

Table 5: Various dosages of MO used for ZSR Round 2 for experiment

Mass of MO used (g)	1.5	1.75	2	3	4	5	6	7
Volume of sludge treated (L)	1	1	1	1	1	1	1	1
Dosage MO used to treat sludge (mg/L)	1500	1750	2000	3000	4000	5000	5000	7000
Volume of alum (mL)	8	8	8	8	8	8	8	8

Jar Test
Round 1



From 10: Jar Tester Used during Sedimentation of Sludge Particles (picture gotten from the lab)

The jar test was performed to identify the effect of seed extract on settling of sludge due to continuous stirring mechanism as specified in the standard methods. Generally the coagulation-flocculation effect of any coagulant is evaluated by conducting a jar-test (Ndabigengesere and Subba Narasiah, 1998). The Jar-test involves a combination of mixing processes – rapid and slow before sedimentation is achieved. The rotational speed of the mixers is changed accordingly to stimulate different mixing intensities which that flocculation occurs (Katayon et al., 2007).

The procedure involved using 500mL glass beakers filled with waste activated sludge which was agitated using the jar test apparatus (figure 12). The measured amount of MO coagulant was added to each of the sludge sample while the suspension was agitates (Table 7). The suspension was mixed at higher speed (120 RPM) initially, followed by a slow mixing at 80 RPM and finally set at 20 RPM for the remainder of the experiment. The suspension was then allowed to settle (at a sped of 20 RPM) for 5 hours for sedimentation to occur. During the settling period, the solid/liquid interface in the beakers was recorded. For comparative analysis the coagulation test was carried out in similar conditions, using treated and untreated sludge (i.e. control). The test had three replicates/trials.

Table 7: Various dosages of MO used for Jar test Round 1

Mass of MO used (g)	1.75	3	5	6
Volume of sludge treated (L)	1	1	1	1
Dosage MO used to treat sludge (mg/L)	1750	3000	5000	6000
Volume of alum (mL)	8	8	8	8

Round 2 (Total Solids)

Due to the inconsistency observed in the data obtained from round 1 of jar test another round (Round 2) was performed under similar conditions as Round 1 including all dosages of MO kept the same. In addition, a total solids test based on the standard methods was performed on all the sludge samples in this round to better understand the settling characteristics of the sludge (APHA, 1998). 'Total solids' was the term applies to the material residue left in the vessel after evaporation of a sample due to drying in an oven. Total solids include total suspended solids and total dissolved solids of the sample being tested. In this round, 30mL of the sludge sample 4cm from the top of the surface of the liquid from each of the glass beakers was carefully pipette out, at regular time intervals. The pipette liquid was then dried in the oven at a temperature of 105^0C over night. The difference in weight of the evaporating dish before and after drying the 30ml sample gave an indication of the suspended solids present at the height in the sludge sample.

Round 3 (Synthetic Sludge)

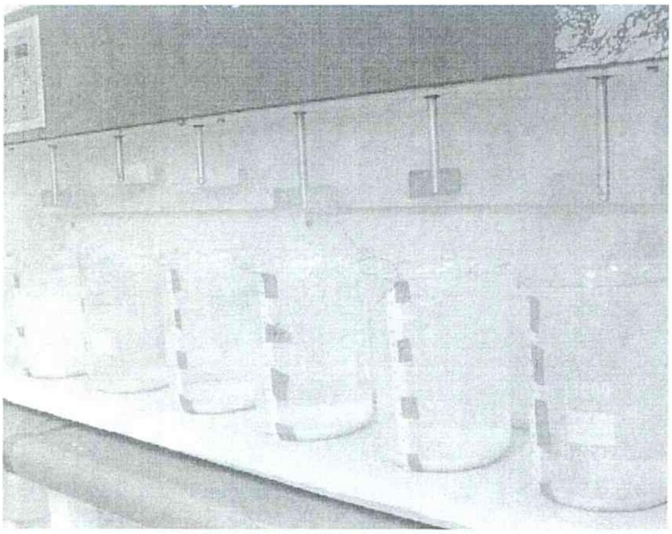


Figure 12: Jar Test Used to Treat Synthetic Sludge (picture gotten from the lab)

Jar tester was used to perform coagulation test on synthetic sludge samples (figure 13). Since the Kaolin samples were too cloudy and turbid, it was difficult to measure the height of the solid/liquid interface. Hence a total solids test was performed instead. This test was carried out without any continuous stirring mechanism during sedimentation. This was because in the initial trial, the stirring speed of 20 RPM (lowest speed possible using the jar tester) appeared to have interfered with the settling of the suspended particles in the artificial sludge. The clay particles seemed to re-suspend rather than settle out. Hence unlike the previous round of the jar test, the continuous stirring was turned off and total solids test was conducted, similar to the previous round. The dosages used in this trial were the same as in the previous rounds of the jar test with untreated, alum treated and a range of MO dosages.

Biogas Experiment

A batch type of anaerobic digester was setup to monitor biogas generation on a daily basis. It consisted of a temperature controlled water bath maintained at 30^0C. IT accommodated 6 bio-digesters, which in this case, were 1L conical flasks. These flasks acted as reactors once they were sealed off after placing the sludge sample inside. Three different samples of sludge were used namely alum treated (8mL), MO treated (5000mg/L) and untreated (control). Two replicates of each sample type were prepared as a cross-reference of treatments. The volume of the sludge used was 1L. Each digester was sealed off using a rubber stopper with a connecting tube. This tube was connected to a graduated gas collector (i.e. 1L measuring cylinder) by means of a connecting tube. (Figure 14).

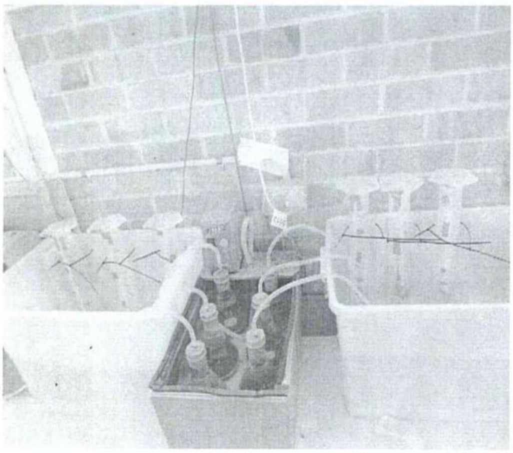


Figure 14: A Batch Type Anaerobic Digester Producing Biogas (picture gotten from the lab)

Each digester was connected to a single gas collector which was held to the plastic container using zip ties. These measuring cylinders which performed as gas collection chambers were filled with water up to the brim and inverted into the plastic container. The plastic container was filled with water to seal the bottom of the gas collectors. The biogas evolved during anaerobic decomposition of the sludge was collected by downward displacement of water in the gas collectors; where the decrease in water level reflected the volume of biogas produced. A pH measurement in each of the reactors was also carried out using pH probe to better understand the conditions inside the reactors.

