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An-Najah National University

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Graduation Project

"Evaluation of Coagulation Efficiency of Moringa Oleifera for Quarry Water Treatment"

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Abstract

Moringa Oleifera is a highly valued plant that is distributed in the tropics and subtropics areas. It had an affirmed importance in food and pharmaceutical industries. Presently, it is considered as an alternative and safe natural coagulant instead of synthetic ones such as Aluminum Sulfate (Alum), which leaded to further related problems such environmental, disposal issues and related health effects despite its approved coagulation efficiency.

The objective of this project was to exploit Moringa Oleifera coagulation activity in reducing the turbidity of quarry's (cutting stone) water to be reused in stone's washing. That was achieved by conducting simple pre-experiments to evaluate the coagulation efficiency of Moringa seeds and dry pods, moreover jar test analysis were applied to determine the optimum dosage of Moringa in comparison with Alum. Moringa samples were tested at two forms; directly without any treatment and extracted in Sodium Chloride solvent (NaCl). Results have shown that extracted Moringa samples had a significant coagulation activity compared with non-treated ones. On the other hand, Moringa seeds efficiency had overpassed dry pods achieving final turbidity value of 31.5 NTU with 0.6 g/L optimum dosage in a period of one day. Moreover, the turbidity removal resulted by extracted Moringa seeds was 70.2% and 71.4% for Alum at the optimum dosage. That approved the convergent coagulation activity of extracted seeds with Alum. The evaluation of Moringa coagulation activity was also applied in high turbid alimentary solution such Aloe Vera juice clarification in non-treated forms. Results have shown a turbidity reduction of 60.4% for the seeds and 30.9% using dry pods. That gave an indication that Moringa works better at high initial turbidity values. It was recommended to use Moringa seeds in a defatted form to avoid the increasment of organic load during sedimentation.

Due to the various applications of Moringa, it was needed to apply a preservation method to keep its nutrients and make it available in its off seasons. Drying was applied on Moringa leaves at ambient temperature and at a range of (55-60) °C. Drying dynamics were studied by identifying the constant rate and falling rate drying periods. Results have shown that drying rate was higher at higher temperatures with shorter drying time of 2.5 hr. where four days were needed at ambient temperature. What's more, drying rate values were higher at constant rate period with shorter time than falling rate period at both experiments. However, Physical changes were observed and it was found that color remained unchanged but the bulk density decreased.

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Nomenclature

kg	Kilogram
g	Gram
L	Liter
Hr.	Hour
Min	Minute
M	Meter
kDa	Kilodalton
°C	Celsius
NTU	Nephelometric Turbidity Unit
pI	Isoelectric Point
$Al_2(SO_4)_3.16H_2O$	Aluminum Sulfate Hexadecahydrate
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
CWE	Coagulation-Water Extraction
CSE	Coagulation-Salt Extraction
SODIS	Solar Water Disinfection

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1 Chapter One: Introduction

1.1 Background

Moringa Oleifera belongs to the monogegeniric family "Moringaceae", it grows in tropical and subtropical areas where the native origin is in India. It is planted in Pakistan, Afghanistan, Bangladesh and the tropical Africa region. Moreover, it grows in farms or in the gardens of the house where it has a breathtaking view. Among the years, Moringa was used in many countries as a useful meal food or as a medicine (Haouvang *et al*., 2017).

Moringa trees are planted at a temperature range of (25-30) °C in a sandy or clay soil (low pH) with moderate rain fall. The seeds grow at a high rate of (5-120) days. Several factors affect the growth of Moringa such as temperature, type of fertilizer and soil condition. However, the quality of the nutrients and vitamins in matured Moringa parts vary depending on the planting country (Gopalakrishnan *et al*., 2016).

Moringa cultivation started few years ago in Palestine, where some people have a knowledge about its miracle benefits and started to planting this tree, one of them was Engineer Nasser Jaradat from Jenin who aimed to use this plant in tea bags or tablets to cure diabetes. Moreover it was successfully cultivated by Dr.Husni Odeh who studied the basic and exact requirements of planting Moringa and its further applications. It should be known that Moringa is somehow suitable to be cultivated in Palestine since it adapts to the mountainous areas and the amount of rain is enough for its growth. However, the growth process of Moringa is continuous throughout the year and Moringa is considered the most rapidly growing tree in the world.

Moringa has several names such as: radish tree, miracle tree, in Palestine it is called the tree of life, the tree of mercy. The reason of giving this plant such names that each part has different and valuable benefits that can be used in different applications, for example the leaves contain more vitamin A than carrots, more calcium than milk, more iron than spinach, more vitamin C than oranges and more potassium than bananas. Moreover the quality of protein in Moringa leaves is better than that in milk and eggs and it is considered as a significant source of beta carotene (Fahey, 2005)(Umar *et al*., 2015). Additionally, Moringa leaves act as a good source of natural antioxidants (Anwar *et al*., 2007).

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The seed oil of Moringa is considered as possible alternative of expensive olive oil after modifications, since it contains all main fatty acids. Moreover, it contains behenic acid ($C_{22:0}$) and lignoceric acid ($C_{24:0}$) (Abdulkarim *et al*., 2005).

Due to the exitance of the mentioned valuable benefits of each part in Moringa, some preservation methods were applied to keep its numerous nutrients such as salting, balancing, soaking and drying (Mbah *et al*., 2012). Drying is considered as the most known processing technique of herbs that provides the existence of transport mechanisms such as surface diffusion, pure diffusion, capillary flow, evaporation, thermo-diffusion, etc. It can extend herbs' shelf life, make them available even in off-season, minimize their weights and so make them easy to transport and storage. Moreover, it helps to reduce herbs moisture content and so minimize the growth of pathogens (Umar *et al*., 2015). Many conventional drying methods were used such as air flow drying, sun drying, shaded drying, oven drying, freeze drying and microwave drying. Each method differs by its drying rate, drying time, quality of the desired product and herbs' nutrient content after processing (Dev *et al*., 2011). However, many factors affect dried herbs' nutrient content such sensitivity of the plant to light, heat and oxygen (Umar *et al*., 2015). Many researches have been conducted to study the nature of the drying kinetics and its effect on the chemical, physical and nutritional composition of the processed plant (Satwase *et al*., 2013).

In addition of using Moringa as a food commodity, it has been used for medical purposes, including lowering blood pressure, controlling diabetes, regulating blood sugar levels, increasing breast milk production and can be used to prevent certain diseases such as cancer and heart disease, also it helps preventing the formation of kidney stones (Bk, 2017). However, Moringa can be used in the manufacturing of household detergents, perfumes and fertilizers (Alegbeleye, 2017). One of the most useful application of Moringa Olefiera is its effective contribution in water turbidity removal (Katayon *et al*., 2006).

