Sludge dewatering from a WTP and WWTP using a natural coagulant

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Abstract

In the wastewater treatment process we protect our environment from eutrophication, bacterial resistance and water contamination with heavy metal... But along this treatment significant amount of sludge are generated contains organic material and nutrients that have agriculture value. For the sludge recovery it should be treated to reduce the water volume before being disposed in the land. In this process generally we use chemicals such as polymers for the sludge dewatering but these products are expensive and can damage our environment. That's why several researches enhance the use of natural coagulants. In this context *Moringa oleifera* showed a good result for sludge dehydration. The *Moringa oleifera* powder replaces the chemical coagulant like polyaluminum and many other chemical products. The use of *Moringa Oleifera* can be a cheap and environmentally solution to the utilization of toxic products. But the main question is about its efficiency for the coagulation process, that's why we try in these theses to compare the yield of chemical polymers and our natural one. The experiment, are done to evaluate the efficiency of the coagulation process by Moringa (solution and powder) also some chemical solutions, the drainage rate for different amount of coagulant in the sorption line were analysed, to compare the velocity of the sludge filtration . Also were measured the filtrate turbidity and total solids in the final cake. Drainage rate, TS and turbidity, for different coagulant dosage, were used to analyse the dewatering of a different volumes of sludge (H sludge – 10, 20 and 40 cm). The efficacy of the water dehydration was notable with Moringa extract: the TS increase average is around 9 times. Moringa showed a better action against Al_2SO_4 which had a good efficiency us the average of TS increase is around 7 times.

Keywords: Waste Water Treatment, Sludge, Dewatering, Natural coagulant, Moringa Oleifera

Resumo

No processo de tratamento de águas residuais, protegemos nosso meio ambiente da eutrofização, resistência bacteriana e contaminação da água com metais pesados ... Mas, ao longo deste tratamento, uma quantidade significativa de lodo é gerada contém material orgânico e nutrientes que possuem valor agrícola. Para a recuperação do lodo, este deve ser tratado para reduzir o volume de água antes de ser descartado na terra. Nesse processo, geralmente usamos produtos químicos, como polímeros, para a desidratação do lodo, mas esses produtos são caros e podem danificar o meio ambiente. É por isso que várias pesquisas aprimoram o uso de coagulantes naturais. Nesse contexto, Moringa oleifera mostrou um bom resultado para a desidratação do lodo. O pó da *Moringa oleifera* substitui o coagulante químico como o polialumínio e muitos outros produtos químicos. O uso de *Moringa Olifera* pode ser uma solução barata e ambientalmente correta para a utilização de produtos tóxicos. Mas a questão principal é sobre sua eficiência no processo de coagulação, por isso, tentamos nessas teses comparar o rendimento de polímeros químicos e o natural.

No experimento, são realizados para avaliar a eficiência do processo de coagulação por Moringa (solução e pó) e também algumas soluções químicas, foram analisadas as taxas de drenagem para diferentes quantidades de coagulante na linha de sorção, para comparar a velocidade de filtração do lodo. Também foram medidos a turbidez do filtrado e sólidos totais na torta final. Taxa de drenagem, TS e turbidez, para diferentes dosagens de coagulante, foram usados para analisar a desidratação de diferentes volumes de lodo (lodo H - 10, 20 e 40 cm). A eficácia da desidratação da água foi notável com o extrato de Moringa: a média de aumento de TS é em torno de 9 vezes. Moringa apresentou uma melhor ação contra Al2SO4 que teve uma boa eficiência e a média de aumento de TS é em torno de 7 vezes.

palavras-chave: Tratamento de águas residuais, lamas, desidratação, coagulante natural, Moringa Olifera

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Introduction

The management of bio-solids and wastes generated by wastewater treatment processes is one of the most difficult and expensive problems in the field of wastewater engineering. The treatment methods used vary not only between countries, but also between rural and urban regions. The water treatment techniques used in industrialized countries are not compatible in developing countries due to the costs associated with water treatment plants. In addition, minimal skills and technology are required in developing countries. Therefore, it is time to focus research. The main concern of wastewater treatment plants today is the lack of space and the efficient disposal of solid waste. Better waste management together with cost-effective production is an essential part of the new strategies that are being implemented by sewage treatment plants.

The material extracted from the raw sewage contains particles of dissolved organic or inorganic substances, bacteria, viruses, algae etc. All these particles are suspended in more or less concentrated form and the resulting liquid is called sludge. The sludge is usually deposited at the bottom of the tanks in liquid or semi-solid form during the primary, secondary and pre-treatment process and contains more water than solids. Therefore, the sludge has higher water content because the particles are evenly distributed due to the repulsive forces.

The problem with handling this sludge is the presence of a high water content that makes it difficult to handle and discard the sludge, and the presence of undesirable chemical and organic substances that require chemical treatment of the sludge prior to landfilling or application on land Therefore, successful waste handling (i.e., sludge removal) depends on the efficiency of solids / liquid separation from the sludge and the rate at which it occurs. It is desirable to provide an inexpensive solution that also increases the amount of water extracted before disposal, thickens the sludge, and reduces disposal costs.

The effectiveness of this treatment depends on the speed and amount of condensation that facilitate the removal of the liquid content. This can be achieved by adding coagulants and flocculants to the sludge [1]. There are many commercially available chemical coagulants that are used in the water industry, usually aluminium sulphate, ferric chloride, metal oxychlorides. However, the disadvantage of chemical treatment of the sludge is the risk associated with using biofuels for terrestrial applications. Therefore, a natural coagulant can be useful because the bio-solid by-product can be used.

Testing the feasibility of using natural coagulants to thicken sewage sludge therefore has great potential to replace chemical conditioning agents in industry and offers a more economical treatment solution if this turns out to be a viable alternative. The natural coagulant tested for this project was *Moringa oleifera* (MO), a plant in the Moringaceae family native in northern India [2]. Previous studies have highlighted the presence of active components called cationic peptides because of their clotting properties. Since most contaminants are negatively charged, *Moringa oleifera* seed extract with a cationic property is expected to efficiently adsorb sludge particles and neutralize the charge on its surface, resulting in more effective coagulation [3].

I. Wastewater treatment plant

Wastewater treatment plant is a facility in which various processes interact (physical, chemical and biological) to treat industrial, urban wastewater and remove pollutants. Wastewater Treatment Plants (WWTP) is designed to prevent pollution and disease by treating wastewater before being released to the environment. Any wastewater that is potentially dangerous to humans or the environment because of its toxicity, flammability, corrosiveness, chemical reactivity requires treatment before it is released back to the water system. Wastewater treatment plants (Figure 1) are no longer considered only like a pollution removal systems but rather resources (nutrients – N and P and energy - biogas) recover plants [4].

Figure 1: Wastewater treatment plant of Braganca

1. Process of wastewater treatment

A purification process generally consists of five successive steps as described in Figure 2: (1) preliminary treatment or pre-treatment (physical and mechanical); (2) primary treatment (physicochemical and chemical); (3) secondary treatment or purification (chemical and biological); (4) tertiary or final treatment (physical and chemical); and (5) treatment of the sludge formed (supervised tipping, recycling or incineration) [6].

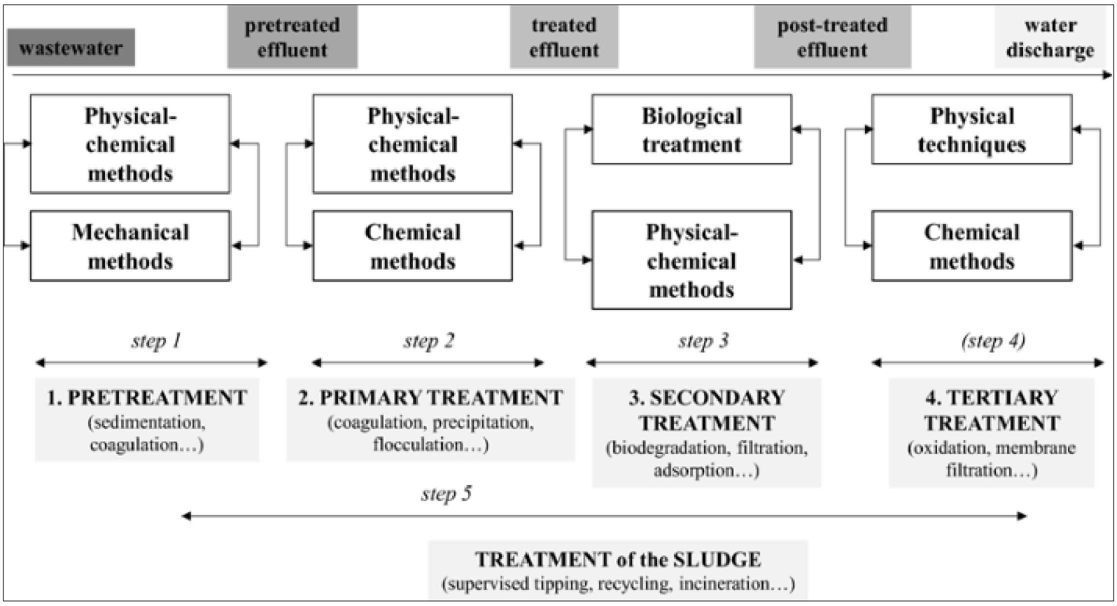

Figure 2: The process steps of wastewater treatment [6]

1.1 Preliminary treatment

As wastewater flows into a treatment facility, it undergoes a first stage operation called preliminary treatment. The aim of this stage of treatment is to eliminate debris that are untreatable and could be taken off by physical means. This first stage makes use of screens to remove the larger inorganic materials such as paper, plastic materials, rags, cans bottles, wood, clogs and other physical debris that may be present at the time. Preliminary treatment comprises of physical unit operations. Other preliminary treatment operations include flow equalization and odour control. The eliminated debris is then collected and deposited in landfills. Following screening, mechanically mixed basins are used to remove and grit and sand-like material that might be present before the effluent is transferred to the primary treatment section [7].

1.2 Primary treatment

This is a physical process in which solids are separated and then sediment in tanks (sedimentation tank). It eliminates the macro pollution. In primary treatment while physical barriers are used to remove larger solids, smaller particles are allowed to settle. This primary treatment occurs in the primary sedimentation tanks or primary clarifiers as the case may be. Inside the clarifier is a mechanically operated large rotating arm or blade which simultaneously remove the settled solids from the bottom of the clarifier and the grease, oil, and other floatables are separated from the top of the clarifier.

This primary sedimentation tanks or clarifiers are covered and always kept in vacuum and also an odour reduction and controlling facility helps to manage odour which is mostly hydrogen sulphide gas which emanates from the wastewater. Pre-aeration or mechanical flocculation with the aid of some special chemicals can be used to facilitate primary treatment [7].

1.3 Secondary treatment

This is a biological process that is carried out by the activity of microorganisms. With this treatment, the wastewater is pumped into shallow stabilisation or oxidation basins, in which microorganisms (microbes) oxidise the organic substance. 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. This process leads to the release of carbon dioxide and the formation of sludge, which is also known as bio-solid. The sludge is continuously aerated to accelerate its oxidation. Algae that grow in the upper illuminated area of the wastewater provide ventilation by generating oxygen [8].

1.4 Tertiary treatment

This is a physicochemical process that eliminates the cloudiness in wastewater caused by nutrients such as nitrogen, phosphorus, etc., dissolved organic substances, heavy metals or pathogens. Tertiary treatment processes are used to purify wastewater from pathogens, contaminants and remaining nutrients such as nitrogen and phosphorus compounds. This step involves the chemical oxidation of wastewater by strong oxidizing agents such as chlorine gas, perchlorate salts, ozone gas and ultraviolet (UV) radiation. After tertiary treatment, the wastewater is discharged into natural water and can be used for irrigation [8].

2. The importance of wastewater treatment

Wastewater treatment process is one of the most important environmental conservation processes that should be encouraged worldwide. Most wastewater treatment plants treat wastewater from homes and business places. Industrial plant, refineries and manufacturing plants wastewater is usually treated at the onsite facilities [3]. Wastewater treatment has a number of benefits. For example, wastewater treatment ensures that the environment is kept clean, there is no water pollution, renew the use of the most important natural resource; water, the treated water can be used for cooling machines in factories and industries, decrease bacterial resistance, prevents the outbreak of waterborne diseases and most importantly, it ensures that there is adequate water for other purposes like irrigation [1]. The occurrence of Dissolved organic carbon (DOC) during the wastewater treatment process is investigated and its removal rates during primary, secondary and overall treatment are being estimated. Furthermore, a correlation is being attempted between DOC and the concentrations of selected Persistent Organic Pollutants (POPs) and Heavy Metals (HMs) in the dissolved phase of wastewaters, to examine whether there are common sources for these pollution parameters in WWTPs. Also, DOC is being correlated with the partition coefficients of the above-mentioned pollutants in wastewater, in order to examine the effect of 'solubility enhancement' in WWTPs and to evaluate the result of this phenomenon in the efficiency of a WWTP to remove organic pollutants [4].