IV. RESULTS AND DISCUSSION

4.0 Zone Stettling Rate

4.1 Round 1

The table (Table 8) below shows the percentage reduction in soli-liquids interface height using zone settling rate test. ZSR test round 1 resulted in greater percentage of reduction in interface height in samples treated with *Moringa oleifera.* It is to be noted that percentage reduction in these experiments refers to the depth of the clear liquid on total depth of the liquid column. This can be observed in the data tabulated in table 1 where the highest percentage reduction is found to be 4.61% given by dosage or MO 1500mg/L. Percentage reduction has been calculated by taking the difference between final and initial interface height and converting it in to a percentage.

Table 8: Percentage Reduction in Interface Height Round 1 (ZSR)

	% Total Height reduction of the interface	
COAGULANT	**30 Min**	**5 hr**
Control	3.12	-
MO 750mg/L	3.36	-
MO 1000mg/L	4.30	-
MO 1250mg/L	4.60	-
MI 1500mg/L	4.61	-
MO 1750mg/L	2.80	-
ALUM 10MmL	3.81	-

From the Experimental Result

Similarly, Most of remaining dosages of MO also resulted in greater sedimentation as indicated by percentage change in the reductions which are greater than in alum treated and the untreated sample. This indicates the addition of MO stock solution had some affect on the settling property of the sludge. ZSR= $\frac{\Delta h}{t}$ where is the change in interface height (mm) and t is time (min).

Figure 15 shows the amount of reduction in mm from the top of the liquid surface to the final height of the solid interface. The highest reduction achieved is 16.75 mm which also corresponds to the faster settling rate as shown in table 9. Hence it can be inferred from these results that addition of MO results in charge neutralization of the suspended particles in the sludge. This charge neutralization causes particles to adhere each other forming larger particles, thus resulting in particles to settle faster.

Table 9: Settling Velocity of the Particle during 30 Minutes Settling Time Round 1 (ZSR)

0-30	**Zone Settling Rate**	
COAGULANT	**Mm/ min**	**Cm/min**
Control	0.361	0.0361
MO 750mg/L	0.406	0.0406
MO 1000mg/L	0.522	0.0522
MO 1250mg/L	0.558	0.0558
MI 1500mg/L	0.556	0.0556
MO 1750mg/L	0.336	0.0336
ALUM 10MmL	0.444	0.0444

From the Experimental Result

Zone settling curve (figure 16) plotted for a settling period of 30 minutes indicate that there is a linear trend in settling rate however after 26 minutes, the curve appears to be reaching constant which is typical of a zone settling curve. MO treated samples had greater settling than those treated with alum however during the experiment it was observed the clarity of the supernatant fluid was better in alum treated sludge than in samples with various dosage of Moringa, while untreated sludge had dark brown/greenish tinge to the supernatant liquid, indicating high presence of small size particles in suspension.

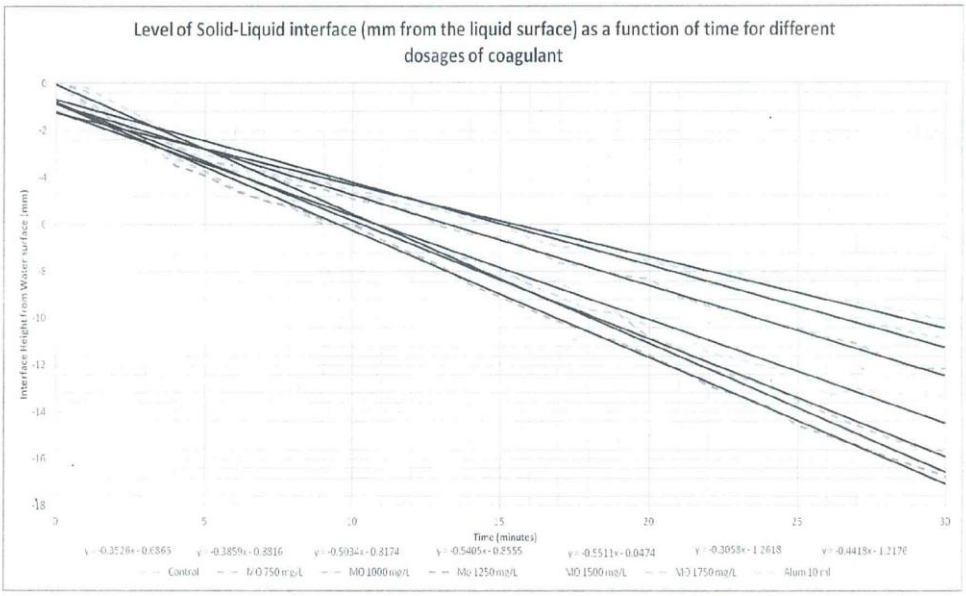


Figure 16: Zone Settling Curve Round 1 (ZSR) as shown in table 9

4.1.1 Round 2

Following the results from round 1 which indicated that sludge treated with MO has better settling property, another round of ZSR was performed by increasing the range of MO dosages. The results obtained are contrary to previous round as the untreated sludge sample (i.e. the control) had greater percentage to reduction in this trial percentage reduction had been calculated for both first 30 minutes as the graph (figure 18) indicates it is the most active phase of the process and after 5hr period. Both half hour and 5hr settling periods indicate that the untreated sludge had better settling than any other. However the percentage difference is not significant between the best performing MO-@5000mg/L (79.3%) and the control (79.7%) and both performed better than the alum (74.1%) after 5 hours (Table 10). For 30 min settling time, untreated sample has 7.4% (Table 10) more reduction than optimum dose of MO among all the various dosages of MO alum had the second highest reduction

Table 10: Percentage Reduction in Interface Height Round 2 (ZSR)

	% Total Height reduction of the interface	
COAGULANT	**30 Min**	**5 hr**
Control	69.7	79.7
Alum	63.8	74.1
MO 1500mg/L	60.8	77.5
MO 1750mg/L	62.3	78.6
MO 2000mg/L	60.5	77.8
MI 3000mg/L	59.4	78.6
MO 4000mg/L	58.8	79.3
MO 5000mg/L	58.5	65.2
MO 6000mg/L	19.9	65.5
MO 7000mg/L	19.9	65.5

From the Experimental Result

However a difference of 1.5% in percentage reduction between alum and MO 1750mg/L (optimum among all MO dosages) suggest the affect of these two coagulants on the sludge is minimal and is of similar affect. However the percentage reduction after 5 hr period indicates MO dosages worked better then alum. This reversal is likely caused by the re-suspension of compacted/settled suspended particles in alum treated sludge. It was observe that after one hour in to the experiment, settled particles re-suspended back in to the supernatant liquid in the alum treated sample. This re-suspension is the reason for lower total reduction obtained after 5 hr settling period.