Worldwide, about 1.1 billion people are suffering from lack of abundant and safe water supplies (Programme and UN-Water, 2009) since the access to clean and safe water is considered as a crucial issue. For that further treatment processes were applied to enhance the effluent's quality. One of the most helping process is coagulation; a chemical process that provides neutralization of suspended particles to be clumped together to form larger particles that are easy to be removed. This is achieved

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by adding chemical components called coagulants, which are applied to remove turbidity, color and organic matter. They are classified into inorganic and synthetic organic polymers. Inorganic coagulants such as Aluminum Sulfate (Alum) are considered the most well-known and used coagulant type. However, one of the related problems of this type is the formation of inorganic sludge which can lead to disposal problems in addition to the induce of Alzheimer disease. "*Whereas synthetic organic polymers such acrylamide have neurotoxic and carcinogenic effects*" (Muthuraman and Sasikala, 2014). The effective solution to these problems was to use natural coagulants such as Moringa Oleifera which can be considered safe for human health and can minimize the high operational costs of water treatment (Nkurunziza *et al*., 2009).

Coagulation properties of Moringa were first discovered in 1981 when a woman in Sudan had used its seeds in clarifying and removing the turbidity of Nile water samples, since then Moringa Oleifera was used as a natural coagulant or as a disinfectant to clarify water for drinking or industrial usage (Nkurunziza *et al*., 2009). It was found that seeds are the most effective part of Moringa acting as a coagulant, thus that relates to the presence of dimeric cationic proteins with a molecular mass of 12-14 kDa and an isoelectric point (pI) between 10 and 11, these proteins are thermoresistance and could be kept active after 3 hrs. of treatment at 95 °C (Ghebremichael *et al*., 2005). However, different pre-treatments methods such as extractions experiments; salt extraction and Soxhlet extraction can be applied to enhance the coagulation activity of Moringa or separate the oil from the seeds (Okuda *et al*., 1999). In addition of considering Moringa as a natural, safe and inexpensive coagulant, its resulted sludge can be used as soil improver when it is applied in sewage treatment (Feria *et al*., 2016).

1.2 Problem Statement

As it was mentioned, Alum is the most well-known synthetic coagulant that have been used to clarify turbid water. However, several serious drawbacks were appeared related to using this coagulant, thus in drinking water clarifications, it causes Alzheimer. Moreover, it was proven its reaction with alkalinity present in treated water which leads to reduction in water pH values (Katayon *et al*., 2006). What may concerns more is the formation of large volume of sludge which causes disposal and environmental problems. Due to these obstacles, Moringa Oleifera was used as an effective and safe alternative coagulant (Muthuraman and Sasikala, 2014).

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Due to the medical values and numerous applications of Moringa Oleifera and because of its low availability in Palestine, there was a need to preserve this plant by drying to make it available even in its off seasons and so conduct the dried samples in coagulation experiments.

1.3 Objectives

The objective of this project was to reduce the turbidity of quarry's water, to be reused in the stones' cutting process and to supply workers with their need of water for daily use, using the treated quarry's water limited by a specified target. This was hoped to be achieved by using Moringa Oleifera as a natural coagulant and finding the optimum values that give the best turbidity removals. Moreover, it was aimed to study the coagulation efficiency of Moringa different parts comparing with Alum in amount and time needed. Likewise, the efficiency of Moringa in juice clarification was studied. On the other hand, the effect of drying process on the physical appearance of Moringa and drying dynamics were aimed to be evaluated at different temperatures and so to find the related constant drying and falling drying equations. This process was important and prior to the coagulation experiment since grinded and dried powder was used.

1.4 Scope of the Work

This study was found to evaluate the coagulation efficiency of Moringa seeds and dry pods in quarry's water purification in Nablus and Aloe Vera juice clarification, by using jar test apparatus to find the optimum dosages needed in comparison with Alum. Moreover, turbidity meter was used to help measuring the reduction in turbidity. However, drying experiments were applied at Moringa leaves using shaded and convection heat drying methods.

1.5 Importance of the project

As it is well known, Palestine suffers from abundant water supplies and so reusing the treated stone cutting water can contribute to solve this problem in a small scale. Moreover, using Moringa Olefiera as a natural coagulant is considered inexpensive and safe. Where the sludge formed from the coagulation process can be separated and the resulted $CaCO_3$ cake can be reused in bricks manufacturing without any environmental concerns.

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For the drying experiment, the shelf life of Moringa powder can be extended with less growth of pathogens by drying. It can be used for different applications such as healing, nutrition or coagulation. Therefore the knowledge of drying kinetic ads new value to this research.

1.6 Constrains and Engineering Standards

Coagulation in water treatment process is constrained by limitations which aim to keep the quality of resulted water. The selected coagulant is confined with the volume of the produced sludge and its nature, for example; if it is hazardous or needs costly disposal operations. Moreover, the amount of used coagulant is considered a substitutional concern in water clarification. In case of using Moringa Oleifera as a coagulant, larger dosages lead to over dosing and reversal of its cationic charge which is the main cause of its coagulation efficiency, that results in increasing of residual turbidity (Muyibi and Evison, 1995). However, Coagulation process was applied based on jar test analysis standards with the selected speeds and time (SNF, 2020).

The working conditions at the second half of the spring semester halted the laboratory work. This directed the research towards more theoretical analysis of the experimental work.

1.7 Organization

This project is divided into different chapters. A brief background about Moringa Oleifera and its various applications, objective and scope of our work were presented in the introduction chapter. Second chapter illustrates previous studies on drying dynamics of Moringa leaves and the related applied methodology in this work. Likewise, Chapter four lighten on coagulation studies of Moringa Oleifera and the selected methodology. Experimental work that was applied by group members is presented in chapter five. Additionally, the results are explained and discussed in chapter six. Finally, conclusion and recommendations were given in the last chapter.

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2 Chapter two: Drying of Moringa Leaves

2.1 Literature Review

- **Determination of the drying kinetics of Moringa Oleifera and effective parameters.**

(Premi *et al*., 2010) have conducted an experiment to investigate the drying behavior of Moringa Oleifera and the suitable model to describe the drying kinetics. 50 g of Moringa leaves were collected and placed in a thin layer of electric convective dryer. The process was accomplished at four different temperatures 50, 60, 70 and 80 °C at a constant air velocity of 0.5 m/hr. Leaves were continuously dried until it reached a constant weight at 3% moisture content. Air drying curves were fitted using different mathematical models versus different moisture content values. Results have shown that the constant drying was absent and the drying process was done in the falling period. Moreover, drying rates have decreased with increasing drying period. However, it was found that air temperature was considered as an effective parameter as when it increased, drying rate increased and moisture content decreased. In the other hand, at high moisture contents values, temperature has higher effect on drying rate. Moreover, an evaluation of leaves color was evaluated, it was found that optimum values of samples' color were gained at 60 °C with less color degradation than other temperature.