II. Sewage Sludge

1. Definition of Sludge

Sludge is the main by-products of the treatment of wastewater produced by a wastewater treatment plant from liquid effluents. During the waste water treatment process, preliminary sludge is produced in primary sedimentation tanks and biological sludge in secondary sedimentation. The sludge (Figure 3) is mainly water, which is removed from liquid wastewater that contains less solid matter [8].

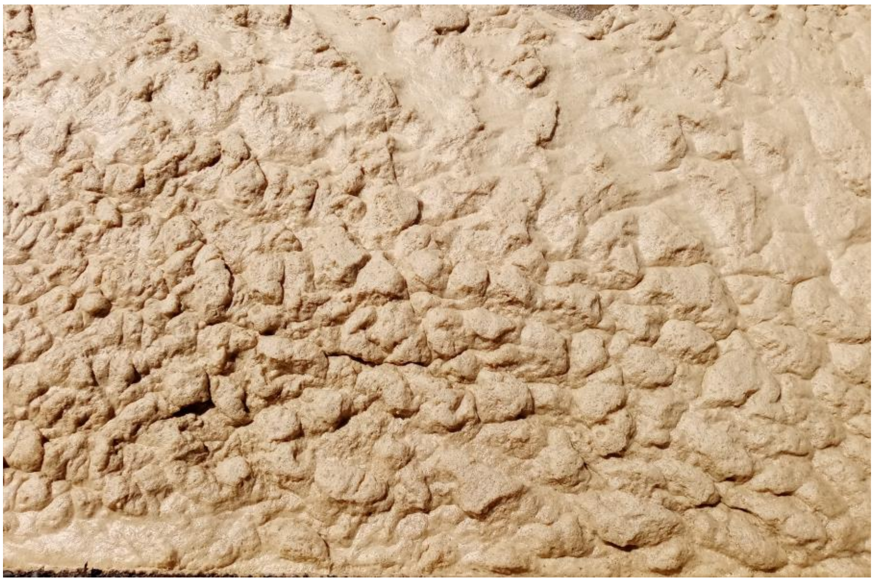

Figure 3: Sewage Sludge from Braganca WWTP

2. Origin of Sludge

Sludge is the name that generally describes a sludgy mass, deposit or sediment as: the precipitated solid matter produced by the water and wastewater treatment processes; sludge from a drilling drill; the sludge sediment in a steam boiler; waste from a coal washer; the precipitated or sediment matter of industrial processes [8].

3. Type of Sludge

Taking as an example a municipal wastewater treatment plant, there are primary sludge obtained from gravity sedimentation at the beginning of the process, secondary sludge generated by the biological treatment, usually activated sludge, and also tertiary. Sludge generated by processes such as chemical precipitation and filtration [8].

4. Composition of Sludge

Sewage sludge is composed of inorganic (nitrogen, phosphorus, and solids that vary with their origin) and organic materials (carbon) that have agricultural value, large concentrations of some plant nutrients, much smaller concentrations of numerous trace elements such us heavy metal (Cu, Cd, Ni, Zn, Mn, Pb, Cr), and some pathogens. The compositions of sewage sludge depend on the composition of the wastewater and the treatment processes used [10].

5. Application of sludge

Wastewater sludge is a very good source of carbon, nitrogen, phosphorus and other nutrients. That's why the sludge is used for agriculture to enhance the soil fertility, land utilization, sanitary landfill, home gardening, incineration treatment, or for erosion control [10]. The dumping into water-body, high-rate activated sludge (HRAS) is the most promising alternative technology to redirect carbon (organic compounds) towards energy as biogas. Incineration can also be performed by mixing sludge with solid waste to generate energy [11]. Furthermore, sludge can be a source for a biogas, biofuel, bio plastique, biodiesel, bio sorbent, bio pesticide, bio fertilized [12]. Because of its composition especially the carbon it supports the growth, the sporulation and the endotoxin production by Bacillus thuringiensis variety kurstaki which had the ability to produce d-endotoxin who is a bio pesticide [13].

6. Problem with sludge

Sludge from wastewater treatment plants poses serious disposal problems. Firstly because of her huge volume that cost too much money for its transportation, Secondly the lack of the suitable landfill for its disposal; Sludge disposal is an expensive operation and could result in new environmental pollution if dealt with improperly. In fact, During wastewater treatment processes, some harmful chemicals and pathogens can become concentrated in sewage sludge especially by adding chemical coagulant during the process. The main problem associated with sludge treatment is the presence of pathogens and toxic metals. As long as the sludge is rich in micro bacteria, when the latter is diversified in the aquatic environment there will be a risk of promoting bacterial resistance; resistant microbes are more difficult to treat, requiring alternative medications or higher doses of antimicrobials. Antibiotics have been polluting the environment since their introduction through human waste. Typically, sludge is reversed into agricultural forest land or dumped in landfills. New methods for sludge disposal are being developed. However, sludge problem disposal remains a common issue [12].To decrease the sludge disposal problem, the sludge should be more concentrated and don't contain much chemical.

7. Sludge treatment

Sludge treatment is one of the most important and expensive steps in water and wastewater treatment plants us show (Figure 4). Treatment of sewage sludge may include a combination of thickening, digestion, dewatering, and disposal processes [15].

7.1 Thickening

Thickening is usually the first step in sludge treatment because it is impractical to treat thin sludge (Figure 4). Concentration is usually carried out in a tank called a gravity concentrator. Thickener can reduce the total amount of sludge to less than half of the original amount. An alternative to gravity concentration is to dissolve air flotation. In this way, air bubbles carry the solid to the surface, where it forms thickened slurry [16].

7.2 Digestion

Sludge digestion is a biological process in which organic solids are broken down into stable substances. Digestion reduces the total mass of solids, destroys pathogens, and makes dehydration or drying of the sludge easier [16]. The digested sludge is harmless and has rich appearance and characteristics of potting soil (Figure 4). Most large wastewater treatment plants use a two-stage digestion system in which organics are metabolized by anaerobic bacteria (in the absence of oxygen). In the first stage, the sludge, thickened to a dry solids (DS) content of approximately 5%, is heated and mixed in a closed tank for several days. Acid-forming bacteria hydrolyse large molecules such as proteins and lipids, breaking them into smaller water-soluble molecules, and then fermenting those smaller molecules into several fatty acids. Then, the sludge flows into a second tank, where dissolved matter is converted by other bacteria into biogas, a mixture of carbon dioxide and methane. Methane is flammable and is used as fuel to heat the first digester and to generate power for the plant. Anaerobic digestion is very sensitive to temperature, acidity and other factors [16].

It requires careful monitoring and control. In some cases, at the beginning of the first stage of digestion, the sludge is inoculated with additional hydrolytic enzymes to supplement the action of the bacteria. It has been discovered that this enzymatic treatment can destroy more unwanted pathogens in the mud and also produce more biogas in the second stage of digestion. Another improvement to the traditional process of anaerobic digestion in two stages is the thermal hydrolysis or degradation of large molecules by heat. This is done in a separate step before digestion. The slurry is mixed with steam in a pulp and this hot homogenized mixture is fed to a reactor where it is held under pressure at about 165°C for about 30 minutes.

At this time, with the complete hydrolytic reactions, a part of the steam is purged (to be supplied to the pulped), and the slurry is suddenly released, even under a certain pressure, in an "immediate container" in which the sudden fall into bursting pressure enters the cell walls of much of the solid matter [16]. The hydrolysed sludge is cooled, diluted slightly with water and then fed directly to the second stage of the anaerobic digestion. Sludge digestion can also be aerobic, in the presence of oxygen. Although aerobic systems are easier to use than anaerobic systems, they generally cost more because of the ventilation required. Aerobic digestion is often combined with small systems for longer aeration or contact stabilization.

Anaerobic aerobic and conventional fermentation converts about half of the organic solids in the sludge into liquids and gases. Thermal hydrolysis followed by anaerobic digestion converts 60 to 70% of the solids into liquids and gases. Not only is the volume of produced solids lower than with conventional fermentation, but the increased production of biogas can make some wastewater treatment plants energy self-sufficient [17].

7.3 Dewatering

Digested sewage sludge is usually dehydrated before disposal. The dewatered sludge still contains a lot of water, usually up to 70%, but even with certain moisture content, the sludge no longer behaves like a solid material like a liquid (Figure 4). The sludge drying bed provides the simplest method of dehydration. The digested sludge slurry is spread on an open sand bed and kept dry. Drying is accomplished by a combination of evaporation and gravity through sand. A pipe network built under the sand collects water, which is then pumped back to the top of the plant. After about six weeks of drying, the so-called sludge cake solids content is about 40%.

It can then be removed from the sand using a gallows or front loader. To reduce drying time in humid or cold climates, a glass cover can be built on the sand bed. Due to the large amount of land needed to dry the beds, this drainage method is often used in rural or suburban towns, rather than in densely populated cities. Alternatives to sludge drying beds include drum vacuum filters, centrifuges and belt filter presses.

These mechanical systems require less space than sludge drying beds and provide a higher degree of operational control. However, they usually have to be preceded by a step called sludge conditioning, in which chemicals are added to the liquid sludge to condense solids and improve drainage [17]. The solids recovery rate varies at each stage of sludge treatment and is shown in Table 1.

Table 1: Solids recovery rate in each treatment stage [18]

Process	**Solids recovery rate**	
Sludge thickening	Gravity thickening	80 to 90%
	Centrifugal thickening	85 to 95%
	Air floatation thickening (dispersed air)	More than 95%
	Gravity belt thickening	More than 95%
Sludge digestion	Sludge reduction ratio due to formation of gas , etc..	
Sludge dewatering	Pressure type screw press dewatering	More than 95%
	Rotary pressure dewatering	More than 95%
	Belt press dewatering	90 to 95%
	Centrifugal dewatering	More than 95%

7.4 Disposal

The final destination of treated sewage sludge is usually land (Figure 4). Dewatered sludge can be buried in underground landfills. It can also be promoted on agricultural land to take advantage of its value as a soil improver and fertilizer. Because sludge may contain toxic industrial chemicals like polymers and heavy metals, it will not spread on land where crops are grown for human consumption [19].

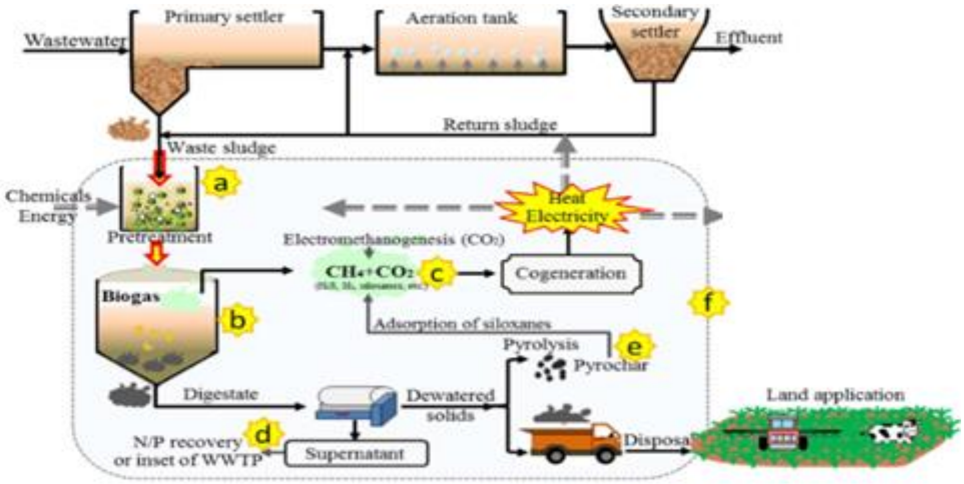

Figure 4: Sludge treatment process [8]

8. Traditional coagulant for sludge dewatering

Traditionally the types of coagulant are chemical conditioners such as polyaluminum chloride, aluminium sulphate, Fenton's reagent, gypsum, and polyacrylamide. The main problem of these products is the damage that they cause not only for the human health but also to the environment [20]. Aluminium salts used as primary coagulant in potable water treatment may lead to increased concentrations of aluminium ions (Al), which leads to water quality and supply problems. Supply problems associated with increased Al concentrations include formation of hydrous Al precipitate in the distribution system that may increase the turbidity as well as decrease the carrying capacity of the pipes [20]. Ferric salts and synthetic polymers have also been used as coagulants but with limited success because of the same disadvantages manifested in the use of aluminium salts. Synthetic organic polymers are also known to contain [20].

III. Coagulation-Flocculation

1. Coagulation

Coagulation is the process of destabilizing the medium in such a way that particles are agglomerated. It is the process of chemically modifying colloids, enabling them to from larger particles through the destabilization of particles [43]. Transformation is visible from stable to unstable state. The formation can be observed in dispersed suspensions, flocs or precipitates due to destabilization whereas dewatering of the suspension is seen in more intense suspension.

Particulate suspensions have a negative surface effect. To bringing certain particles, the surface charges must be neutralised together. The charge neutralization process of particles to micro-floc particles is achieved by coagulation. Therefore both inorganic and organic coagulants used in sludge treatment are cationic [44]. Figure 5 is an example of formation of micro floc upon the addition of a coagulant to clay particles in solution.