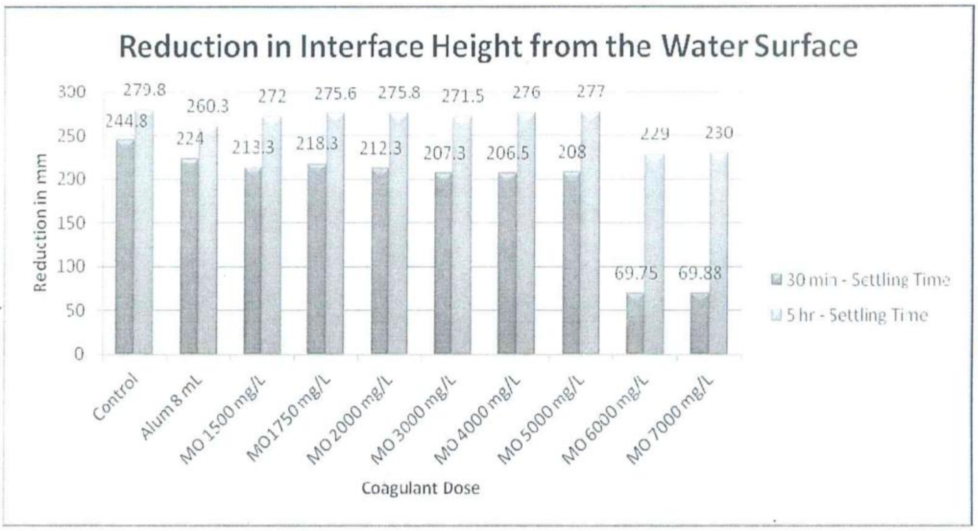


Figure 17: Reduction in Interface Height from Liquid Surface Round 2 (ZSR) as shown in table 10

This re-suspension phenomenon, which has been observed in other studies, indicates the flocs strength formed by adding alum is weak and is dependent upon the inter-particle bonds between the components of the aggregates (Parker et al., 1972).

The significant difference between the previous round and this round is the amount of reduction achieved for 30 minute settling time. The maximum reduction achieved using MO 1500mg/L in previous round is 16.67mm whereas in this trial its 213.3mm (figure 17). This huge increase in reduction could be due to change in concentration of sludge used. As sludge collected from different days from WWTP has different concentrations depending on the treatment processes at the plant. The sludge used has a TS concentration of 5585mg/L which is less than 6500mg/L of TS for previous round sludge used. Ideally it would be anticipated that less concentrated sludge would have faster settling capacity however the result obtained implies particle size of the suspended particles in the sludge may play a role in settling of sludge.

When referred to ZSR curve (figure 18) for this trial, it can be seen the curve is only linear during first 20 minutes of the settling period and the settling gradually decreases resulting the curve to reach constant. Hence the velocities represented are calculates using the data obtained during first 30 minute settling period (Table 11). The significant increase in settling velocity from previous is most likely due to sludge concentration.

Table 11: Settling velocity of the particle during 30 minute settling time Round 2 (ZSR)

0-30 min	**Zone Settling Velocity**	
COAGULANT	**30 Min**	**5 hr**
Control	8.16	0.816
Alum	7.47	0.747
MO 1500mg/L	7.12	0.712
MO 1750mg/L	7.28	0.728
MO 2000mg/L	7.08	0.708
MI 3000mg/L	6.91	0.691
MO 4000mg/L	6.88	0.688
MO 5000mg/L	6.93	0.693
MO 6000mg/L	2.33	0.233
MO 7000mg/L	2.33	0.233

From the Experiment Result

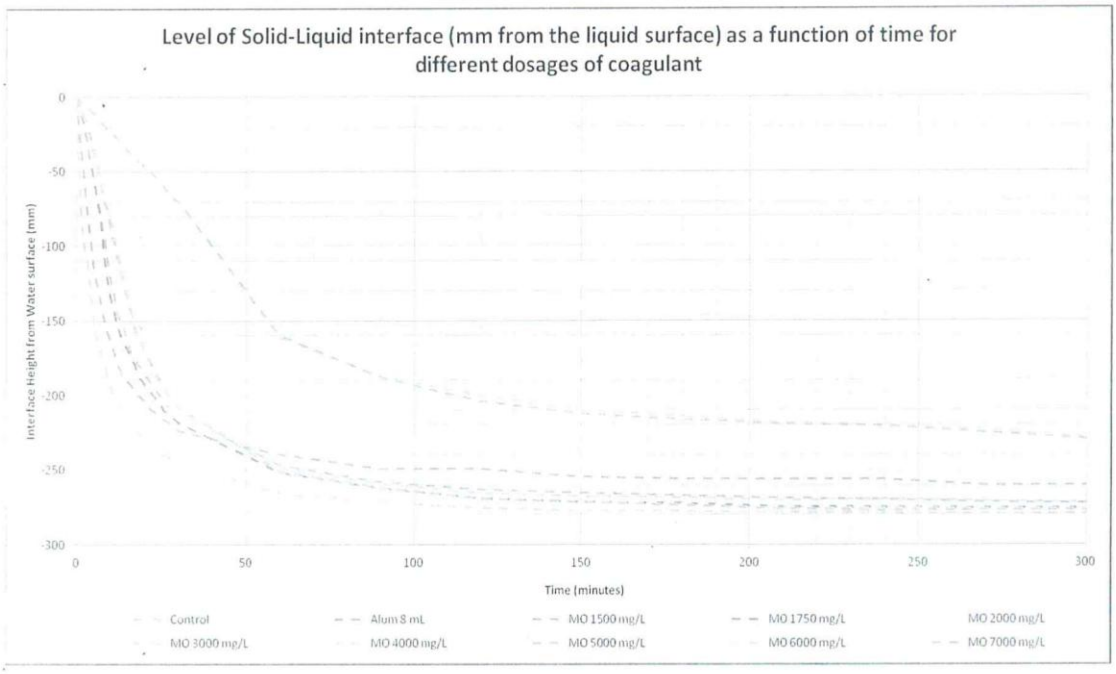


Figure 18: Zone Settling Curve Round 2 (ZSR) as shown in table 11

Jar Test
Round 1

Jar test was performed aiming to obtain more consistent results compared to ZSR test. It was noted that ZSR test lacked continuous stirring mechanism and hence Jar tester was used to provide continuous stirring. The percentage reduction is found to be maximum in alum treated sludge both after 30 minutes and 5 hr settling time. However the difference in percentage reduction between other sample is minimal indicating the affect of adding alum and MO coagulants has been highly ineffective. This is evident from Table 14 which shows the percentage reduction and Figure 21 showing the reduction in mm.