- **Comparison between different drying methods of Moringa leaves.**

A study was conducted in Nigeria to compare between four drying methods; freeze drying, sun drying, oven drying and shaded drying related to fresh leaves and to evaluate the proximate and mineral content of Moringa after drying. Moringa leaves were collected mature, healthy away from insects, they were washed with water, air dried and then weighed. The resulted Moringa samples were divided into 5 portions. In sun drying, leaves were placed on a tray covered with net for 7 days in the morning period exposed to sunlight. For shaded drying, the leaves were kept on a well ventilated place at room temperature. However, oven drying was applied by pre-heating at 60 °C and then leaves were exposed to heat for 4 hrs. The last method was freeze drying, in which samples of 15 °C were dried for 6 hrs. at a condition temperature of -60 °C. Results have shown that protein and carbohydrate contents increased with drying and they were maximized using freeze drying. Whereas fat content decreased with drying to achieve a minimum value using freeze drying. Moreover, Fiber content was duplicated using all methods. The same situation was with elemental content and it was proved that freeze drying was the best drying method but the most expensive one (Umar *et al*., 2015).

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Other comparison study was applied by (Foline *et al*., 2011), in which 300 g of Moringa leaves were collected and divided into 3 parts for each method; Sun drying, air drying and multipurpose drying (enclosed drying device at 50 °C). Drying mechanism was applied until it was reached a constant weight of Moringa samples and then kept at (30-37) °C. Results have shown that protein content increased with drying process and it was maximized using air drying where it recorded lower values using sun drying. There were no difference in pH and fiber contents using the three methods. However, microbiology existence was evaluated and it was found that multipurpose drying had the lowest values where it was higher using air drying. It was concluded that air drying is the best method to keep the nutrients but multipurpose drying was more suitable to lower the microbial growth.

(Mbah *et al*., 2012) have studied the effect of sun drying, shaded drying and oven drying on proximate evaluation and antinutrients composition of Moringa leaves. Leaves were collected fresh and undamaged, cleaned, weighed and then applied to the three methods. In sun drying, leaves were placed on a cotton cloth and exposed to sunlight for 4 days. Where they were placed in a well ventilated place for 6 days in the shaded way. For oven drying, forced air was used at 60 °C for 4 hrs. Results have proved that protein, fiber and carbohydrate contents were increased where fat content was decreased. For antinutrients composition, it was found that drying decreased the oxalate content and oven drying had the lowest percentage.

2.2 Material and Methodology

Moringa Oleifera fresh leaves were gathered in a dry form and applied into two experiments with different initial weights and temperatures at 60% humidity. In the first part, 500 g of fresh leaves were exposed to the ambient air temperature (T= 20-22) °C at a well ventilated room shaded from the sunlight and dust using (0.09) m^2 drying plate. Where in the second part, 200 g of fresh leaves were weighed using a balance with 0.01 resolution, distributed on (0.0177) m^2 drying plate. Hot air (T= 55-60) °C was applied using convection heat. Thermometer was used to measure both temperature and humidity values. The loss in weight was observed with time (hr.) by identifying the difference in moisture content using the following equation :

$$Xt = \frac{W - W_s}{W_s} \qquad (2.1)$$

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Where :

Xt: Moisture content in ($\frac{kg\ moisture\ content}{kg\ dry\ solid}$).

W: Total weight of the wet solid in (kg).

W_s: Weight of dry solid in (kg).

Since the free moisture content (X) equals the difference between actual moisture content (X_t) and equilibrium moisture content (X^*), a plot of free moisture content (X) versus time (t) was conducted. The slopes of the curve at any point (dx/dt) were measured as drying rate . Drying rate in common is given by the following equation:

$$R = \frac{-L_s}{A_s} * \frac{dx}{dt} \qquad (2.2)$$

Where :

R: Drying rate in ($\frac{kgH_2O}{h.m^2}$).

L_s: Weight of dry soild in (kg).

A_s: Area of the drying plate in (m^2).

Both constant rate and falling rate regions were identified on the curve and falling rate equation was measured. Moreover, the physical changes during drying were observed. Knowing that the experimental part of this section was done by Dr Husni Odeh in the Chemical Engineering laboratory.

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3 Chapter Three: Coagulation Experiments

3.1 Literature Review

As it was mentioned before, Moringa Oleifera has a high coagulation efficiency because of its protein content. Many experiments have been established to study the nature of the protein content in Moringa Oleifera. (Santos *et al*., 2009), have worked on isolation of protein from different parts of this plant. They found that seeds have the highest protein content of 4.9 mg/L, where 1.7 mg/L for stream bark. However, leaf tissue had the lowest content of 1 mg/L.

According to such studies, Moringa Oleifera had been used in different coagulation and flocculation applications, either in water treatment or juice purification techniques. The predominant used part was the seeds because of the high protein content.

3.1.1 Water treatment

- **Evaluation of Moringa Oleifera turbidity removal and related parameters.**

(Nkurunziza *et al*., 2009) have worked on water treatment in Rawanda rivers by using natural coagulant such as Moringa Oleifera. They determined the influence of the initial turbidity values and Moringa oleifera dosages on the turbidity removal percentage. Seeds were shelled and dried, they were applied as a powder in 1 µ NaCl solution. Jar test technique was used for both low range turbidity (50 NTU) and high range turbidity (450 NTU). Turbidity meter was applied to measure the difference between the initial and final values of tested water. They found that as Moringa Oleifera concentration increased, the turbidity removal increased. Moreover, Moringa worked better at high initial turbidity values with percentage removal of 99.8% at 450 NTU and 83% at 50 NTU, that could be explained by the absence of enough particles to create nuclei for flocs formation at low initial turbidity values. In addition they have discovered that as Moringa concentration increased, color, Iron and Manganese removals increased. Where it had no effect on pH value of treated water and so the hardness content, where using Alum reduce the value of pH which resulted in increasment in the dosage.

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- **Evaluation of the optimum effective storage conditions and process's parameters.**

Many efforts were experienced to study the conditions that may affect the Moringa Oleifera efficiency as a natural coagulant. (Katayon *et al*., 2006) have studied the suitable storage conditions of Moringa Oleifera and their effect on its coagulation activity. Seeds powder were diluted in distilled water to extract the coagulant molecules. Synthetic water was prepared by kaolin suspension at three turbidity ranges; low to medium (50 NTU), high (100-200) NTU and very high (greater than 300 NTU). After jar test was applied, one beaker was left opened where the other was closed for one, three and five months at two values of temperature 28 °C and 3 °C. Results have shown that turbidity removal was independent of storage temperature and the container status, however it decreased with increasing storage periods. In addition to that, Moringa Oleifera worked better at higher turbid water.