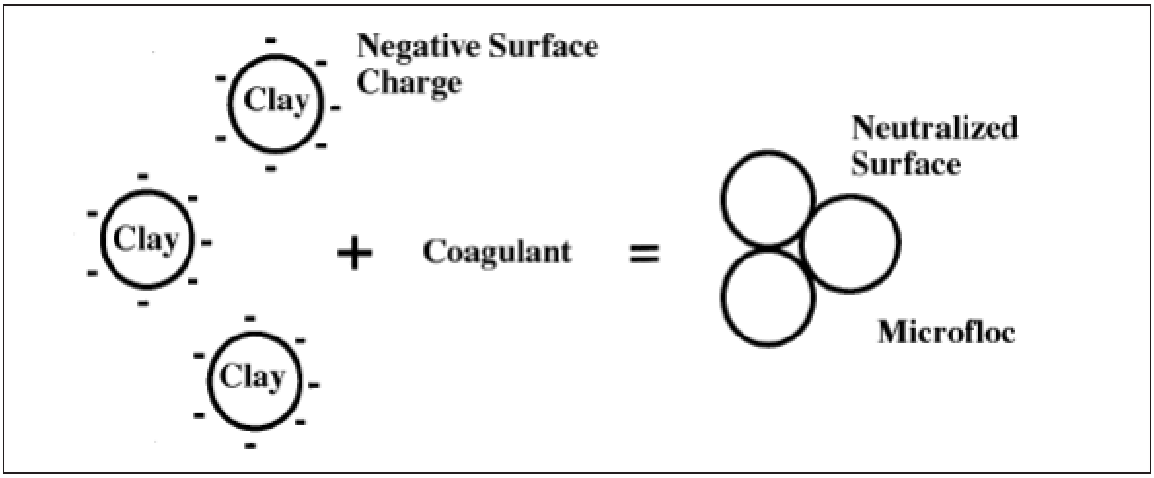

Figure 5: Formation of micro floc [44]

2. Flocculation

Flocculation is the process which results from destabilization and aggregate. Flocculation is the process of linking coagulated colloids to each other for the formation of large aggregates [45]. Figure 6 shows a pictorial representation of aggregate formation in clay particles.

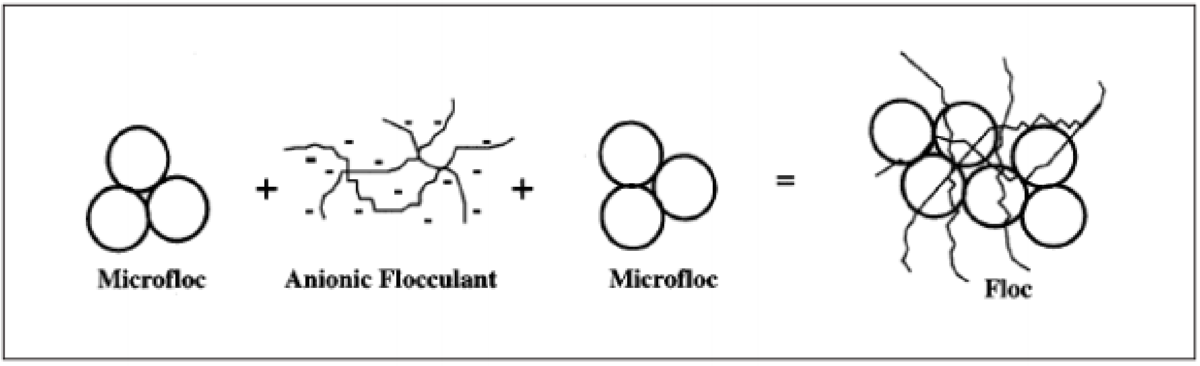

Figure 6: Formation of a floc from micro floc [44]

IV. Coagulants

1. Chemical coagulant

There are many chemical coagulants available in the industry for example: Ferric chloride, Alum and lime are commonly used for thickening sludge. There are two classes of coagulants in the chemical as shown Table 2. (i) Coagulants based on aluminium, including Aluminium sulphate, chloride and sodium aluminate; and (ii) coagulants based on iron, including ferric sulphate, chloride and ferrous sulphate [46]. Coagulant such as aluminium, ferric sulphate and cationic polyelectrolytes have the same function of suppressing the zeta potential of the colloidal system to a significantly low value, so that colloidal particles collide and then collide under the influence of slow stirring [46]. While chemical coagulants have disadvantages, for example reports indicate a connection with residual aluminium in processed water and Alzheimer's disease [47].

In fact, sludge that has been thickened with chemical coagulants and polymers is present a danger to the atmosphere because the leaching of chemicals from soil deposition may be a source of the ground water contamination [48]. Also the cost of chemical conditioning exceeds half of the cost of sludge management and handling [20]. Investigating the viability of using a natural coagulant to thicken wastewater sludge is therefore a worthwhile prospect, as it has a great potential to replace chemical conditioners in the industry if it proves to be viable, ultimately providing a cheaper and sustainable solution. The coagulant dosage necessary for wastewater treatment by coagulation/flocculation depends on the wastewaters characteristics [20]. Then, coagulant dosages were primarily optimized at raw wastewater pH, to attain the maximum removals for each parameter in study. Generally 400 mg of coagulant/L of water is used in European union.

Table 2: A list of typically inorganic coagulants [49]

Name	Typical formula	Typical strength	Typical forms used in water treatment	Density	Typical uses
Aluminium sulphate	$Al_2(SO_4)_3$-14 to 18 H_2O	17%Al_2O_3	Lump granola or powder	60-70 Ib/tt3	Primary coagulant
Alum		8.25% Al_2O_3	Liquid	11.1 Ib/gal	
Alum chloride	$AlCl_3$-6H_2O	35% $AlCl_3$	Liquid	12.5 Ib/gal	Primary coagulant
Ferric sulphate	$Fe_2(SO_4)_3$-9H_2O	68%$Fe_2(SO_4)_3$	Granola	70-72 Ib/tt3	Primary coagulant
Ferric chloride	$FeCl_3$	60%$FeCl_3$	Crystal, solution	60-64 Ib/tt3	Primary coagulant
Sodium aluminate	$Na_2Al_2O_4$	38-46 $Na_2Al_2O_4$	Liquid	12.3-12.9 Ib/gal	Primary coagulant

2. Natural coagulant

2.1 Definition

The natural coagulation is a natural phenomenon based on herbal coagulant for reducing turbidity in coagulation and flocculation process for waste treatment. Such Hibiscus Rosa Seinnsis and *Moringa Oleifera* [21].

2.2 Moringa Oleifera

2.2.1 Description of the tree

Moringa oleifera known as "Moringa" or "Malunggay" is a tropical plant native to India and widely cultivated in tropical and subtropical areas. It is the most widely cultivated species of the genus Moringa (Figure 7). Its young seed pods and leaves are used as vegetables. All parts of the Moringa tree are edible and have long been consumed by humans [22]. India is the largest producer of moringa, with an annual production of 1.2 million tonnes of fruits from an area of 380 km2 [12].

Moringa is grown in home gardens and as living fences in South Asia and Southeast Asia, where it is commonly sold in local markets. In the Philippines and Indonesia, it is commonly grown for its leaves, which are used as food. Moringa is also actively cultivated by the World Vegetable Center in Taiwan, a center for vegetable research.

More generally, moringa grows in the wild or is cultivated in Central America and the Caribbean, northern countries of South America, Africa, South and Southeast Asia, and various countries of Oceania.

Figure 7: Moringa Oleifera Tree [22]

2.2.2 Application of seed in water treatment

2.2.2.1 As adsorbent

Several experiments have shown that *Moringa Oleifera* seeds outstanding adsorbent properties and have been used to adsorb concomitants such as heavy metals, organic matter and even pesticides. The adsorptive ability of the seed is attributed to the inclusion in the composition of proteins, certain fatty acids, carbohydrates comprising cellulose interlinked lignin [28].

According to Sharma et al., in 2006, the potential of seeds to extract heavy metals was examined using Fourier Transform Infrared (FTIR) spectrometry, which demonstrated the amino acid-metal bonding interactions responsible for the sorption process [29]. Selected relevant literature on the use of *Moringa oleifera* as an adsorbent for the removal of heavy metals and organic concomitants are presented in Table 3.

Table 3: Selected relevant literature on the use of *Moringa oleifera* seed as adsorbent [23]

Form of Moringa oleifera seeds	Heavy metals	Outcome	References
Shelled Moringa oleifera seed	Arsenic (Ar) (III &V)	60.21%, 85.06% deletion of As (III) and As (V) was obtained with dosage of 2 g, 25 mg.L^{-1} metal concentration, touch time: 60 min, test volume: 200 mL, pH 7.5 For As (III), for As (V), pH 2.5	[35]
Shelled Moringa oleifera seed	Cadmium (Cd)	85.01% removal was achieved at dosage of 4 g, contact time of 40 minutes, metal concentration of 25 µg.mL^{-1}, test solution of 200 ml at pH of 6.5	[36]
Seed powder	Silver (Ag)	Optimum conditions obtained were 2g of adsorbent dosage, contact time of 20 minutes, pH of 6.5metal concentration of 25 mg/l, test volume of 100 mL	[37]
Seed powder	Nickel (Ni)	About 90% removal was achieved.	[38]
Seed powder	Copper (Cu)	Kinetics study was described to be pseudo second order mode, optimum removal not discussed	[39]
Seed powder	Lead (Pb)	68.43% removal was achieved	[40]
Seed powder, Residue after coagulant extraction,	Chromium (Cr) (III)	97%, 94%, and 99.9% removal was achieved using the whole seed, residue after coagulant extraction and activated carbon from husk respectively	[41]
Seed Biomass	Zinc (Zn)	Over 90% removal was achieved within 40 minutes of contact	[41]
Seed	Manganese (Mn)	Over 95% removal was achieved	[42]

2.2.2.2 As disinfectant

One new and important feature is the usage of *Moringa Oleifera* seed as disinfectant water. While several literature have reported its antibacterial properties against both gram negative and gram positive [30].

2.2.2.3 As coagulant

The seed extractor of *M. oleifera* can be used for water treatment since the active components of coagulation are contained in the seeds. The coagulant of *M. oleifera* (MOC) is traditionally extracted with water and used to treat waste water [23]. Some research has shown that the coagulation efficiency of Moringa oleifera seeds can be greatly increased by extracting its active agents with salt solution with one valence electron such as NaCl, KCl etc. [31].

The proposed mechanism of the reactive coagulant components in seed protein of *Moringa Oleifera* is assumed to attach positively charged proteins through electrostatic interaction to parts of surfaces of negatively charges particles. This helps in the creation of negatively and positively charged surface areas off the particles. Particulate collision and neutralization result in the enmeshment of suspended particles that form flocks [32].

2.2.2.4 As dewatering or sludge conditioner

Chemical treatment increases the drainage properties of sludge but they are quickly becoming controversial due to their high costs as well as environmental impact. Seeds of *Moringa oleifera* have been reported to produce more compact sludge [33] this reducing the volume of sludge. The developed sludge is very biodegradable and can be used as a bio fertilizer. Studies has showed that seed extracts from *Moringa oleifera* can be used alone in the sludge dewatering process or can be used with alum to dewater sludge[34].

2.2.3 Other uses of MO

Moringa is used worldwide in traditional medicine for various disorders such as skin infections, anaemia, anxiety, asthma, blackheads, blood impurities, bronchitis, colds, chest congestion, cholera, infections and fever, glandular, swelling, headaches, abnormal blood pressure, hysteria, joint pain , Pimples, psoriasis, respiratory diseases, scurvy, sperm deficiency, sore throat, sprain, tuberculosis, intestinal worms, lactation, diabetes and pregnancy.

Some parts of this plant, such as leaves, roots, seeds, bark, fruits, flowers and immature pods, act as cardiovascular stimulants, antitumor agents, antipyretics, antiepileptic, anti-inflammatory, anticonvulsants, diuretic, hypertension, cholesterol lowering agents. Antioxidants, Antidiabetics, Hepatoprotektoren, Antibiotics and Antifungals, and are used to treat various diseases in indigenous medicine [17]. Moringa has high anticancer proprieties [24]. Also, as a traditionally important food, Moringa oleifera has received attention as a "natural diet of the tropics" [25].

2.2.4 Chemical Composition of Moringa oleifera Leaves

The result of the analysis shows that the percentages (%) of proteins, moisture, fat and carbohydrates of the leaves are respectively 11.9; 73.9; 1.1 and 10.6% for cold matter. For the dry matter, the protein, moisture, fat and carbohydrate contents are 27.2; 5.9; 17.1 and 38.6%. The result of the mineral composition in mg for 100 g of substance is 847.1; 151.3; 549.6; 17.5; 1,3 and 111,5 in the cooling substance for calcium, magnesium, potassium, iron, zinc and phosphorus. The levels of the same minerals tested for dry matter are 2098.1 each; 406.0; 1922.0; 28.3; 5.4 and 351.1.

The results showed a satisfactory composition and significant variability between the nutrient contents of different sectors. This plant can be appreciated for a balanced nutrition of the populations [26].