Table 14: Percentage Reduction in Interface Height Round 1 (Jar test)

	% Total Height reduction of the interface	
COAGULANT	**30 Min**	**5 hr**
Control	22	41
Alum 8 mL	22	44
MO 1750mg/L	20	42
MI 3000mg/L	18	42
MO 5000mg/L	15	40
MO 6000mg/L	13	40

From the Experiment Result

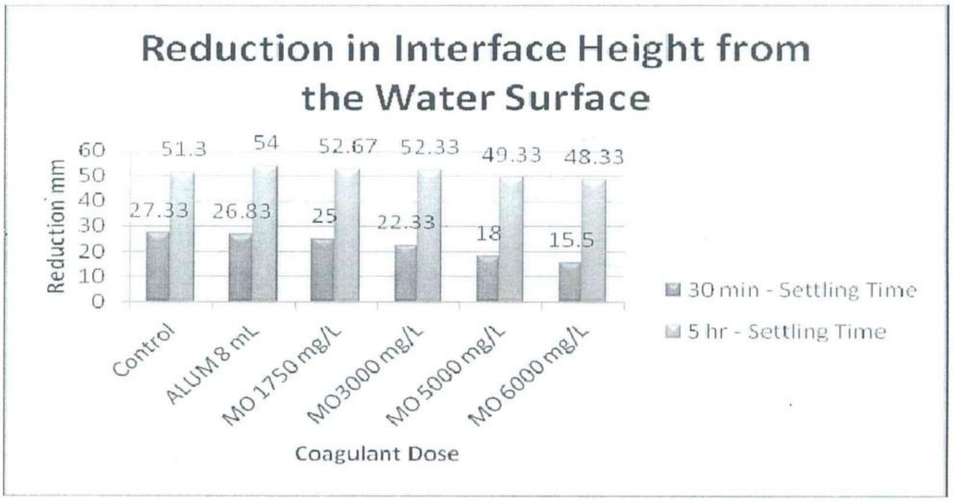


Figure 21: Reduction in Interface Height from liquid surface round 1 (jar test) as shown in table 14

The velocities calculated (Table 15) are using data from first half hour, this is where the ZSR curve (Figure 22) is in the most active phase and is linear. The velocities are reflective of amount of reduction achieved where sludge sample with fast settling rate had maximum reduction. The data obtained are not consistent enough to comment on the affect of coagulants in aiding with settling process. Moreover, the type of sludge used could also have a significant effect on the settling coagulation process. Factors such as particle size, surface charge also play key role in affect coagulation. The smaller the particle size, the greater total surface area per unit weight of solids, hence increase in the dose required to coagulate fine particles (Pillai J, 4004). Therefore, the lack of reduction observed in this round could be because there is abundant presence of smaller particles than larger particles in which case the dose tested is not effective enough.

Table 15: Settling Velocity of the Particle during 30 Minute Settling Time Round 1 (Jar test)

0-30 min	**Zone Settling Rate**	
COAGULANT	**Mm/Min**	**Cm/min**
Control	0.911	0.0911
Alum 8 mL	0.894	0.0894
MO 1750mg/L	0.833	0.0833
MO 3000mg/L	0.744	0.0744
MO 5000mg/L	0.6	0.06
MO 6000mg/L	0.517	0.0517

From the Experimental Result

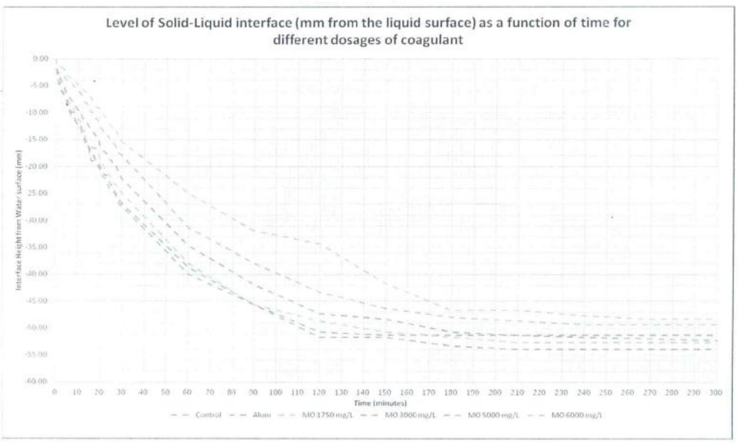


Figure 22: Zone Settling Curve Round 1 (Jar test) as shown in table 15

Round 2
ZSR

The result in terms of reduction achieved is similar to the previous round where the untreated sample has settled better than the treated sample during first thirty minutes (Table 16). However after 5 hrs, MO 6000 mg/L had reduced more any other sample. Alum seems to have 2 % greater reduction than MO dosages initially but finally all samples had similar or equal total reduction (Figure 23) except for MO 6000mg/L. The result is inconclusive in terms of coagulant affect on settling of sludge as the difference observed between each differently treated sludge sample is minimal.

Table 16: Percentage Reduction In Interface Height Round 2 (Jar test)

	% total height reduction of the interface	
COAGULANT	**30 min**	**5 hr**
Control	20	39
Alum 8 mL	19	39
MO 1750mg/L	17	39
MO 3000mg/L	16	39
MO 5000mg/L	16	38
MO 6000mg/L	17	42

From the Experiment Result

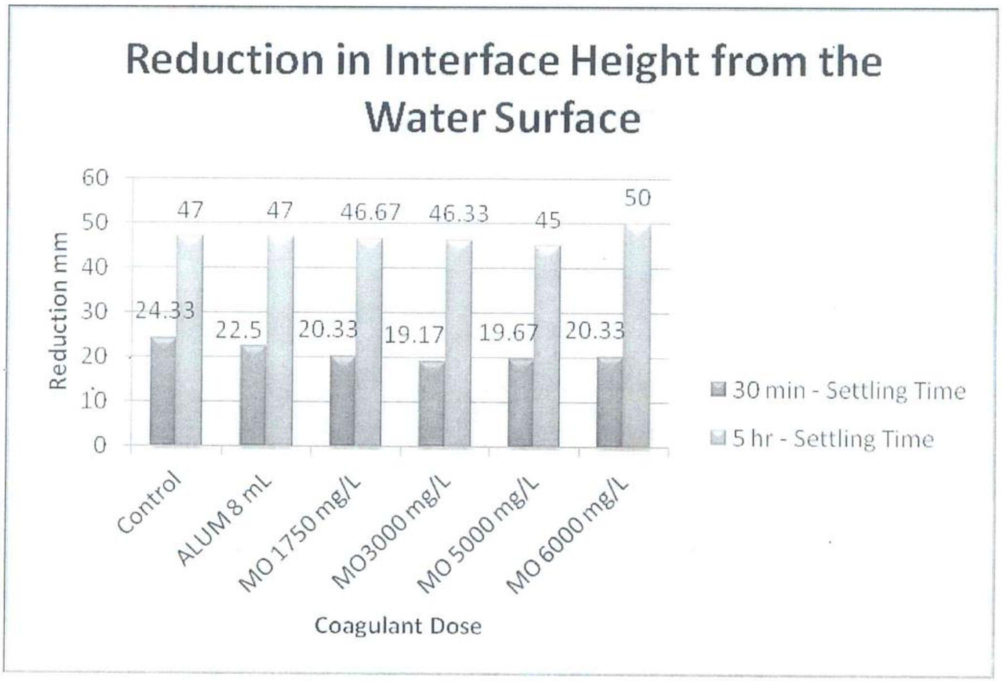


Figure 23: Reduction in Interface Height from Liquid Surface Round 2 (Jar test) as shown in table 16

Table 17: Settling Velocity of the Particle during 30 Minute Settling Time Round 2 (Jar test)

0-30 min	**Zone Settling Rate**	
COAGULANT	**Mm/Min**	**Cm/min**
Control	0.811	0.0811
Alum 8 mL	0.75	0.075
MO 1750mg/L	0.678	0.0678
MO 3000mg/L	0.639	0.0639
MO 5000mg/L	0.656	0.0656
MO 6000mg/L	0.678	0.0678

From the Experimental Result

The velocities again correspond to percentage reduction where samples with higher velocity had more reduction in solid-liquid interface (Table 17)

Total Solids

Graph on next page shows the percentage of total solids reduced over the settling period (Figure 25). As can been seen by the graph, the first thirty minutes of the settling period is the most active phase as indicated by the steep slope of each of the curves of different dosages. This test was done in order to better understand the settling process, however the trend observed in the graph does not reflect the settling regime explained above as untreated sample has lowest reduction in total solids.