Another study was accomplished to determine the parameters that can affect the coagulation efficiency of Moringa. University of Newcastle conducted an experiment to study the effect of physical parameters such as mixing speed, mixing time, Moringa dosage and initial turbidity values on the turbidity removal and the optimum values for each. Moringa seeds were extracted in distilled water and then applied to jar test analysis, mixing speed was calibrated by custom made paddle in a buffered beaker. Results showed that the optimum dosage of Moringa was 50 mg/L for low (50-150) NTU and high (250-550) NTU ranges of turbidity. In addition to that optimum values for rapid mixing speed and time were found to be 432 round/s and 1 minute at low turbidity ranges, where 443 round/s and 4 min at high ranges. Optimum values for slow mixing speed and time were similarly recorded at 149.9/s and 20 min for low turbidity values and 208.5/s and 25 min for high ranges (Muyibi and Evison, 1995).

- **Comparison between different natural coagulants efficiency and different extraction solvents.**

(Asrafuzzaman *et al*., 2011) have optimized a study to reduce turbidity and bacteriological levels of water by using three natural coagulant plants; Moringa Oleifera, Cicer arietinum and Dolichos lablab and then using the treated water at household applications. Synthetic water was prepared and 1% suspension of all plants in water was made. Jar test in a batch style was conducted at different initial turbidity values. The coagulation efficiency for each plant was measured by applying the turbidity meter before and after coagulation. It was found that Cicer arietinum had the highest coagulation

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efficiency with 95.8% at high turbidity values which is the same percent as Alum. Where Moringa gave the highest coliform removal of 96%.

Another comparison study was done by (Muthuraman and Sasikala, 2014). They have conducted an experiment to compare the coagulation efficiency between Moringa Oleifera, Strychnos potatorum and Phaseolus vulgari using three different solvents; NaCl, Sodium Hydroxide (NaOH) and distilled water. Seeds were prepared into a powdered form, extracted using the three mentioned solvents and then applied to jar test apparatus. To measure the turbidity removal, settling column test was conducted at optimum dosages and fixed time. It was found that Moringa gave the highest turbidity removal and NaCl solvent extracted the largest amount of the coagulant. Several parameters in addition to turbidity removal were measured such as pH value, dissolved oxygen, water conductivity, sulphate and chloride concentration.

(Ghebremichael *et al*., 2005) have designed an experiment to compare the coagulation efficiency of Moringa Oleifera by using NaCl and distilled water as solvents for coagulant extraction and so compute the protein concentration in each. Seeds were oily extracted by using 95% ethanol solution, dried and filtered. 5% (w/v) samples were prepared from the dried solids by using distilled water coagulation extraction (CWE) and 0.5 µ NaCl coagulation extraction (CSE) solvents. Moreover, aqueous Alum was prepared as a 5% (w/v) solution, all solutions were applied into jar test. The results showed that CSE had a higher coagulation activity assay than CWE due to the formed precipitants of NaCl when mixed with treated water which results in nuclei particles that supports flocculation process. However, the experiment showed that CWE had the same coagulation efficiency as Alum at high turbid water.

- **Comparison between coagulation efficiency of defatted and non-defatted Moringa seeds' powder.**

(Garcia-Fayos**,** B *et al*., 2016) have noticed the significant increase in treated water's organic load when using Moringa Oleifera as a coagulant because of its oily seeds' content. So they have conducted an experiment to study the effect of using defatted seeds on coagulation activity and compare it with non-defatted ones. Three different solvents were used; hexane, acetone and ethanol by using two extraction methods; batch and Soxhlet. In batch extraction, 5 g of seeds were stirred in each solvent for 30 minutes, the supernatant layers were centrifuged and then filtered. The experiment was

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reconducted by using Soxhlet extraction. Both non defatted and defatted seeds' powders were then stirred in distilled water to extract the coagulant and then applied to jar test apparatus. Results showed that defatted seeds gave higher turbidity removal of 88% where 30% for non-defatted ones. Soxhlet extraction gave the higher oil extraction percentage. However, all three solvents gave the same protein content but ethanol gave the smallest optimum Moringa dosage.

Another study was conducted in Brazil to evaluate how Moringa seeds worked with and without oil extraction through low turbidity water (5-10) NTU and high turbidity water (30-60) NTU. Moringa Oleifera was applied to jar test analysis in three different forms; pressurized extracted oil seeds, ethanol oil extracted seeds followed by stirring in NaCl solution and finally non defatted seeds stirred in NaCl solution. It has been proved that oil extraction is not necessary when Moringa is used in coagulation, flocculation or sedimentation processes. Moreover, Results showed that oil and active coagulant extraction was not needed at high initial turbidity ranges since it achieved 90% turbidity removal at all cases. For low turbidity ranges, active coagulant extraction was necessary to remove up to 60% of turbidity (Camacho et al., 2017).

- **Comparison between Moringa oleifera natural coagulant and Alum.**

(Ali *et al*., 2010) in Malaysia have compared between using Alum as a coagulant and Moringa Oleifera. Seeds were oily extracted by using hexane in electro thermal Soxhlet extraction, it achieved up to 35% oil content. Then the residual solid was extracted using NaCl and filtered by microfiltration and ultrafiltration techniques. Turbidity removal was measured by using turbidity meter after applying jar test analysis. It was found that microfiltration gave the smallest optimum Moringa dosage of 0.8 mg/L and turbidity removal of 94.8%. Where Alum needed another 5 mg/L to achieve such a result. Moreover, the effect of using these coagulants on pH value was measured. It was found that it reached 7.03 by using microfiltered Moringa, where 5.8 for Alum and so that must be followed by adding lime to adjust pH value to its standard range (6.5-8.5). Despite all other researches, Moringa worked efficiently at low turbidity levels.

- **Indirect usage of Moringa Oleifera in water treatment.**

The usage of Moringa as a natural coagulant was not confined in direct water treatment and purification methods. (Keogh *et al*., 2017) have used Moringa Oleifera as a pretreatment step for solar water disinfection (SODIS) which is a process to disinfect contaminated water to remove some

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pathogens such as *E.coli* and *E.faecalis*. The main concern in such technique that it cannot work at turbidity values higher than 30 NTU which may affect the penetration of sunlight to the treated water. It was agreed that Moringa seed powder enhanced the efficiency of SODIS by decreasing turbidity to 26 NTU. Moreover, several studies proved the anti-microbial properties of Moringa on number of pathogens and so that increased the SODIS efficiency up to 48 hrs. without any bacterial growth.

3.1.2 Juice clarification

(Costa et al., 2014) have optimized an experiment to study the coagulation efficiency of Moringa oleifera in sugar cane juice clarification and the removal of different impurities such as calcium phosphate that may affect the crystallization and evaporation stages. Moringa leaf extract was obtained from fresh leaves and applied to sugar juice at 5 mg/L concentration. Synthetic polyelectrolyte clarifier was obtained at 1.5 mg/L concentration. The results showed that Moringa leaf extract gave better juice quality compared to the synthetic coagulant. However, both coagulants have not showed any change of sugar quantity in the clarified juice when compared to the original juice.