2.2.5 Seed oil extraction

The seed are the most important part in our plant (Figure 8) in fact the oil extracted from Moringa seed is known as Ben oil and reportedly contains 70% of oleic acid, an 18-carbon long monounsatured- rated fatty acid [27].

Figure8: Seeds of Moringa Oleifera us raw material

There are various methods to extract the active coagulant from Moringa seed, these techniques are shown in Table 4.

Table 4: Oil extraction methods from *Moringa Oleifera*

Oil extraction methods	Solvent	Optimized condition	Amount of MO seed	Oil yield	Comments	Reference
Soxhlet extraction	petroleum ether	52 °C, 8 h	4 g (powder)	39.16 ± 0 .19[a]	The best yield for this method	[26]
Conventional solvent extraction (CE)	petroleum ether	30 °C, stirring of 325 r/min for 50 min	10 g (powder)	35.26 ± 0 .44[c]	_	[26]
Ultrasound-assisted Solvent extraction (UAE)	petroleum ether	ultrasound (5 min, 200 W, 30 °C) & stirring 15 min	10 g (powder)	35.77 ± 0 .04[c]	_	[26]
Microwave-assisted solvent extraction (MAE)	petroleum ether	300 W, 7 min (at intervals of 5 times)	10 g (powder)	36.89 ± 0 .29[b]	_	[26]
Methanol extraction	20 mL of 80% aqueous methanol		2 g			[25]
Soxhlet extraction	200 mL n-hexane	1h 68.7 °C	10 g	27.6		[25]

Table 4: Oil extraction methods from *Moringa Oleifera* (continue)

Soxhlet extraction	200 mL n-hexane	3h 68.7 °C	10g	**42**	The best yield for this method	[25]
Soxhlet extraction	200 mL ethyl acetate	1h 77.1 °C	10g	10.5		[25]
Soxhlet extraction	200 mL ethanol	1h 78.1	10g	7.35		[25]
Soxhlet extraction	200 mL ethanol	3h 78.1 °C	10g	8.24		[25]
Soxhlet extraction	210 mL ethanol/ hexane	6h 40-60 °C	10 g	**38**	The best yield for this method	[22]
Supercritical Fluid Extraction (SFE)	_	10 min of static extraction , 30 min of dynamic extraction , CO_2 flow rate = 0.66 g/min.	20 - 30 g	35		[22]

V. Objectives

The purpose of this dissertation is to investigate the technical feasibility of using a natural product to replace the chemical coagulants currently used for sludge treatment in the water/wastewater 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 sludge dewatering.

VI. Materials and methods

1. Equipment

Commercial grinder, vacuum filtration apparatus, soxhlet extraction apparatus for M. oleifera seeds oil extraction, cylinder beakers (HmbG, 1 L), laboratory balance (RADWAG, WTC 2000), pH meter (WTW, inoLab), turbidimeter (WTW, Turb 550), stopwatch, magnetic stirrer, scientific laboratory oven series 9000 and jar test apparatus were used.

2. Material preparation

2.1 Sludge preparation

2.1.1 Sludge collecting

The sludge used in the experiments was supplied by the Wastewater Treatment Plant of Bragança. The sludge was collected to the secondary sedimentation tank outlet and was chemicals free. The sludge was transported to the lab in plastic containers and stored until used in the experiments.

2.1.2 Sludge characterization

2.1.2.1 Total solids TS (mg/L):

Total solids are the term applied to the residual material left in a vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total solids include total dissolved solids (TDS), the portion of total solids retained by a filter, and total dissolved solids, the portion that passes through the filter [50]. The apparatus to do the total solids are an evaporating dish, a porcelain one of 100 mL with 90 mm diameter, drying oven, for operation at 103 to 105°C, desiccator, and analytical balance.

This is the procedures followed;

i. Properly wash and dry a dish in the laboratory oven at a temperature of 105°C for one hour. Store and cool the dish in a desiccator until needed.

ii. Weigh the empty dish before use.

iii. Add the sample to the dish and diligently place it in the laboratory oven at a temperature of 105°C. Dry the substrate sample to a constant mass for a period of 1 hour.

iv. Cool down the dish plus substrate residue in a desiccator to balance temperature.

v. Weigh the dish plus substrate (material) residue using an analytical balance [50].

Calculate the percentage total solids using Equation (1):

$$\%TS = (w1 - w2) \div (w3 - w2)$$

Where,

%TS = Percentage total solid

W1 = Weight of dried dish + dried residue

W2 = Weight of dish

W3 = Weight of wet sample (substrate) + dish

2.1.2.2 Volatile solids VS (mg/L)

The term total volatile solids refer to materials that are completely volatilized from water at higher temperature (550ºC). These solids are often referred to the organic content of the water.

The following procedures were followed in the determination of the volatile solid of the substrates used.

i. Ignite the residue obtained from total solids determination at 550°C for duration of 30 minutes using a muffle furnace.

ii. Cool the dish in air before transferring it to the desiccator for complete cooling.

Calculated the percentage volatile solid using Equation (2).

$$\%VS = (w1 - w4) \div (w1 - w2)$$

Where,

%VS = Percentage Volatile solid

W4 = Weight of dish + weight of residue after ignition [50]

2.1.2.3 pH:

The pH is a measure of the chemical activity of hydrons in solution by pH-meter. The concept of pH is unique among the physicochemical quantities commonly found listed in the IU PAC Green Book, in that it describes.

pH = - log a (H+)

It involves a single ion quantity, the hydrogen ion activity, which is unmeasurable by any thermodyn amically valid method and requires a convention for its assessment. It is measured on a scale from 0 to 14 [49].

2.1.2.4 Turbidity:

The clarity of water is an important determinant of its condition and productivity. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton. An expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample [49].

2.2 Coagulant

2.2.1 Chemical coagulant

2.2.1.1 Aluminum Sulphate

Aluminium Sulphate (also refers to as alum) is a widely used water treatment coagulant. Hydrated cations of aluminium and iron reactions to insoluble from in aqueous systems hydroxides to metal [51]. As for alum ($Al_2(SO_4)_3 .14\ H_2O$) is applied to naturally occurring.

Occurring water Alkalinity, general reaction is as follows:

$$Al2(SO4)3\ .14H2O + 3\ Ca(HCO3\ )2 \leftrightarrow 2\ Al(OH)3\ + 14\ H2O$$

2.2.1.2 Ferric chloride

Ferric chloride ($FeCl_3$) is used in sewage treatment and drinking water production as a coagulant and flocculent, it is an inorganic coagulant.

2.2.2 Natural coagulants

2.2.2.1 Moringa Oleifera without oil extract

Dried *Moringa oleifera* seeds were used for the experimental purposes. Seeds were removed from the pods and select the good quality seeds for the study. The winged seeds are shelled to remove the kernels that have been ground into a fine powder using a blender. To obtain an active coagulant we did two solutions the first one is with sodium chloride. In fact, the active coagulant of the MO seed was extracted by dissolving 10 g of powder in 100 mL of NaCl solution (1M) to obtain a 10% solution. The solution was blended using a magnetic stirred for 1 h. The same procedure was done but the 10 g of active coagulant was dissolved in 100 mL of distilled water to have a solution of 10%. This solution represents a natural coagulant with the lowest prices, eco-friendly and nontoxic.

2.2.2.2 Moringa Oleifera with oil extract

Oil extraction from *Moringa oleifera* seeds is performed using various techniques such as solvent extraction. Among the methods, the solvent extraction technique is a conventional technique used for vegetable oils extraction. The soxhlet technique, a conventional solvent extraction method, is widely used to extract oil-free moringa seeds from Moringa oleifera seeds for characterizing the physicochemical prosperities of it.

There are other methods of extraction like conventional solvent extraction (CE), ultrasound-assisted solvent extraction (UAE) and microwave-assisted solvent extraction (MAE). The total oil content of *Moringa oleifera* seeds was determined by soxhlet extraction, according to the standard method GB 5009.6 (2016c). Briefly, ethanol (boiling point 30 – 60 °C) and 10 g of the *Moringa oleifera* seeds powder (<0.43mm) were heated to reflux for 6 h.

Soxhlet extractor consists of a glass body (4) in which is placed a thick filter paper cartridge in the form of a stick (5), a siphon tube (6-7) and a adduction (3). In the assembly, the extractor is placed on a flask (2) containing the extraction solvent (1). In the extractor is inserted a cartridge in which is placed the powder containing the species to be extracted; then a cooler (9-10-11) is fitted above the extractor (it is also desirable to use a balloon heater with integrated magnetic stirring, in order to avoid boiling spurts which cause rise of the liquid contained in the flask and not of pure solvent vapours (failing this, glass beads can be placed in the flask).

When the flask is heated, the solvent vapours pass through the adductor tube, condense in the refrigerant and fall back into the extractor body, thus macerating the solid in the solvent (heated by the vapours below). The condensed solvent accumulates in the extractor until it reaches the top of the siphon tube, which then causes the liquid to return to the flask, accompanied by the substances extracted, and the solvent contained in the flask therefore gradually enriches itself. The solvent then continues to evaporate; while the extracted substances remain in the flask (their boiling temperature must be significantly higher than that of the extracting solvent).

2.3 Experimental methods

2.3.1 Conditioning

For sludge conditioning test, a jar test apparatus was used. Jar test simulates a flocculation cycle of treatment chemicals in a water treatment plant which helps to assess the appropriate amount of treatment chemicals to increase plant efficiency.

The Jar test was performed to determine the effect of the seed extract on the seedling of the sludge by continuous stirring mechanism as specified in the Standard Methods. Generally, the coagulation effect of any coagulant is evaluated by conducting a jar test [37]. It has stirrer with speed control and 6 beakers (1 L size). Different amounts of conditioning chemicals (1, 2, 5 and 10 mL) were added to the beakers of 500 mL and mixed with 200 ml of sludge. Rapid mixing was done at 250 rpm for 20 s (or 150 rpm, 3 min) and the intensity was reduced to 40 rpm and mixed further for about 2 min (20 rpm, 12 min). In the case of dual coagulant addition, alum was first added and mixed for 15 s at 250 rpm (or 90 s, 150 rpm) and then MO was added and further mixed for 15 s (or 90 s) before the mixing intensity was reduced to 40 rpm.

2.3.2 Dewatering

The dewatering test is done using 9 cm regular Buchner columns with a Whatman No 3 filter paper, multiracial CST (MRCST) unit (modelTW166 triton Electronics Ltd.) and sand columns. The role of these column is to study how a natural coagulant using different forms to prepare this), can be a good solution in the dewatering sludge process.

The filter bed consists in a Perspex glass columns 3.0 cm diameter and 6 cm high. Each fill with 20 cm deep sand (size 0.3–1.0 mm) (Figure 9). Observe the sludge drainage through the sand bed and record the time as well as the volume of filtration for complete drainage. Study the effect of the sludge loading drilling, application depths of 10, 20 and 40 cm.

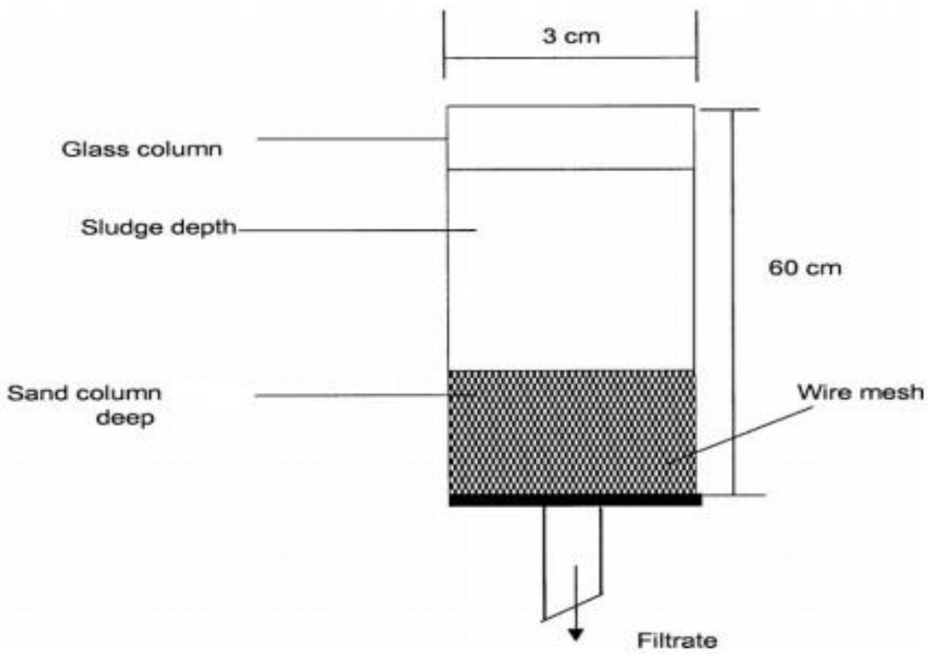

Figure 9: Sand drainage column to use in the experiment of sludge dewatering [20]

2.3.3 Analyses

The drainage rate is read each min. The filtrate from the column was analysed for turbidity using a turbidity meter. Total solids concentration of the raw sludge and dry solids concentration of sludge cake samples from the columns.