Round 3

The graph on next page (Figure 26) shows the percentage reduction in total solids in synthetic sludge samples. Results from this test suggest that alum treated had settled well as total solids present in the supermarket liquid reduced as time elapsed. However MO treated samples have less reduction compared to untreated sludge sample suggesting that MO coagulant is ineffective ins settling the suspended particles in Kaolin samples.

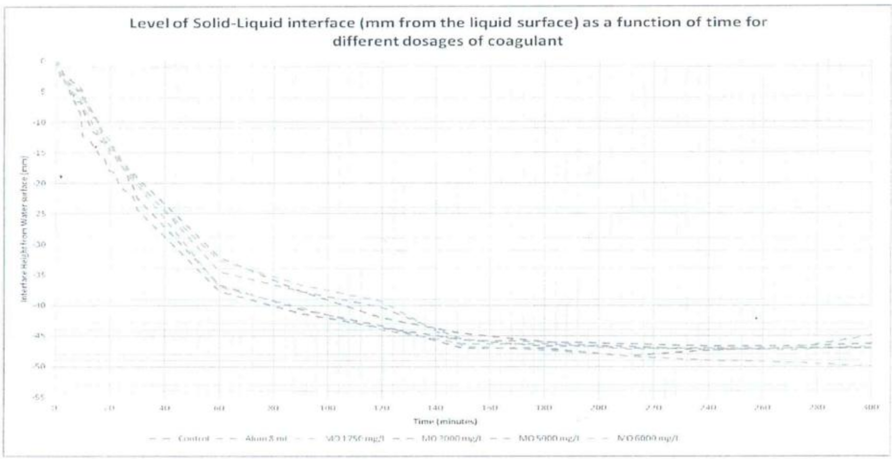


Figure 24: Zone settling Curve Round 2 (Jar test graph)

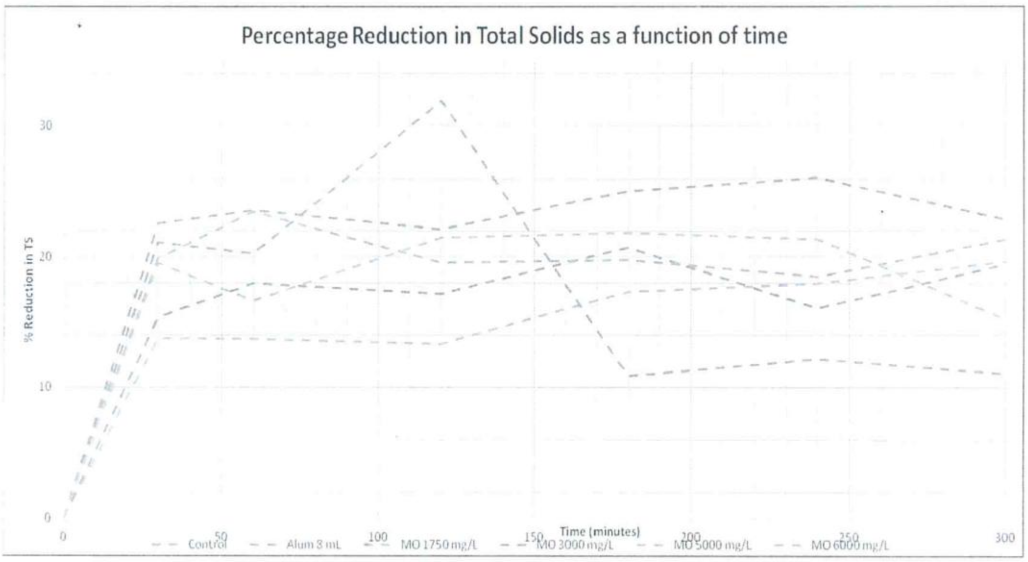


Figure 25: Percentage Reduction in Surface Solids (For Natural Sludge)

Anaerobic Digestion – Biogas Production

The biogas production curve (figure 27) indicates that there has been no production of biogas from the alum treated sludge sample. This indicates the conditions inside the reactor are not favourable to produce any biogas. This could be due to very low pH measured inside the reactor. A pH of 3.66 indicates acidic conditions inside the reactor hence resulting in low decomposition rate of organic matter indicated by zero production of gas. In anaerobic digestion, the biological hydrolysis is identified as the rate-limiting step (Hanjie, 2010). Most soluble organic materials which can be converted in to biogas are produced during hydrolysis process. Therefore biogas production is highly dependent on the hydrolysis rate. In this step, cell walls are ruptured and extracellular polymeric substances are degraded resulting in the release of organic material for acidogenic micro- organisms (Hanjie, 2010). At this stage, if the pH is either too high or too low it can significantly affect the biogas generation which is evident from figure 27 for the alum sample.

In contrast, the amount of gas produced is greater in the untreated sample than that treated with MO and the difference in pH between the samples with control and MO having 6.72 and 5.50 respectively could be a possible reason. Studies indicate that methanogenic bacteria are extremely sensitive to pH with optimum range of 6.5-7.2 (Appels et al., 2008). Hence the reactor with a pH of 6.72 i.e. untreated sludge produced more gas as the conditions were favourable for bacterial activity to take place. The higher production of gas from untreated sample indicates the possible presence of high microbial activity in the reactor. This could also mean the addition of MO might be inhibiting the process to a smaller extent when compared to the untreated sludge. However the general trend observed is an increase in gas production until the optimum is reached and gas production starts to cease gradually. Since all the sludge samples used had same concentration of total solids the amount of organic matter and microbes available on day 1 should be the same. This implies that the difference in production observed is due to a change in conditions that occur as the result of the chemical reactions taking place in the reactors. This is further supported by the oxidation-reduction potential (QRP) obtained at the end of observational period. Redox potential measured in alum treated, MO treated and untreated were 66.5, 52.8 and -11.9mV respectively. Researchers have indicated that an increasing or positive QRP is correlated to inhibited or decreasing levels of digester performance (Blanc and Molof, 1973). The results of this experiment have reflected this.