Another study on sugar cane juice treatment was conducted by (Hamad *et al*., 2016). They aimed to evaluate the ability of Moringa seeds' powder as a natural clarifying material in sugar cane juice. Moringa seeds were either applied directly or by diluting powder in water and then mixed with juice. The results showed that using low concentration of Moringa seeds powder (< 3 g) could reduce the turbidity from 1.6 to 0.47 NTU. However, when using higher amount of Moringa it can reduce up to 0.19 NTU.

3.2 Material and Methodology

Coagulation efficiency of Moringa was tested using seeds and dry pods in both fields; water treatment and juice purification. The used parts of Moringa for all experiments were prepared three months before in which known amounts of seeds and shelled dry pods were grinded using coffee mill machine to a fine powder and then sieved using 0.1 mm mesh. For all fields of experiment, turbidity meter of model (TU-2016) was used to measure the turbidity values. Calibration of the device was conducted by using the standard solutions of the device at both (0 and 100) NTU.

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3.2.1 Water treatment

Coagulation experiments were applied using stones' cutting turbid water which was taken from Abu-Aslsood quarry in Nablus. The experiments were divided into two parts and accomplished in a comparative manner, in the first part, coagulation efficiency of Moringa samples was tested directly without any treatment. However, in the second part some modifications were applied to Moringa samples such as oil extraction from the seeds and extraction of the active coagulant material using the selected salt. The coagulation efficiency was evaluated using plastic bottles as a simple pre-experiment and then using jar test analysis to define the optimum dosage of Moringa samples comparing with selected type of Alum ($Al_2(SO_4)_3.16H_2O$) and blank solution.

3.2.1.1 Without pre-treatment

- **Pre-experiments:**

Quarry's water was poured equally into three plastic bottles of 0.5 L capacity and shacked, the initial turbidity values were measured for the three solutions by laboratory nephelometer device. Known amounts of Moringa's seeds and dry pods powder were weighed, added to two bottles and shacked carefully, where the last bottle was marked as the control solution. Turbidity values were measured in a duplicated mood after 30 min and during 24 hrs. The experiment was re-conducted by using higher dosages of Moringa powder

- **Jar test analysis:**

The jar test was performed to evaluate the coagulation activity of Moringa Oleifera. Five beakers of 2 L capacity were filled with turbid water and placed in the slots of the jar tester. The solutions were rapidly mixed for 2 min and the initial turbidity values were recorded. Various dosages of seeds powder (0.1, 0.15 and 0.2 g) were added to three of the beakers, 0.1 g of Alum were added to the fourth beaker, where the last one was marked as the control solution. The suspensions were agitated for 2 min at 150 rpm and then the speed was reduced to 30 rpm for 30 min. The turbidity values were measured using the supernatant layer of each solution in a duplicated way. All suspensions were let to settle for other 30 min, turbidity values were observed for 24 hrs. The experiment was re-conducted in the same manner using Moringa dry pods powder.

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3.2.1.2 With pre-treatment

- **Extraction of seeds' oil:**

Known amount of Moringa seeds powder was weighed, washed and mixed with known volume of hexane solvent to extract the presence oil. The mixture was filtered using filter paper of 125 mm pore size and Buckner funnel until we ended up with the defatted seeds powder .The filtered powder was dried at room temperature for 24 hrs. and kept for further jar test analysis.

- **Extraction of active coagulant material:**

NaCl solvent was prepared by dissolving 58.5 g of the salt in 1 L of distilled water and mixed gently for few minutes. Two suspensions were prepared by dissolving known weights of both Moringa seeds and dry pods powder in NaCl solution. Each suspension was stirred using hot plate and magnetic stirrer for a period of time at a moderate speed. The suspensions were filtered using Buckner funnel. Moreover, the resulted solid material of each suspension were kept at room temperature for further coagulation experiments.

The coagulation efficiency of the treated powder was tested in a small scale using the plastic bottles' experiment. In which known amounts of the treated powder of both seeds and dry pods were used and then reconducted using higher dosages at the same mentioned procedure.

The experiment was accomplished in a larger scale by applying the jar test experiment in the same standards but using 1 L solutions' capacity. The turbidity values were observed for 24 hrs. However for all experiments, the turbidity removal for each solution was measured using the following equation:

$$Turbidity\ removal\% = \frac{Initial\ Turbidity - Final\ Turbidity}{Initila\ Turbidity} * 100\% \qquad (3.1)$$

For each experiment, a graph of turbidity removal versus Moringa and Alum dosage was monitored.

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3.2.2 Juice clarification

The coagulation efficiency of Moringa seeds and dry pods in juice clarification was tested using Aloe Vera juice. Two suspensions of Aloe Vera juice and Moringa powder were prepared by dissolving known amounts of both seeds and dry pods powder in known volume of juice and shacked carefully. Third flask was marked as the control solution of Aloe Vera juice only. The time needed to separate the Aloe Vera small green particles from each mixture was observed. However, the quality of the resulted juice and the turbidity values were measured for each mixture and so the turbidity removal%.

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4 Chapter Four: Experimental Work

The experimental part that was accomplished by research team was confined to coagulation and its related operations in the two mentioned fields; water treatment and juice clarification.

4.1 Preparation of Moringa samples

1. Twenty dry pods of Moringa were brought from Dr Husni Odeh, shelled, chipped handily and separated from the seeds.
2. The chipped dry pods were grinded using stainless steel miller and then re-grinded to a fine powder using a simple coffee miller. Same procedure was done to the separated seeds.
3. The powder of both seeds and dry pods were sieved using 0.1 mm mesh to achieve the required uniformity of particles.
4. The resulted powder was kept tightly in a well shaded bags away from light and moisture.

4.2 Calibration of turbidity meter

1. Turbidity meter of model (TU-2016) was calibrated at two standard values (See **Figure A 3**).
2. 10 ml of the standard solution of 0 NTU was tested and the turbidity value was measured to give 0 NTU.
3. 10 ml of the standard solution of 100 NTU was tested until the device gave the same turbidity value.

4.3 Coagulation Experiments Using Quarry's Water

4.3.1 Without pre-treatment

- **Pre-experiments:**

1. 1.5 L of quarry's water were poured equally into three plastic bottles of 0.5 L capacity and shacked carefully.
2. Initial turbidity values were measured for each solution.
3. 0.05 g of Moringa seeds and dry pods powder were added directly to two of the bottles and shacked, where the third one was marked as the control solution.

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4. After 30 min of settling, 10 ml were taken from the supernatant layer of each solution and the turbidity values were recorded twice for each trial. The turbidity observation was repeated after 24 hrs.
5. The same procedure was re-conducted by using higher dosages (0.1 g/0.5 L).