3. Methodology

1. Evaluate, characterize and quantify the sludge generated in a WTP/WWTP.
2. Research and preparation of different ways of using Moringa oleifera seed in the dehydration process (dry powder or solution with seed powder).
3. Experimental sludge treatment using different dosages of Moringa (powder or extract);
4. Experimental studies to compare the Moringa performance with that of coagulants and polymers usual in the sludge dewatering process.

For this work it was used the experimental installation shown in Figure 10. In order to evaluate the performance of each coagulant, the following parameters were considered: drainage rate ($mL.min^{-1}$), the solid concentration on the final cake and the filtrate turbidity.

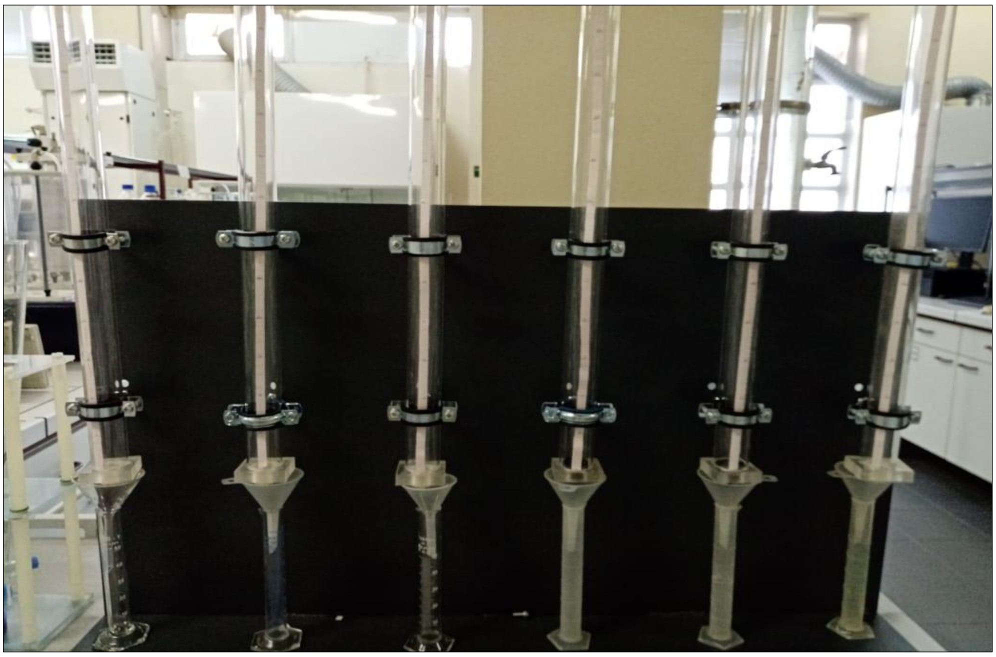

Figure10: The experimental installation

VII. Results and Discussion

In this chapter, the experimental data from the whole work are shown. The data are shown in both table and figure form. From the figures, the optimal dose and dosing condition of coagulant found during different step within the experiment. There is also explicit discussion in every step within the experiment.

1. Preparation of the coagulant

In this study, a comparison is doing between bio coagulants obtained in different way. It was prepared a solution; 10 g of *Moringa oleifera* were added to 100 mL of NaCl solution, so it was obtained an ionic solution. In other hand it was prepared an aqueous solution. The objective of these two solutions is to know how the best coagulant, the ionic or the aqueous one is. In order to have other coagulant's options, one way explored was the preparation of a coagulant after extracting the oil from Moringa by sohxlet extractor. In order to assess the effectiveness of the new coagulants, these were compared with the traditional coagulants used in the dewatering (Al_2SO_4 and $FeCl_3$).

2. Sludge dewatering

In experiments carried out, sludge depths of 10, 20 and 40 cm treated with different coagulants were tested using a sand column, Parameters like drainage rate, turbidity TS were used to assess the efficiency of the dewatering process. The process was not continuous.

2.1 Moringa without oil extract

2.1.1 Set 1 MO-NaCl

To evaluate the efficiency of the coagulation process by Moringa without oil extract mixed with NaCl, the drainage rate for different amount of coagulant in the sorption line were analysed, to compare the velocity of the sludge filtration. In Table 5 are shown the values of the drainage rate after 15, 30, 60 and 300 min, for the control and four concentrations studied. To more understand the efficiency of the coagulant, Figure 11 shows the values of drainage rate in function of the different coagulants' concentration. Also were measured the filtrate turbidity and total solids in the final cake.

To have a good dewatering and an efficient coagulant, we should have a low total drainage rate; in fact the sludge is dewatered in the column due to the action of the coagulant. Also the drainage rate should decrease along the dewatering process. Regarding the filtrate turbidity this should be low, it means that the sludge filtrate has small amount of suspended solids and colloids, and the solids are in the cake.

A higher sludge volume is used to confirm the results obtained with the other sludge volume. Table 6 contain the results of dewatering process with 20 cm of sludge; Figure 12 explain more the drainage rate in function of the 4 amount of 10% MO-NaCl. Table 8 shows also the results obtained with H sludge 40 cm.

Table 5: Results obtained with MO-NaCl (H sludge 10 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant dosage (mL $MO.L^{-1}$sludge)	Turbidity NTU)	TS ($mg.L^{-1}$)	TS (increase times)
Control	126	198	8
5	115	210	8
10	165	218	8
25	123	236	9
50	206	412	16

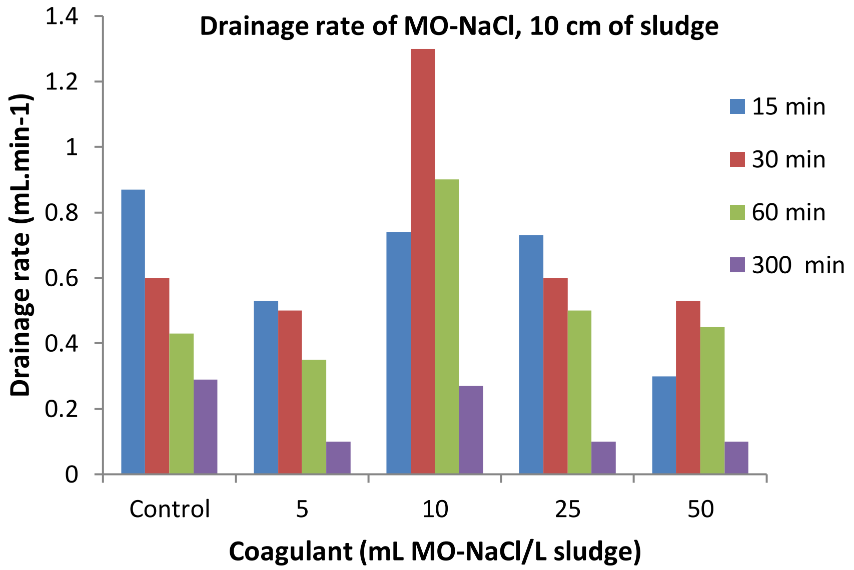

Figure 11: Drainage rate in function of different amount of MO-NaCl, H sludge-10 cm

Table 6: Results obtained with MO-NaCl (H sludge 20 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (MO) (mL MO.L sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase times)
Control	33	44	2
5	11	46	2
10	26	14	0.5
25	101	194	7

50	103	130	5

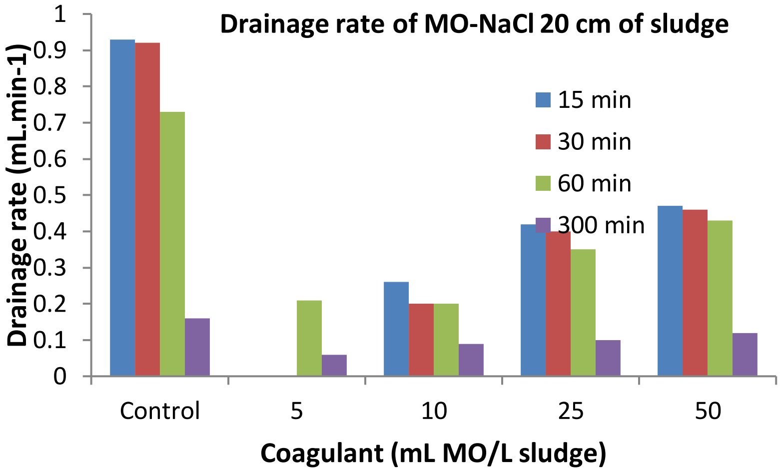

Figure 12: Drainage rate in function of different amount of MO-NaCl, H sludge-20 cm

Table 7: Results obtained using MO-NaCl (H sludge 40 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant(MO) (mL MO.L of sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase times)
Control	62	31	1
5	67	62	3
10	81	54	2
25	78	88	3
50	52	72	3

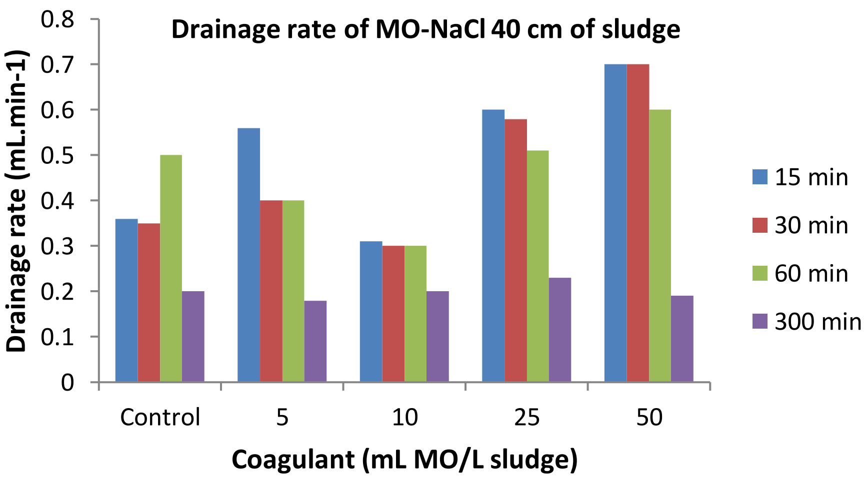

Figure 13: Drainage rate in function of different amount of MO-NaCl, H sludge-40 cm

In similar experiments of Muhammad Azroie [3] the turbidity decreased by 95% for a concentration of 50 $mL.L^{-1}$. In this study using *Moringa oleifera* as a coagulant and the same concentration, a turbidity decrease of 85% was attained for a sludge height of 40 cm (it ranged from 352 NTU to 52 NTU). The difference between these percentages can be explained due to the highest initial turbidity in [3].

In all experiments higher turbidity values were recorded for the higher concentrations of coagulant (25 and 50 $mL.L^{-1}$), compared to the control test (without addition of coagulant). Probably this increase in turbidity is due not only to suspended solids in sludge, but also to compounds released by Moringa. Set1-H sludge 20 cm, for control and 25 and 50 $mg.L^{-1}$ dosages were obtained turbidity values of 33, 101 and 103 NTU, respectively (Table 6).

About the total solids (TS), it is expected to be higher given that it refers to the solid concentration in the final sludge. In fact, when the sludge is well dewatered and the volume of sludge is small, the solids concentration in the cake increases. In experiment done with a sludge height of 10 cm, the concentration of TS increased from 8 to 16 times when the 10% solution MO-NaCl ranged from 5 to 50 $mg.L^{-1}$, and the best result obtained was 412 mg $TS.L^{-1}$ (Table 6). When the amount of sludge used in the experiment increases, 20 and 40 cm (Tables 6 and 7), the sludge thickening is not as effective. TS concentration showed a decreasing behaviour for height sludge of 20 and 40 cm (TS increases only 7,5 and 3,4 times).

According data in Tables 6-8, the drainage rate (DR) decrease along the process with all doses of 10% MO-NaCl, so this solution shows a dehydration action onto the sludge. This is supported by comparing the control and 50 $mg.L^{-1}$ samples (Table 5; H sludge -10 cm); when DR of control sample decreases from 0,87 to 0,29 $mL.L^{-1}$ during the period of 300 min, the DR with a coagulant dosage of 50 $mg.L^{-1}$ varied from 0,30 to 0,10 $mL.L^{-1}$. The addition of the coagulant shows a particle aggregation, which hinders the passage of the liquid fraction, leading to smaller values drainage rate over time. The results of the drainage rate show an adequacy of the sludge dehydration process using Moringa, consistent with several studies in the literature.

In conclusion, it should be noted that the Moringa solution (10% MO-NaCl) shows more satisfactory results with regard to sludge dehydration, for a lower sludge height (H sludge-10 cm), using a sand column.

2.1.2 Set 2 MO-H_2O

In Set 2 the process is similar like in Set 1, but using as a coagulant a different solution. Moringa without oil extract (10 g) was mixed with distilled water (100 mL) to prepare the solution. Drainage rate, TS and turbidity, for different coagulant dosage, were used to analyse the dewatering of a different volumes of a sludge (H sludge – 10, 20 and 40 cm), Tables 8 – 10. One better visualization of the drainage rate using 10% MO-H_20 as coagulant is represented in Figures 14, 15 and 16, for the three sludge height tested: 10, 20 and 40 cm, respectively.