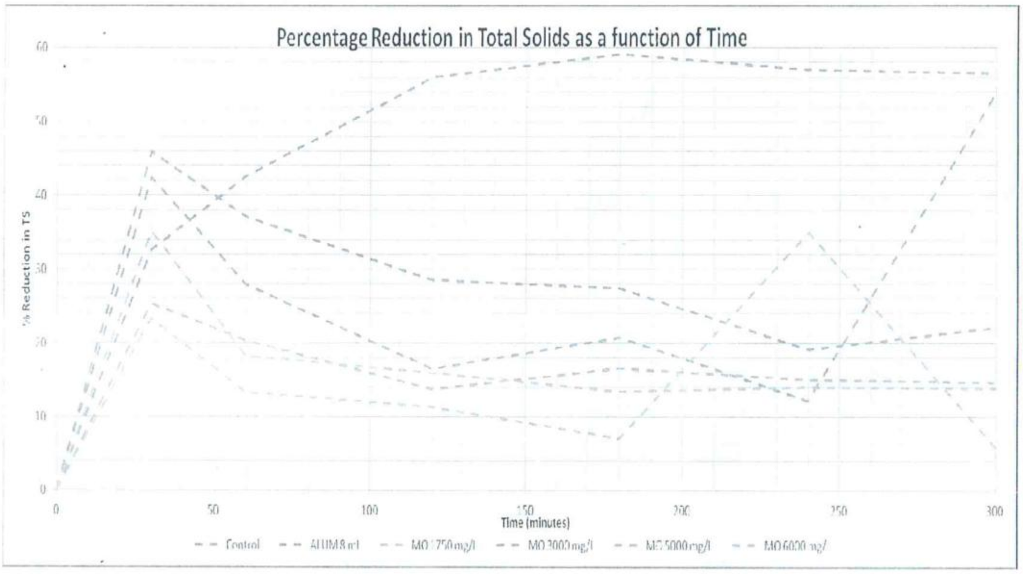


Figure 26: Percentage Reduction in Total Solids (Synthetic Sludge)

VI. CONCLUSION

The quality and the accessibility of drinking water are of paramount important to human health systematic water quality control and monitoring are required. This request reveals that *moringa oleifera* seed has a potential of being an alternative or a supplement to aluminum sulphate or other proprietary polyelectrolyte and can save cost. The advantage of *moringa oleifera* over the conventional chemical coagulants is that it is an environmentally safe method of water purification. Initial result from Zone Settling Rate test on MO indicates treating the sludge with MO seed extract resulted in better settling of particles due to charge neutralization causing particles to adhere each other forming larger particles to settle faster.

Jar test results indicate the difference in percentage reduction between the samples is minimal suggesting the treatment of sludge using alum and MO coagulants has been highly ineffective. In addition, the data obtained are not consistent enough to comment on the affect of coagulants in aiding with settling process. Moreover, the type of sludge used could also have a significant effect on the settling coagulation process.

Finally, the amount of biogas produced is greater in the untreated sample than that treated with MO and the difference in pH between the samples with control and MO having 6.72 and 5.50 pH respectively could be a possible reason. And acidic conditions in alum treated reactor resulted in zero gas production. This implies that the difference in production observed is due to a change in conditions that occur as a result of the chemical reactions taking place in the reactors.

VII. RECOMMENDATIONS

After the treatment of water sample with moringa oleifera powder the test showed a reduction in the coliform unit present which was within the WHO limit for drinking water standard. The purified protein powder had the highest reduction efficiency of the total coliform unit present followed by the oil and then shelled moringa oleifera seed powder respectively. The turbidity of the water sample after treatment with *moringa oleifera* seed reduced the turbidity of the water sample. The purified protein powder had the highest turbidity removal efficiency.

This is the reason for showing maximum percentage reduction observed when coagulation has no oil contents. This therefore implies addition treatment, such as bio-sand filtration must be applied to the water sample before it is assumed safe for human consumption. Moringa oleifera seed poses no toxic effect on human and the environment. It is friendly and of cheaper method of purification of water and therefore can be used in the rural areas where no facilities are available for treatment of drinking. After treatment of moringa oleifera seed, the sludge get settle at the bottom of tank. Large scales treatment at village level produce large quantity of sludge

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APPENDICES

APPENDICES A-ZSR INTERFACE HEIGHT DATA

TABLE A-1: Interface Height From The Top Of Liquid Surface (Mm) Round 1 (ZSR).

TIME	Interface Height From The Top Of Liquid Surface (mm)						
(min)	Control	Mo 750 mg/L	Mo 1000 mg/L	Mo 1250 mg/L	Mo 1500 mg/L	Mo 1750 mg/L	ALUM 10 ml
0	0	0	0	0	0	0	0
1	-0.17	-0.33	-0.67	-0.83	-0.58	-0.92	-1.00
2	-0.83	-1.67	-1.67	-2.00	-1.42	-1.25	-2.17
3	-1.50	-2.17	-2.33	-2.42	-1.75	-2.08	-2.67
4	-2.25	-2.67	-3.17	-3.50	-2.50	-2.58	-3.33
5	-3.08	-3.33	-3.75	-3.92	-3.08	-3.25	-3.50
6	-3.17	-3.50	-4.50	-4.58	-3.50	-3.75	-4.17
7	-3.50	-3.83	-5.00	-5.00	-4.25	-3.75	-4.33
8	-3.83	-4.33	-5.33	-5.25	-4.58	-4.17	-5.00
9	-4.00	-4.50-	-6.00	-5.83	-4.92	-4.17	-5.00
10	-4.67	-4.92	-6.00	-6.00	-5.42	-4.75	-5.83
11	-4.67	-5.17	-6.33	-6.67	-6.08	-4.92	-6.00
12	-5.00	-5.42	-.6.75	-7.25	-6.42	-5.17	-6.50
13	-5.33	-6.08	-7.25	-7.75	-7.08	-5.42	-7.33
14	-5.83	-6.42	-7.50	-8.58	-7.42	-5.67	-7.67
15	-6.00	-6.58	-7.92	-9.08	-8.08	-5.83	-8.17
16	-6.58	-7.00	-8.58	-9.67	-8.67	-6.25	-8.33
17	-7.00	-7.67	-9.08	-10.17	-8.92	-6.25	-8.50
18	-7.00	-7.83	-9.67	-10.58	-9.75	-6.75	-9.17
19	-7.33	-8.17	-9.83	-11.00	-10.00	-7.50	-9.83
20	-7.67	-8.33	-10.83	-11.58	-11.17	-7.50	10.33
21	-7.83	-9.08	-11.25	-12.17	-11.33	-7.83	-10.58
22	-8.58	-9.08	-12.17	-12.92	-12.17	-8.00	-11.50
23	-8.75	-9.75	-12.50	-13.33	-12.83	-8.08	-11.75
24	-9.08	-10.17	-12.92	-13.75	-13.58	-8.67	-12.08
25	-9.67	-10.42	-13.50	-14.58	-14.00	-8.83	-12.25
26	-9.83	-10.83	-14.08	-15.00	-14.58	-9.17	-13.33
27	-10.25	-11.08	-14.58	-15.42	-15.17	-9.33	-13.00
28	-10.33	-11.67	-15.08	-15.92	-15.67	-9.58	-13.17
29	-10.67	-12.17	-15.50	-16.33	-16.17	-9.83	-13.33
30	-10.83	-12.17	-15.67	-16.75	-16.67	-10.08	-13.33

TABLE A-2: Interface Height From The Top Of Liquid Surface (Mm) Round 2 (ZSR).