- **Jar test analysis:**
  1. Five beakers of 2 L capacity (having the same height) were filled with quarry's water. Four beakers were placed in the slots of the jar test apparatus, while the last one was marked as the control solution.
  2. The paddles of the jar test apparatus were placed at a moderate height and the device was turned on at 150 rpm for 2 min.
  3. Initial turbidity values were recorded for the five solutions.
  4. 0.1, 0.15 and 0.2 g of Moringa seeds where added to the beakers, where 0.1 g of Alum were added to the fourth beaker.
  5. The suspensions were rapidly mixed at 150 rpm for 2 min and then the speed was reduced to 30 rpm for 30 min.
  6. The device was turned off and the turbidity values for the five solutions were recorded directly. All solutions were left then to sedimentation for 30 min and the turbidity values were observed in a duplicated mood.
  7. Turbidity observation was repeated after 24 hrs. of settling.
  8. The same procedure was done using Moringa dry pods powder.

4.3.2 With pre-treatment

- **Extraction of seeds' oil:**

1. 3 g of Moringa seeds powder were washed with 25 ml of hexane solvent and then mixed with other 25 ml using a metallic rod.
2. Th resulted suspension was filtered using filter paper of 125 mm pore size (See **Figure A 4**) and Buckner funnel.
3. The filtrated powder were dried at room temperature for 24 hrs. and kept for further jar test analysis.

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- **Extraction of active coagulant material:**

1. 1 µ NaCl solution was prepared by dissolving 58.5 g of the salt in 1 L distilled water and mixed carefully.
2. 0.5 g of each seeds and dry pods powder were weighed and added to 17 ml of NaCl solution for each.
3. The two mixtures were stirred using two small magnetic stirrer and hot plate for 20 min at a moderate speed (See **Figure A 5**).
4. The two suspensions were filtered using Buckner funnel (See **Figure A 6**).
5. 0.05 g of the resulted powder of seeds and dry pods were applied to plastic bottles experiment as it was mentioned before. The experiment was repeated using higher dosages of 0.3 g/0.5 L (See **Figure A 7**).
6. 0.6, 0.9 and 1.2 g of treated Moringa seeds and dry pods powder were applied to jar test analysis by using only 1 L of quarry's water for the five beakers. The experiment was conducted in the same mentioned procedure without repetition using dry pods (See **Figure A 8**).
7. For all experiments, turbidity removal percentages were calculated.

4.4 Juice purification

1. Three graduated cylinder of 100 ml capacity were filled with 25 ml of Aloe Vera juice and then completed with distilled water.
2. Initial turbidities of all suspensions were measured using turbidity meter.
3. 0.1 g of non-treated Moringa seeds and dry pods were added to two of the flasks where the third one was marked as the control solution.
4. The turbidity values were observed after 30 min of settling. Moreover, the speed and time needed for each solution to end up with a purified transparent juice were monitored.

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5 Chapter Five: Results and Discussion

5.1 Drying of Moringa Leaves

Drying mechanism has been applied on Moringa Oleifera leaves at two different temperature ranges; ambient temperature of initial weight of 500 g and (55-60) °C of 200 g, to study the drying rates and the resulted physical changes. **Table 1** and **Table 2** describe the loss of weight during drying time.

Table 1: Experimental Data for Drying of Moringa Leaves at T= 22 °C.

Time (hr.)	Weight (g)
0	500
10	350
24	205
30	140
40	115
50	90
60	78
70	74
80	72
90	70
100	71

Table 2: Experimental Data for Drying of Moringa Leaves at T= 55-60 °C.

Time (min)	Weight (g)
0	200
10	160
20	112
30	70
40	48
50	38
60	35
70	33

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80	31
90	29
100	28
120	27
140	27.6

For each experiment, moisture content values were determined and the resulted values are found in **Table A 1** and **Table A 2** (in sample of calculation section in the appendices). A plot was found to represent the variation of these values over time as shown in **Figure 1** and **Figure 2**.

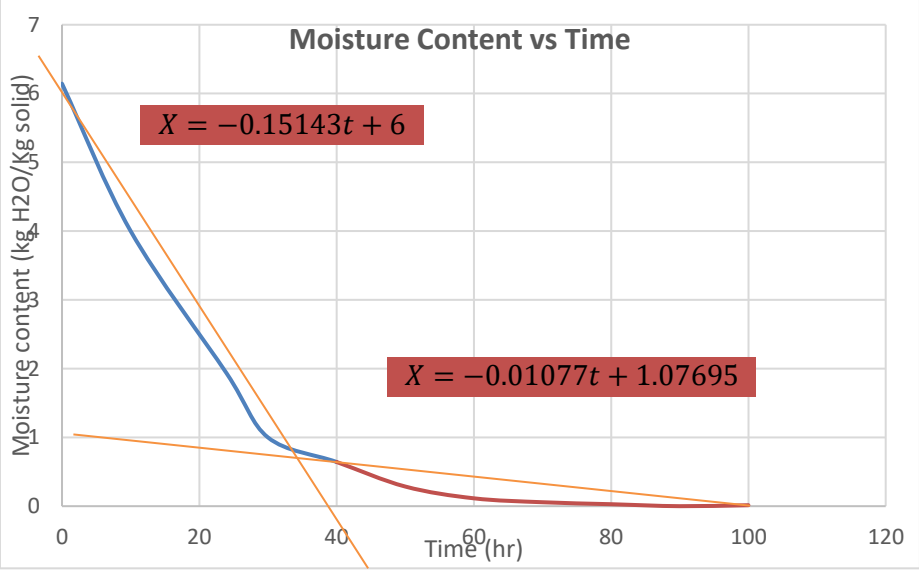

Figure 1: Variation of Moisture Content with time at T= 22 °C.

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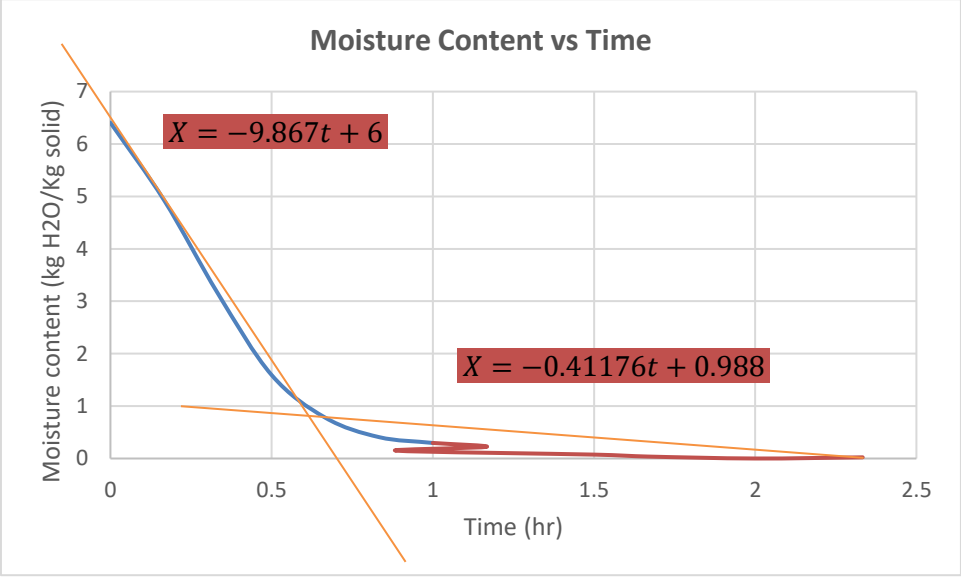

Figure 2: Variation of Moisture Content with time at T= 55-60 °C.