Table 8: Results obtained with MO-H_2O (H sludge 10 cm, TS_0 26 mg.L^{-1}, $Turb_0$ 352 NTU)

Coagulant (MO) (mL MO.L sludge)	Turbidity (NTU)	TS (mg.L^{-1})	TS (increase times)
Control	126	27	1
5	173	29	1
10	201	28	1
25	203	95	4
50	197	50	2

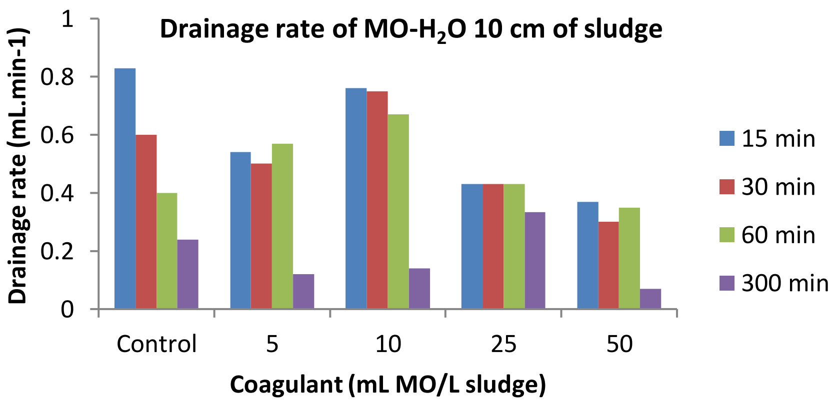

Figure 14: Drainage rate in function of different amount of MO-H_2O, H sludge-10 cm

Table 9: Results obtained by MO- H_2O (H sludge 20 cm, TS_0 26 mg.L^{-1}, $Turb_0$ 352 NTU)

Coagulant (MO) (mL MO.L sludge)	Turbidity (NTU)	TS (mg.L^{-1})	TS (increase Times)
Control	33	44	2
5	13	79	3
10	36	45	2
25	102	46	2
50	206	62	2

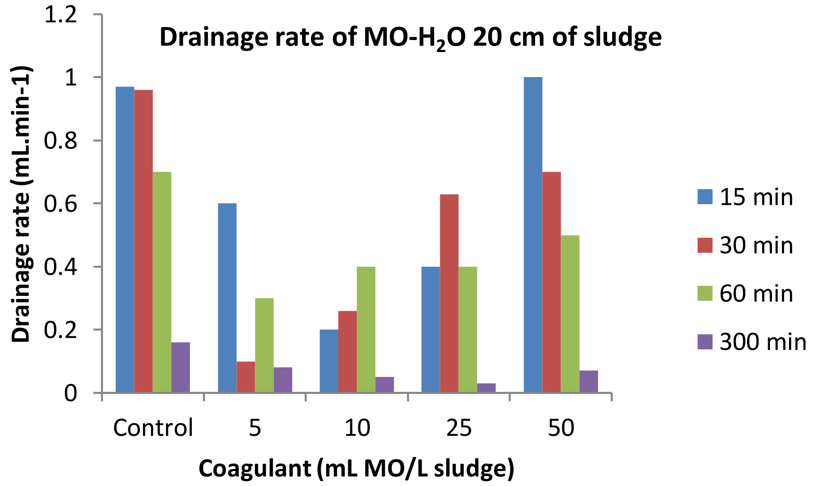

Figure 15: Drainage rate in function of different amount of MO- H_2O, H sludge-20 cm

Table 10: Results obtained with MO-H_2O (H sludge 40 cm, TS_0 26 mg.L^{-1}, $Turb_0$ 352 NTU)

Coagulant (MO) (mL MO. L of sludge)	Turbidity (NTU)	TS (mg.L^{-1})	TS (increase Times)
Control	62	176	1
5	68	35	1
10	72	19	1
25	102	65	3

50	56	81	3

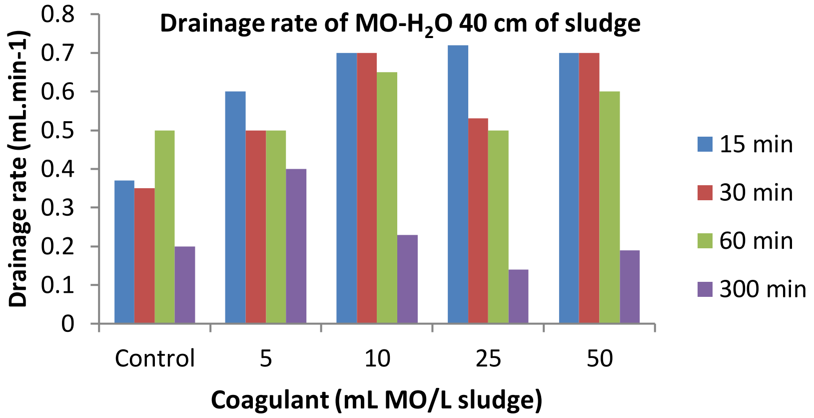

Figure 16: Drainage rate in function of different amount of MO- H_2O, H sludge-40 cm.

The behaviour observed, with this coagulant (solution of 10% MO-H_2O), is similar to that obtained in Set 1; drainage rate (DR) decrease during the period of 300 min (with some exceptions), according to what is expected in sludge dehydration by coagulants' addition (Tables 8-10; Figures 14-16).

According Table 8 and Figure 14 the lowest DR values are obtained for a dosage coagulant of 50 $mL.L^{-1}$ of sludge, they ranged from 0,37 to 0,07 $mL.min^{-1}$. Although these reduced flows, that doesn't correspond to the most effective dehydration process.

Once again, the filtrate turbidity values attained using dosage coagulant of 5, 10, 25 and 50 $mL.L^{-1}$ decreased significantly compared to the initial value (decrease of 44-51%). But, the reduction was more significant for the control sample, approximately 64%, which can be attributed to the release of compounds form the Moringa into the medium.

Regarding the solids content in the final sludge (TS $mg.L^{-1}$), the most satisfactory results were achieved for the lowest volume of sludge processed (H sludge – 10 cm), as found in the experiment with solution 10% MO-NaCl. So, a TS of 95 $mg.L^{-1}$ was obtained with a coagulant dosage of 25 mL 10%MO-H_2O, that represents an increasing of 3,7 times in solids content (Table 8).

Comparing the dewatering sludge process in Set 1 and Set 2, the solution prepared with Moringa in 1M NaCl showed more promising results. Starting from a sludge, solids concentration of 26 $mg.L^{-1}$, there was an increase in the amount of solids in the final sludge of 16 times (412 $mg.L^{-1}$), against the 3.7 times of coagulant 10%MO-H_2O. The extraction of compounds responsible for the coagulation process and consequent availability is more effective using ionic solutions.

2.2 Set 3 Moringa with oil extract

Set 3 is done after the extraction of Moringa oil with Soxhlet using the ethanol as an extraction agent during 6h. The efficiency of this extract in different concentration is shown in Table 11, 12 and 13 and Figure 17, 18 and 19.

Table 11: Results obtained with Moringa extract (H sludge 10 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (MO) (mL MO.L sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase Times)
Control	126	366	14
5	106	584	22
10	88	530	20
25	77	372	14
50	347	26	1

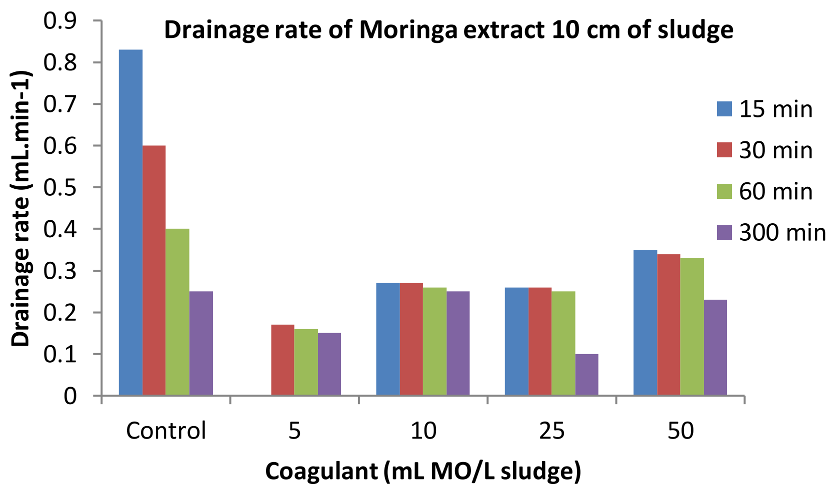

Figure 17: Drainage rate in function of different amount of Moringa extract, H sludge-10 cm

Table 12: Results obtained by Moringa extract (H sludge 20 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (MO) (mL MO.L sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase Times)
Control	33	44	2
5	199	130	5
10	30	224	9
25	83	142	6
50	86	160	6

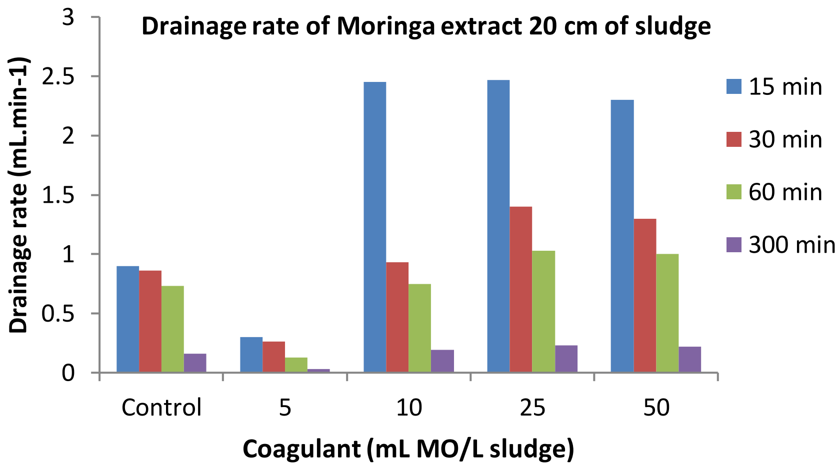

Figure 18: Drainage rate in function of different amount of MO extract, H sludge-20 cm

Table 13: Results obtained with Moringa extract (H sludge 40 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (MO) (mL MO. L of sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase Times)
Control	62	176	7
5	128	210	8
10	101	240	9
25	177	164	6

50	162	282	3

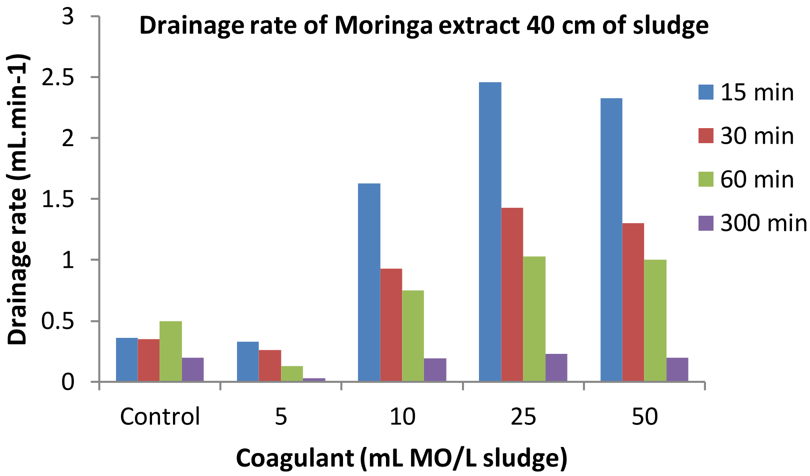

Figure 19: Drainage rate in function of different amount of MO extract, H sludge-40 cm

The behaviour of Moringa extract is similar to that obtained in Set 1 and set 2; drainage rate (DR) decrease during the period of 300 min without some exceptions. For all sludge volume and all doses of MO extract the DR decrease along all the process. So MO extract had a good efficiency in dewatering. And it can replace the chemical coagulant.

According Table 11 and Figure 17 the lowest DR values are obtained for a dosage coagulant of 25 $mL.L^{-1}$ of sludge, they ranged from 0,26 to 0,10 $mL.min^{-1}$. The downward trend of TS comparing that of 5 $mL.L^{-1}$ 372 versus 584 $mg.L^{-1}$ could be attributed to biological activity in the sludge and sand column.

Overall the dehydration action were achieved at both 5 and 10 $mL.L^{-1}$ M. oleifera doses. As both shows a low turbidity respectively and 106, 88.3 NTU respectively also a high TS 584; 530 $mg.L^{-1}$ respectively with H sludge 10 cm. So the experiment with other volume of sludge is primordial.

Once again, the filtrate turbidity values attained using dosage coagulant of 5, 10, 25 and 50 $mL.L^{-1}$ decreased significantly compared to the initial value decrease of 22% sludge H sludge 10 cm, 93% H sludge 20 cm and 29% 40 H sludge 40 cm. The upward trend for the turbidity with H sludge 20 cm (10 $mL.L^{-1}$) can be explained by the lowest concentration of Moringa. The average of turbidity deceasing is around 37.5%.