Time	Interface Height From The Top Of Liquid Surface(mm)								
(min)	Control	Alum	Mo 1500mg/L	Mo 1750mg/L	Mo 2000mg/L	Mo 3000mg/L	Mo 4000mg/L	Mo 5000mg/L	Mo 6000mg/L	Mo 7000mg/L
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	-70.3	-30.0	-7.5	-9.8	-6.8	-11.0	-8.0	-7.3	-2.8	-3.0
2	-97.0	-49.0	-17.5	-15.5	-11.3	-12.3	-10.0	-11.8	-5.5	-5.0
3	-107.8	-75.0	-30.8	-24.3	-20.0	-18.8	-16.3	-17.8	-7.3	-6.5
4	-126.3	-92.0	-43.8	-38.5	-35.0	-32.0	-24.3	-25.0	-9.0	-9.0
5	-152.3	-115.3	-53.8	-56.5	-46.5	-39.5	-31.8	-36.0	-12.0	-10.8
6	-160.8	-125.3	-68.5	-65.0	-55.0	-49.0	-41.3	-43.0	-13.0	-13.8
7	-171.8	-137.0	-81.0	-80.0	-66.8	-58.3	-52.8	-57.8	-16.3	-16.3
8	-179.3	-147.8	-90.8	-105.0	-75.0	-66.5	-60.3	-69.5	-17.8	-18.8
9	-186.0	-157.8	-109.3	-122.3	-95.3	-76.5	-72.8	-75.5	-21.3	-21.8
10	-193.8	-164.5	-122.3	-134.3	-106.8	-91.8	-79.5	-86.3	-23.0	-23.5
11	-201.0	-170.8	-133.0	-144.3	-119.0	-97.8	-89.3	-97.0	-24.8	-25.3

12	-205.0	-179.5	-145.3	-153.5	-132.5	-109.3	-103.0	-105.3	-27.5	-27.8
13	-209.3	-183.8	-151.0	-160.3	-142.8	-118.3	-111.8	-116.3	-30.5	-30.5
14	-213.5	-187.5	-155.8	-165.5	-147.8	-126.5	-119.0	-128.5	-33.3	-33.5
15	-218.5	-190.8	165.3	-169.5	-153.3	-137.0	-130.0	-135.8	-35.3	-36.3
16	-220.5	-193.0	-171.5	-176.3	-155.3	-146.8	-137.0	-143.5	-37.8	37.3
17	-223.0	-198.3	-175.3	-179.3	-168.8	-153.0	-144.5	-155.3	-39.8	-39.8
18	-224.5	-200.3	-179.5	-187.5	-172.3	-159.5	-147.8	-162.3	-42.0	-43.3
19	-228.0	-201.5	-182.3	-189.8	-175.3	-153.8	-158.0	-165.8	-44.8	-44.8
20	-229.3	-204.3	-186.5	-193.3	-181.0	-172.5	-169.0	-171.8	-47.3	-46.3
21	-230.8	-207.3	-188.8	-196.0	-184.5	-176.5	-173.3	-175.0	-49.5	-49.3
22	-233.5	-209.5	-192.3	-198.5	-189.3	-181.0	-179.8	-178.5	-51.3	-50.8
23	-235.5	-211.5	-195.5	-201.3	-192.8	-185.8	-186.8	-183.8	-53.0	-53.3
24	-236.5	-214.0	-199.0	-204.3	-195.3	-190.3	-187.5	-187.8	-55.0	-55.0
25	-239.0	-215.0	-201.5	-206.5	-198.0	-192.8	-190.5	-191.3	-57.5	-57.5
26	-240.3	-216.8	-204.5	-210.5	-200.5	-195.8	-194.5	-194.8	-62.0	-60.0
27	-241.0	-217.8	-207.0	-212.0	-204.3	-199.0	-198.0	-198.8	-66.3	-62.8
28	-242.5	-219.8	-208.0	-214.5	-207.8	-204.0	-200.3	-201.5	66.3	64.3
29	-244.3	-221.0	-210.6	-216.0	-208.5	-204.5	-205.0	-204.3	-68.0	-68.5
30	-244.8	-224.0	-213.3	-218.5	-212.3	-207.3	-206.5	-208.0	-69.8	-69.9
60	-265.8	-239.6	-247.0	-251.5	-250.8	-248.0	-249.9	-251.5	-161.5	-160.0
90	-271.4	-249.5	-258.0	-262.3	-261.3	-259.0	-262.3	-261.6	-187.3	-188.3
120	-275.4	-249.5	-263.0	-268.5	-268.8	-265.3	-268.4	-268.9	-200.0	-204.0
150	-277.0	-254.5	-265.3	-271.3	-271.3	-267.3	-271.3	-271.1	-210.3	-212.3
180	-277.5	-256.0	-266.8	-272.0	-272.5	-268.0	-273.1	-272.3	-214.3	-216.3
210	-278.3	-256.5	-268.8	-274.3	-274.0	-269.8	-276.1	-275.5	-218.3	-219.8
240	-278.8	-256.5	-269.5	-274.8	-274.5	-269.0	-275.3	-276.8	-220.8	-221.3
270	-279.8	-260.3	-271.3	-275.4	275.5	-270.3	-275.9	-277.0	-223.3	-225.5
300	-279.8	-260.3	-272.0	-275.6	-275.8	-271.5	-276.0	-277.0	-229.0	-230.0

APPENDIX B: JAR TEST INTERFACE HEIGHT DATA

TABLE b-1: Interface Height From The Top Of Liquid Surface (Mm) Round 1(Jar test).

Time	**Interface Height From The Top Of Liquid Surface(mm)**					
(min)	**Control**	**Alum**	**Mo 1750mg/L**	**Mo 3000mg/L**	**Mo 5000 mg/L**	**Mo 6000 mg/L**
0	0.0	0.0	0.0	0.0	0.0	0.0
1	-2.67	-4.00	-3.83	-3.67	-2.50	-1.33
2	-5.33	-5.67	-4.50	-3.67	-2.67	-1.33
3	-6.00	-6.33	-5.00	-4.67	-2.83	-1.67
4	-7.00	-7.00	-6.00	-5.33	-3.50	-2.17
5	-8.17	-7.67	-7.00	-6.33	-4.00	-3.17
6	-9.67	-8.67	-8.00	-7.17	-4.33	-3.50
7	-10.67	-10. 00	-9.00	-7.67	-4.33	-3.67
8	-11.00	-10.00	-9.33	-8.17	-5.00	-3.67
9	-11.67	-11.67	-10.50	-9.00	-5.50	-4.50
10	-12.33	-12.33	-11.00	-9.50	-11.00	-4.83
11	-12.50	-12.33	-11.67	-9.67	-6.33	-5.00
12	-14.00	-13.17	-13.00	-11.00	-7.00	-5.67