The tangents of the plots were defined to help represent the variation of drying rates with moisture content values as shown in **Figure 3** and **Figure 4** where **Table A 3** and **Table A 4** in the appendices represent the values of drying rates for the two experiments. In each plot a constant rate period from point A to B was found, knowing that warming up for a short time happened before point A. Falling drying rate started from the critical point X_B which equals 1 kg H_2O/kg dry solid for the first experiment and 0.77 kg H_2O/kg dry solid for the other till point D. The falling rate of drying was estimated for each experiment by finding straight line equations as the following:

- **Ambient temperature:**

$R = 0.1X + 0.01$

- **T = 55-60 °C**

$R = 17.37X$

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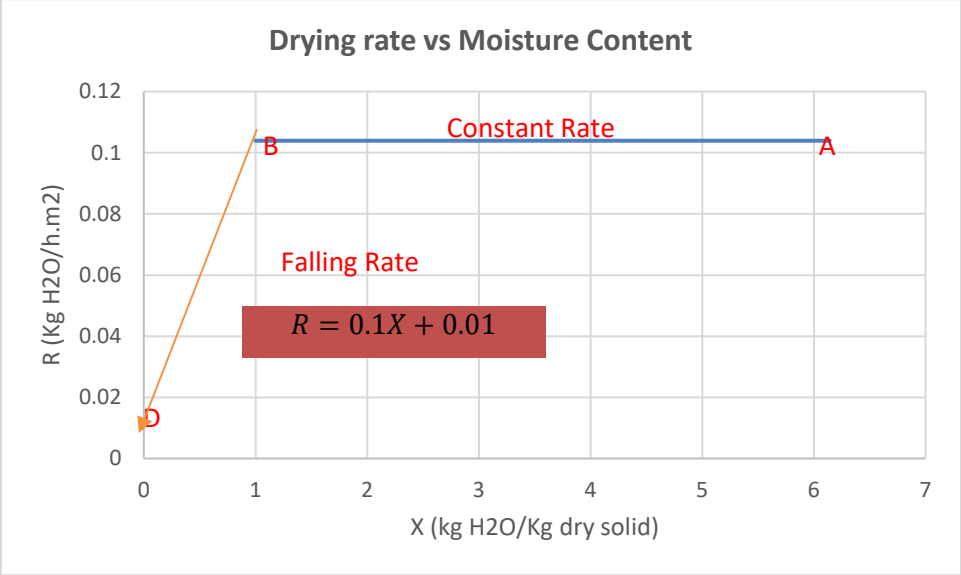

Figure 3: Drying Rate vs Moisture content at T= 20-22 °C.

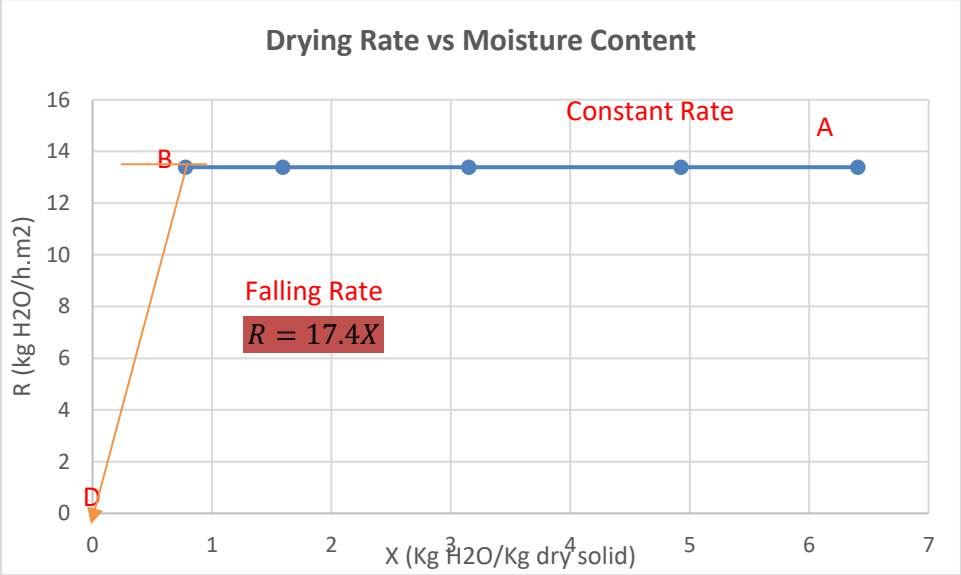

Figure 4: Drying Rate vs Moisture content at T= 55-60 °C.

The drying rate was found higher in the second experiment in both constant rate and falling rate periods, to prove that, falling rate drying values were found for two experiments at X= 0.5 kg H_2O/kg dry solid. It was found that R = 0.06 kg H_2O/h.m^2 at ambient temperature, where it equals 8.68 kg H_2O/h.m^2 at T= 55-60 °C. Additionally, the constant drying rate value at ambient temperature was 0.1 kg H_2O/h.m^2 where 13.38 kg H_2O/h.m^2 at the higher temperature range. Moreover, the total time needed to achieve drying was approximately four days in the first experiment, in contrast 2.5 hrs. of drying were needed in the second one. What concerns more, that constant rate period took shorter

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time of drying than falling rate in both experiments, for example, in the first experiment, constant rate needed 30 hrs. where the second period took 70 hrs. That could be explained by the slow transportation of moisture content to the surface in the falling rate period which leaded to a reduction of drying rate with increasment in time needed. All sample of calculations can be found in the appendices (sample of calculation section).

For physical changes during drying, it was noticed that dried leaves' color remained unchanged, but the bulk density decreased significantly during drying. It can be expected that the drying process was under conditions, which were adequate for the studied plant.

5.2 Coagulation Experiments

5.2.1 Water treatment

As it was mentioned before, different experiments were conducted to evaluate the coagulation efficiency of Moringa Oleifera using quarry's water. The experiments were accomplished using two types of samples; treated and non-treated Moringa to apply the comparison. However, each experiment was done at two stages; simple pre-experiments and jar test analysis as it will be discussed below.

5.2.1.1 Without pre-treatment

- **Pre-experiments:**

These experiments were considered as the first stage by using plastic bottles. The purpose of applying them was to study if Moringa Oleifera works as a coagulant in small scales before conducting the experiment in a larger scale (jar test), however Alum was not applied to this stage because of its affirmed efficiency. Moringa samples were used directly without any treatment, the results were gathered using both seeds and dry pods at 0.05 g/0.5 L and then 0.1 g/0.5 L as shown in **Table 3** and **Table 4**.