Table 12 gives that the concentration of 10 mL.L^{-1} had the lowest turbidity 30 NTU and high TS 224 mg.L^{-1} but the DR range between 2.45 and 0.19 the upward trend of DR could be because of the sand column.

From Table 13 with 10 mL.L^{-1} MO extract had the lowest the filtrate turbidity is 101 NTU but not lowest then the control and that can be due to the high concentration of NaCl. The TS increase by 9 times with 10 mL.L^{-1} MO extract. So, by comparing this result the best results is obtained with 10 mL.L^{-1} MO extract.

The TS increase average for all the doses and all the sludge height is around 9 times. Comparing the effect of using Moringa with sodium chloride and Moringa extract, we conclude that Moringa oil extract is better than Moringa in sodium chloride solution.

2.3 Chemical coagulant

2.3.1 Set 4 Al_2SO_4

For long time chemical coagulant shows a good efficiency in water dewatering; sulphate aluminium is the most common. Table 14, 15 and 16 refers to the value of the drainage rate in function of different concentrations of Al_2SO_4, the value of filtrate turbidity and the total solids of the final cake for 10, 20 and 40 cm height of sludge respectively .Figure 20 shows more the drainage rate values for each amount of coagulants. The results obtained in this experiment using chemical coagulants Al_2SO_4 with 40 cm of sludge are shown in the Table 17 and the drainage rate is explained more in the Figure 22**.**

Table 14: Results obtained with Al_2SO_4 (H sludge 10 cm, TS_0 26 mg.L^{-1}, $Turb_0$ 352 NTU)

Coagulant(Al_2SO_4) (mLAl_2SO_4.Lsludg)	**Turbidity (NTU)**	**TS (mg.L^{-1})**	**TS (increase Times)**
Control	126	212	8
5	263	226	9
10	103	214	8
25	31	246	10
50	24	336	13

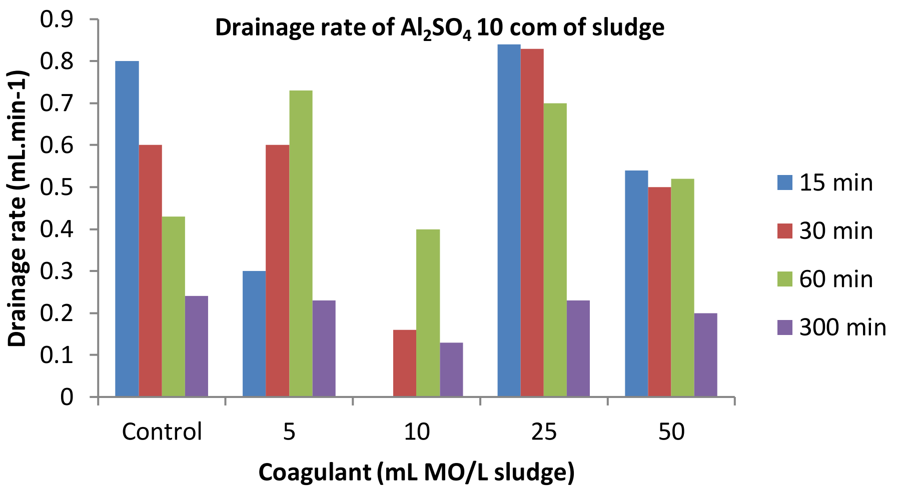

Figure 20: Drainage rate in function of different amount of Al_2SO_4, H sludge-10 cm

Table 15: Results obtained using Al_2SO_4 (H sludge 20 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (Al_2SO_4) (mL Al_2SO_4.L sludge)	**Turbidity (NTU)**	**TS ($mg.L^{-1}$)**	**TS (increase Times)**
Control	33	44	2
5	90	44	2
10	61	36	1.5
25	33	48	2
50	43	49	2

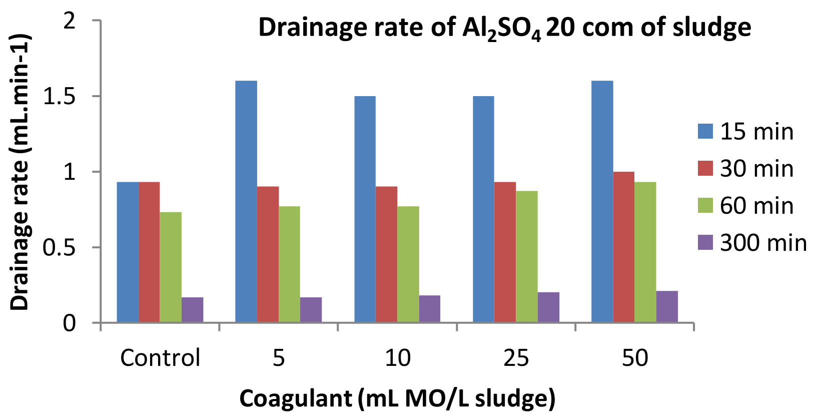

Figure 21: Drainage rate in function of different amount of Al_2SO_4, H sludge-20 cm

Table 16: Results obtained with Al_2SO_4 (H sludge 40 cm, TS_0 26 mg.L^{-1}, $Turb_0$ 352 NTU)

Coagulant (Al_2SO_4) (mL Al_2SO_4.L of sludge)	Turbidity (NTU)	TS (mg.L^{-1})	TS (increase Times)
Control	62	76	3
5	153	110	4
10	85	32	1
25	95	83	3
50	60	784	30

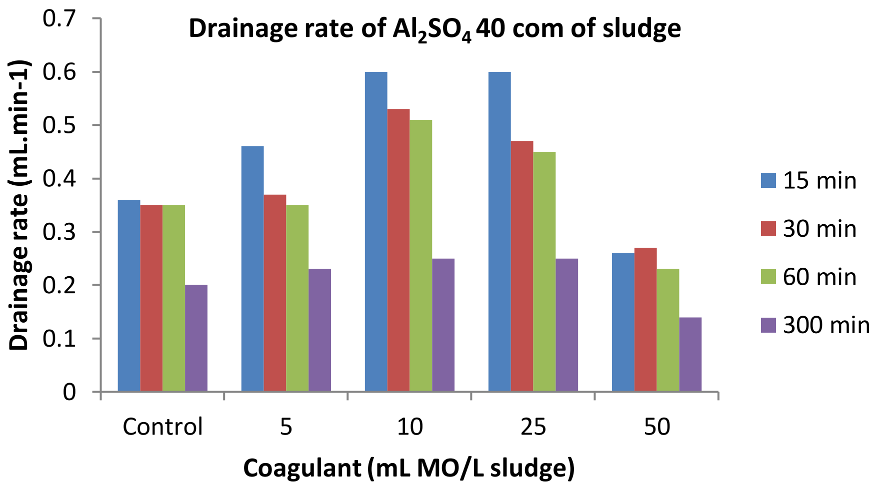

Figure 22: Drainage rate in function of different amount of Al_2SO_4, H sludge-40 cm.

For 10, 20 and 40 cm of sludge, Al_2SO_4 had the perfect dewatering results comparing to all the other solutions . According to the analysis of Table 14-16 and Figures 20-22 the perfect dose is 50 mL.L^{-1}of Al_2SO_4 with the lowest turbidity for the 3 height of sludge (except with 20 cm where the lowest turbidity is with 25 mL.L^{-1} it can be because of the high concentration of sodium chloride), 24.1 43 60 NTU respectively. Regarding the solids content in the final sludge (TS mg.L^{-1}), the most satisfactory results were achieved for 50 mL.L^{-1}of Al_2SO_4 with TS increase time ranged between 1.9 and 30.1; this last value is the highest increasing TS times with all solution.

According data in Tables 14-16, the drainage rate (DR) decrease along the process with all doses of Al_2SO_4, so this solution shows a good dehydration action onto the sludge.

The average of TS increasing with Al_2SO_4 is around 7 times taking into account the 3 sludge height and the 4 doses.

As shown in Table 14-16, at coagulants dosages up to 50 $mL.L^{-1}$ residual turbidities in the case of alum and Moringa are almost the same. It may be recalled that with an initial turbidity of 352 NTU the MO-NaCl and the extract Moringa were effective as coagulants as seen in Figure 11-13 and 17-19 but with an initial turbidity of 352 NTU, the dosage required for turbidity removal is 37.5 for Moringa extract and 24% with AL_2SO_4 higher for Moringa than for AL_2SO_4 ones. This is to be expected since Moringa extract had better action to the turbidity than the other solutions.

The volume of sludge produced is considerably less in case of Moringa than in case of alum. Using chemical coagulant shows good results of dewatering, however the biological coagulant show the same effect as the chemical one.

2.3.2 Set 5 Fe_2Cl_3

In set 5 Table 17, 18 and 19 refers to the value of the drainage rate in function of different concentrations of Fe_2Cl_3, the value of filtrate turbidity and the total solids of the final cake; for 10, 20 and 40 cm of sludge. Figure 20, 21 and 22 shows more the drainage rate values for each amount of chemical coagulants for 10, 20 and 40 cm sludge.

Table 17: Results obtained with Fe_2Cl_3 (H sludge 10 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (Fe_2Cl_3) (mL Fe_2Cl_3.L sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase Times)
Control	126	72	3
5	20	174	7
10	374	98	4
25	21	186	7
50	37	102	4

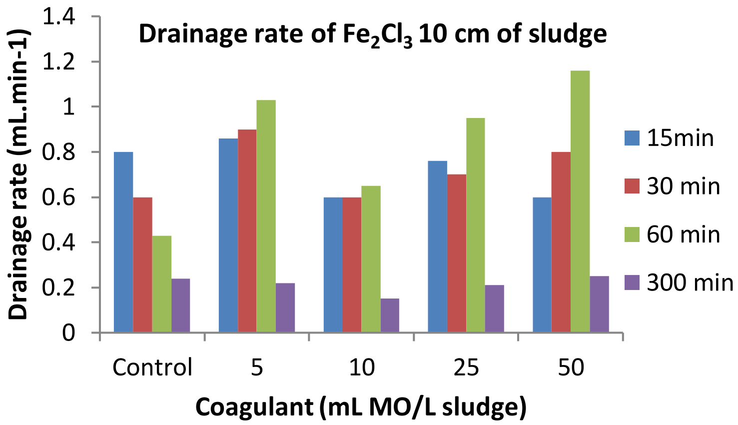

Figure 23: Drainage rate in function of different amount of Fe_2Cl_3, H sludge-10 cm.

Table 18: Results obtained using Fe_2Cl_3 (H sludge 20 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (Fe_2Cl_3) (mL Fe_2Cl_3.L sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase Times)
Control	33	44	2
5	102	42	2
10	62	46	2
25	95	50	2
50	53	13	0.5

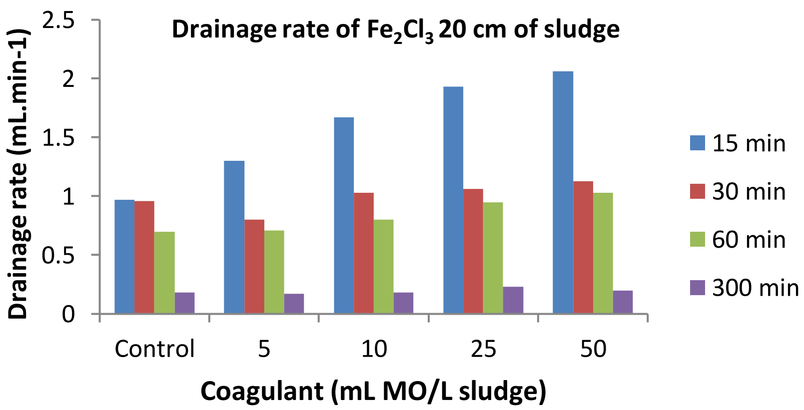

Figure 24: Drainage rate in function of different amount of Fe_2Cl_3, H sludge-20 cm.

Table 19: Results obtained with Fe_2Cl_3 (H sludge 40 cm, TS_0 26 mg.L^{-1}, $Turb_0$ 352 NTU)

Coagulant (Fe_2Cl_3) (mL Fe_2Cl_3. L of sludge)	Turbidity (NTU)	TS (mg.L^{-1})	TS (increase Times)
Control	62	76	3
5	120	62	2
10	135	72	3
25	62	262	10
50	92	240	9

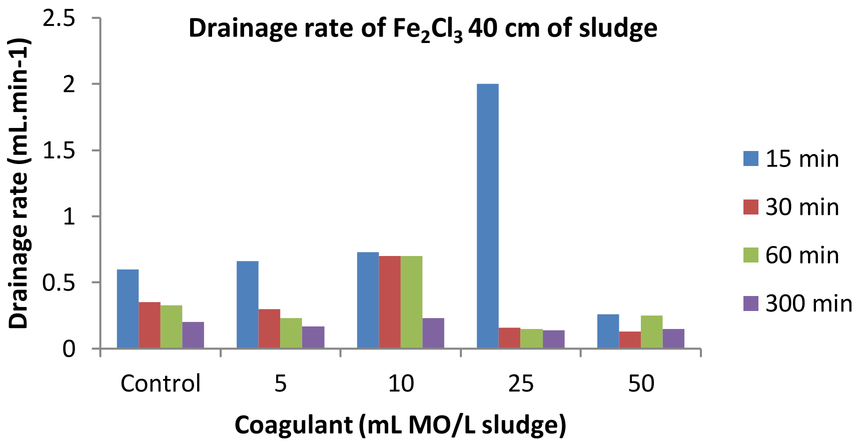

Figure 25: Drainage rate in function of different amount of Fe_2Cl_3, H sludge-40 cm

From Table 17 the best results of TS and turbidity is with 25 mL.$L^{-1}$of Fe_2Cl_3 186 mg.L^{-1} 21 NTU respectively.