13	-15.33	-14.17	-13.67	-11.33	-8.00	-6.00
14	-16.33	-16.000	-15.50	-11.83	-8.33	-6.67
15	-16.67	-16.33	-16.000	-12.50	-8.67	-683
16	-19.00	-17.33	-16.33	-13.50	-10. 00	-7.33
17	-19.00	-17.83	-16.67	-13.67	-10. 00	-8.00
18	-19.67	-19.00	-16.67	-14.33	-11.17	-9.00
19	-19.83	-19.00	-17.33	-14.67	-11.33	-917
20	-20.67	-20.17	-19.00	-16.33	-12.67	-9.50
21	-21.83	-20.69	-19.33	-16.67	-13.17	-10.17
22	-22.00	-21.67	-20.33	-17.33	-14.00	-10.67
23	-22.67	-21.67	-21.00	-17.67	-14.00	-11.17
24	-24.00	-22.67	-21.33	-18.67	-14.67	-11.17
25	-24.33	-23.33	-22.00	-18.83	-15.33	-12.50
26	-24.67	-24.00	-23.00	-19.67	-15.67	-12.83
27	-25.17	-25..00	-23.33	-19.67	-16.17	-13.50
28	-26.33	-26.33	-23.67	-20.67	-17.33	-13.83
29	-27.17	-26.33	-24.33	-21.33	-17.67	-14.83
30	-27.33	-26.83	-25.00	-22.33	-18.00	-15.50
60	-40.00	-38.67	-38.00	-34.67	-31.33	-25.00
90	-45.67	-45.67	-45.67	-42.00	-38.00	-32.00
120	-50.67	-51.67	-48.67	-47.33	-43.33	-34.33
150	-51.33	-51.67	-50.67	-48.33	-46.33	-41.67
180	-51.33	-53.33	-51.67	-50.67	-48.00	-46.67
210	-51.33	-54.00	-52.67	-51.33	-48.67	
240	-51.33	-54.00	-52.67	-51.67	-49.33	
270	-51.33	-54.00	-52.67	-52.00	-49.33	-48.33
300	-51.33	-54.00	-52.67	-52.33	-49.33	-48.33

TABLE B-2: Interface Height From The Top Of Liquid Surface (Mm) Round 2 (Jar test).

Time		**Interface Height From The Top Of Liquid Surface (mm)**				
(min)	**Control**	**Alum**	**Mo 1750 mg/L**	**Mo 3000 mg/L**	**Mo 5000 mg/L**	**Mo 6000 mg/L**
0	0.0	0.0	0.0	0.0	0.0	0.0
1	-1.3	-1.0	-0.8	-0.3	-0.8	-0.7
2	-3.2	-1.8	-1.5	-1.3	-2.3	-2.3
3	-3.0	-2.5	-2.5	-2.2	-2.7	-3.2
4	-4.0	-3.0	-3.7	-2.3	-3.2	-3.3
5	-4.8	-4.3	-4.7	-3.0	-3.7	-4.0
6	-6.0	-5.0	-5.3	-3.3	-4.0	-4.0
7	-6.7	-6.0	-5.3	-3.7	-4.3	-4.3
8	-7.7	-6.7	-6.0	-4.0	-4.8	-4.7
9	-8.7	-6.7	-6.3	-4.3	-4.8	-4.7
10	-12.3	-7.8	-7.0	-5.0	-6.2	-5.8
11	-12.7	-9.2	-8.3	-6.7	-7.0	-6.7
12	-13.0	-10.0	-9.0	-7.0	-7.5	-7.8

13	-13.3	-11.0	-9.7	-8.0	-8.7	8.7
14	-14.0	-11.7	-10.7	-8.7	-9.0	-9.3
15	-14.7	-12.0	-11.3	-9.7	-9.7	-9.8
16	-15.3	-12.8	-12.0	-10.5	-10.0	-10.7
17	-16.0	-13.3	-12.7	-12.3	-11.3	-12.0
18	-16.0	-13.3	-13.7	-13.0	-12.2	-13.0
19	-17.5	-13.7	-14.7	-13.5	-12.7	-13.3
20	-18.0	-14.7	-15.3	-14.0	-13.0	-13.7
21	-18.2	-14.7	-15.5	-14.0	-14.3	-14.7
22	-18.7	-15.7	-15.8	-15.0	-15.0	-16.0
23	-19.8	-16.0	-16.3	-15.3	-16.0	-16.8
24	-20.3	-16.8	-16.5	-16.3	-16.3	-17.0
25	-21.2	-17.7	-17.3	-17.0	-16.3	-17.8
26	-21.5	-18.0	-18.0	-17.2	-17.5	-18.3
27	-21.7	-20.0	-19.2	-17.8	-18.7	-18.7
28	-22.0	-20.2	-19.3	-18.5	-18.7	-19.3
29	-23.0	21.3	-20.0	-18.5	-19.3	-20.3
30	-24.3	-22.5	-20.3	-19.2	-19.7	-20.3
60	-37.7	-36.7	-37.0	-32.2	-34.5	-32.7
90	-41.3	-40.7	-40.3	-37.7	-37.7	36.7
120	-43.7	-43.3	-44.0	-42.0	-40.3	-39.3
150	-45.7	47.0	-46.3	-44.7	-45.7	-46.7
180	-46.7	-47.0	-46.3	-46.0	-46.0	47.3
210	-46.7	-48.3	-47.2	-46.3	-47.0	48.3
240	47.3	-47.3	-47.0	-46.7	-47.0	-49.0
270	-47.0	-47.0	-47.3	-46.7	-47.0	-49.3
300	-47.0	-47.0	-46.7	-46.3	-45.0	-50.0

NOTE: Negative measurements indicates the direction i.e. settling of particles away from the surface.

Table B – 3: Total Dried Solids (Mg/L) Round 2 (Jar test)

Time		**Total Dried Solids (mg/L)**				
(min)	**CONTROL**	**ALUM**	**MO 1750 mg/L**	**MO 3000 mg/L**	**MO 5000 mg/L**	**MO 6000 mg/L**
0	7635	8587	8639	8457	9993	10559
30	1612	1936	1186	1297	1988	2062
60	1545	2024	1183	1517	2343	1754
120	2435	1898	1152	1449	1953	2268
180	828	2149	1494	1752	1976	2309
240	929	2239	1553	1355	1847	2257
300	842	1963	1698	1646	2135	1602

Table B – 4: Total dried solids (mg/l) round 3 (Jar test)

Time		**Total Dried Solids (mg/L)**				
(min)	**CONTROL**	**ALUM**	**MO 1750 mg/L**	**MO 3000 mg/L**	**MO 5000 mg/L**	**MO 6000 mg/L**
0	7157	7575	7763	8700	10425	12036
30	3287	2472	1815	3696	2640	4240

60	2657	3232	1035	2431	2121	2192
120	2041	4243	884	1431	1429	1919
180	1959	4476	551	1811	1729	1613
240	1372	4342	2712	1063	1571	1692
300	1585	4283	457	4684	1528	1664

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