According to the Table 18 the highest TS is for 25 mL.L^{-1} (50 mg.L^{-1}). In this concentration the turbidity is more and less low. So with H sludge – 20 cm the TS value and the turbidity value didn't match together, it could be because of the initial experiment condition.

The average of TS decreasing for all the doses and all the sludge high is 4.5% .This low percentage can because of a limit at the level of the reaction between Fe_2Cl_3 and the sludge.

By taking a look to Table 20, 25 mL.L^{-1} of Fe_2Cl_3 had the best effect with the highest concentration of solids around 262 mg.L^{-1}, the lowest turbidity of filtrate water around 62 NTU. But Al_2SO_4 is more efficient. Ferric chloride is far from being a good coagulant.

2.4 Set 6 Combined coagulants

In order to know the efficiency of combined Table 20, 21 and 22 refers to the value of drainage rate of different concentration of combined coagulants for 3 heights. Figure 26, 27 and 28 shows also the drainage rate in function of different amount of Bio-chemical coagulants in different way for the 3 sludge heights.

Table 20: Results obtained with combined coagulants (H sludge 10 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (Al_2SO_4+MO) (mL Al_2SO_4+MO.L sludge)	Turbidity (NTU)	TS ($mg.L^{-1}$)	TS (increase Times)
Control	126	76	3
5 + 5 MO-NaCl	24	263	10
5 + 50 MO-NaCl	36	130	5
50 + 5 MO-NaCl	5	320	12
50 + 50 MO-NaCl	9	282	11
5 + 5 MO-H_2O	37	167	6
50 + 50 MO-H_2O	42	203	8

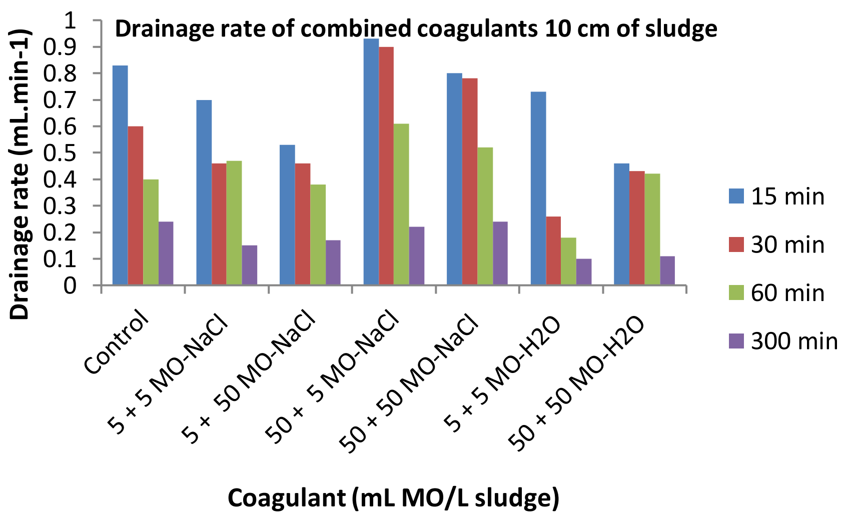

Figure 26: Drainage rate in function of different amount of combined coagulants, H sludge-10 cm

Table 21: Resuls obtained using combined coagulants set 6 (H sludge 20 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (Al_2SO_4 –MO) (mL Al_2SO_4 –MO .L sludge)	**Turbidity (NTU)**	**TS ($mg.L^{-1}$)**	**TS (increase Times)**
Control	33	44	2
5 + 5 MO-NaCl	53	16	1
5 + 50 MO-NaCl	102	26	1
50 + 5 MO-NaCl	52	52	2
50 + 50 MO-NaCl	53	24	1
5 + 5 MO-H_2O	203	52	2
50+ 50MO-H_2O	53	13	1

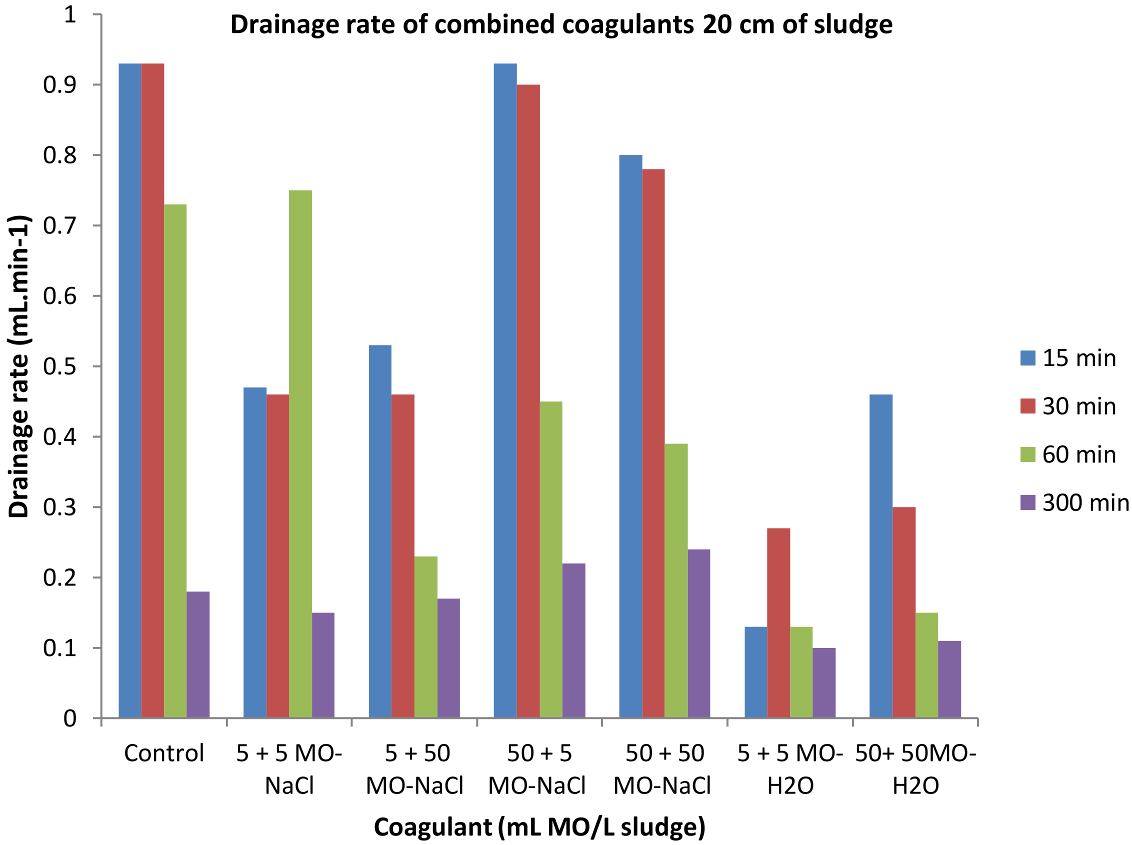

Figure 27: Graphic of drainage rate in function of different amount of combined coagulant, H sludge-20 cm.

Table 22: Results obtained with combined set 6 (H sludge 40 cm, TS_0 26 $mg.L^{-1}$, $Turb_0$ 352 NTU)

Coagulant (Al_2SO_4 –MO) (mL Al_2SO_4 –MO .L sludge)	**Turbidity (NTU)**	**TS ($mg.L^{-1}$)**	**TS (increase Times)**
Control	61.9	176	7
5 +5 MO-NaCl	56.3	182	7
5 + 50 MO-NaCl	58	162	6
50 + 5 MO-NaCl	102	286	11
50 + 50 MO-NaCl	93	236	9
5 + 5 MO-H_2O	84	150	6
50 + 50 MO-H_2O	43	175	7

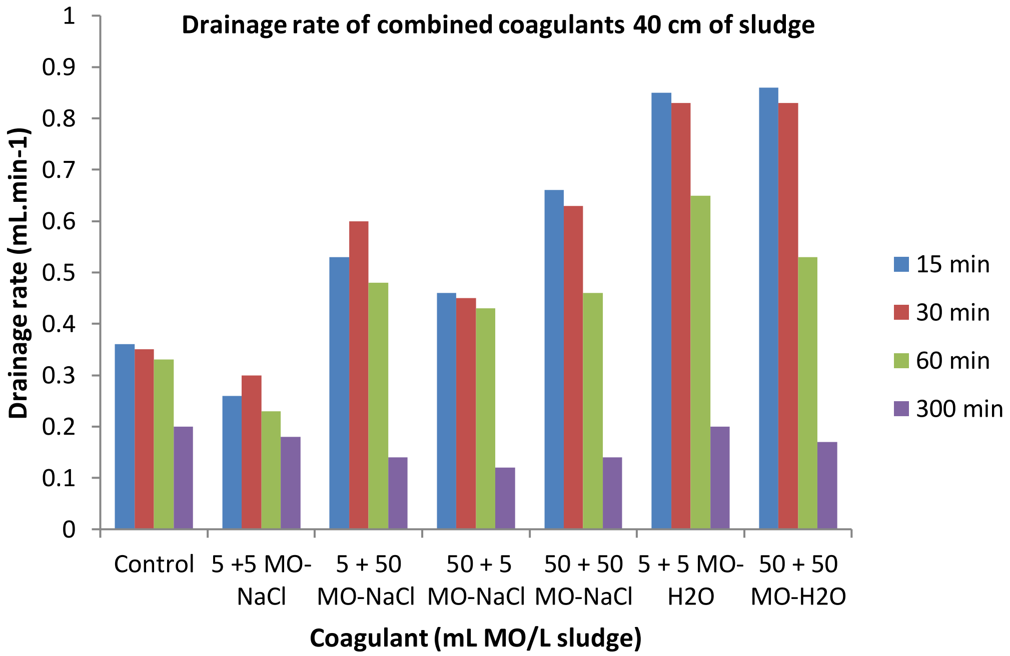

Figure 28: Drainage rate in function of different amount of combined coagulant, H sludge-40 cm

By combining chemical coagulant and bio-coagulant we obtain a good coagulant effect, the most efficient combination for H sludge – 10 cm is Al_2SO_4 50 $mL.L^{-1}$+ MO-NaCl 5 $mL.L^{-1}$ with a TS value around 320 $mg.L^{-1}$, turbidity value around 5.4 NTU.

From Table 21 the better results are obtained with the concentration of 50 $mL.L^{-1}$ Al_2SO_4 + 5 $mL.L^{-1}$ MO-H_2O with 52 NTU and 52 $mg.L^{-1}$.

Comparing the different results obtained with sludge – 40 cm the combination of Al_2SO_4 50 mL.L^{-1} + MO-NaCl 5 mL.L^{-1} is the optimum results of dewatering with; 102 NTU and 286 mL.min^{-1}. From set 6 the most efficient combination in dewatering is Al_2SO_4 50 mL.L^{-1} + MO-NaCl 5 mg.L^{-1}.

From all the experiment done the extract of Moringa with the ethanol had an amazing dewatering effect for sludge since it increases the TS in the final cake around 20 times. And it can be better then Al_2SO_4 with increase the TS in the final cake by 25 times; especially by looking for the environmental damage done with chemicals.

Conclusion

Experiments about dewatering sludge was done and some solutions MO-NaCl 10%, MO-H_2O 10%, Moringa extract, Al_2SO_4, Fe_2Cl_3 and different combination between natural and chemical coagulants were used. For each solution we test 3 heights 10, 20 and 40 cm using a sand column. The best results were obtained with 5 $mL.L^{-1}$ of Moringa extract with increasing TS by 20 times and a good reduction of turbidity from 352 NTU to around 130 NTU.

In another hand, the use of *Moringa Oleifera* seed oil is a good solution to diel with the sludge dewatering. In fact, when *Moringa oleifera* is compared with conventional chemical coagulants, in fact with MO-NaCl TS concentration showed a decreasing behaviour for height sludge of 20 and 40 cm and achieve an important % of TS increasing like 16 and 7.5 times. And the turbidity decrease in a good way with different doses, especially with H-sludge 40 cm around 81-52 NTU. For Moringa extract the TS concentration showed a better behaviour especially with height sludge of 10 cm and achieves 22 %. Comparing with sulphate aluminium that shows a high dehydration action with 10 cm of sludge with TS concentration around 8.2-13 times. According to Fe_2Cl_3 the TS increase with 40 cm height of sludge from 2.4 to 9.2 times.

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