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Table 3: Turbidity Values using 0.05 g/0.5 L of Moringa Samples.

		Turbidity values (NTU)		
Time (hr.)	Amount (g)	Control	Seeds	Pods
0	0.05	245	252	240
0.5		205	205	211
24		85	91	85

Table 4: Turbidity Values using 0.1 g/0.5 L of Moringa Samples.

		Turbidity values (NTU)		
Time (hr.)	Amount (g)	Control	Seeds	Pods
0	0.1	132	204	166
0.5		114	206	131
24		77	60	77

The variation in turbidity values with time were represented for both experiments in **Figure 5** and **Figure 6** , as it can be seen, in the first experiment seeds and pods solutions had the same turbidity values as the control solution without any effect. Where in the second experiment a slight change was conducted by Moringa seeds but it could not be considered significant.

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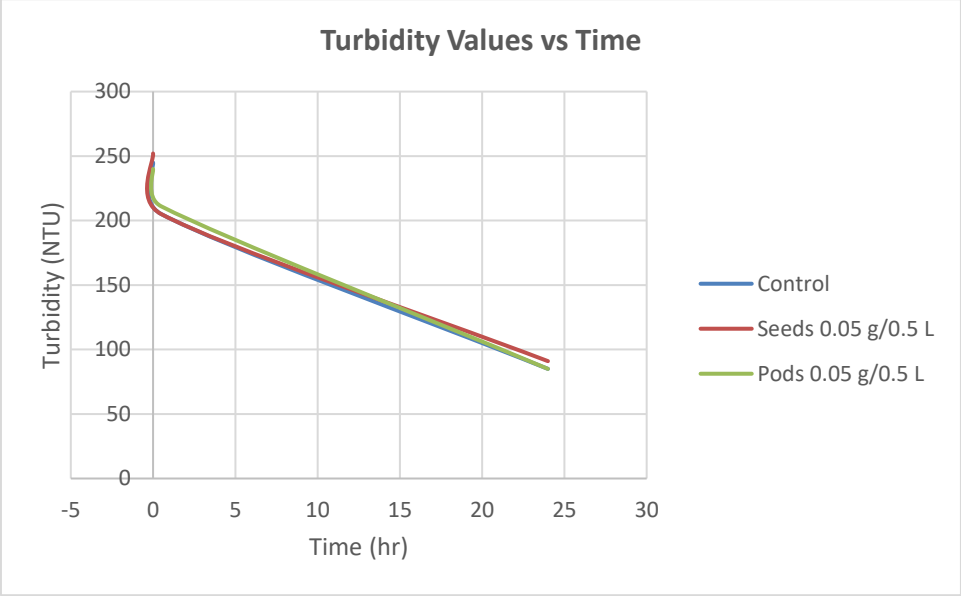

Figure 5: Turbidity Values vs Time using 0.05 g/0.5 L of Moringa Samples.

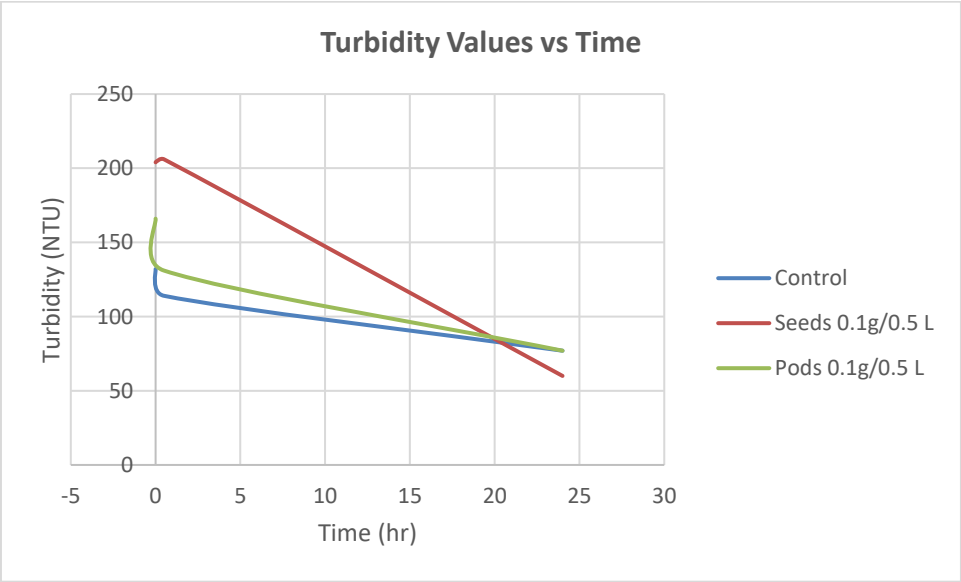

Figure 6: Turbidity Values vs Time using 0.1 g/0.5 L of Moringa Samples.

- **Jar test analysis:**

Due to the slight effect of Moringa seeds, jar test experiment was conducted to evaluate the coagulation efficiency in a larger scale and so the optimum dosage. The experiment was conducted using Moringa seeds followed by using dry pods compared with Alum, since it is considered the most used synthetic coagulant with the highest efficiency. The dosage of Moringa samples were selected

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based on the standard range of Alum (0.05-0.1) g/L. Moringa samples were applied in three beakers of 2 L capacity and so the dosages were duplicated, Alum was used in the lowest dosage since we need to achieve this optimum value using Moringa. The last beaker was the control solution of cutting stone water to test the nature of its turbidity reduction .All beakers of water were agitated at 150 rpm for 2 min before adding the coagulants to end up with same initial turbidity values. The results were gathered in a duplicated mode, **Table A 5**, **Table A 6** and **Table A 7** in the appendices (in sample of calculation section) presented that in details. However, **Table 5** and **Table 6** below give the summary for the two experiments. Moreover, **Figure 7** and **Figure 8** present the variation of turbidity with time.

Table 5: Variation in Turbidity Values Using Moringa Seeds in Jar Test Analysis.

	Turbidity Values (NTU) in 2 L				
Time(hr.)	Control	Alum 0.1 g	seeds 0.1 g	seeds 0.15 g	seeds 0.2 g
0	98	110	113	122	125
0.5	92.5	71.5	125.5	131.5	170
1	93.5	37.9	111.5	119	123
24	54	12.3	49.3	48.2	53.5

Table 6: Variation in Turbidity Values Using Moringa Dry Pods in Jar Test Analysis.

	Turbidity Values (NTU) in 2 L				
Time(hr.)	Control	Alum 0.1 g	Pods 0.1 g	Pods 0.15 g	Pods 0.2 g
0	684	783	729	749	744
0.5	625	535	737.5	658	661
1	535.5	50.805	525	558.5	574.5
24	206	17.21	157.5	164	199

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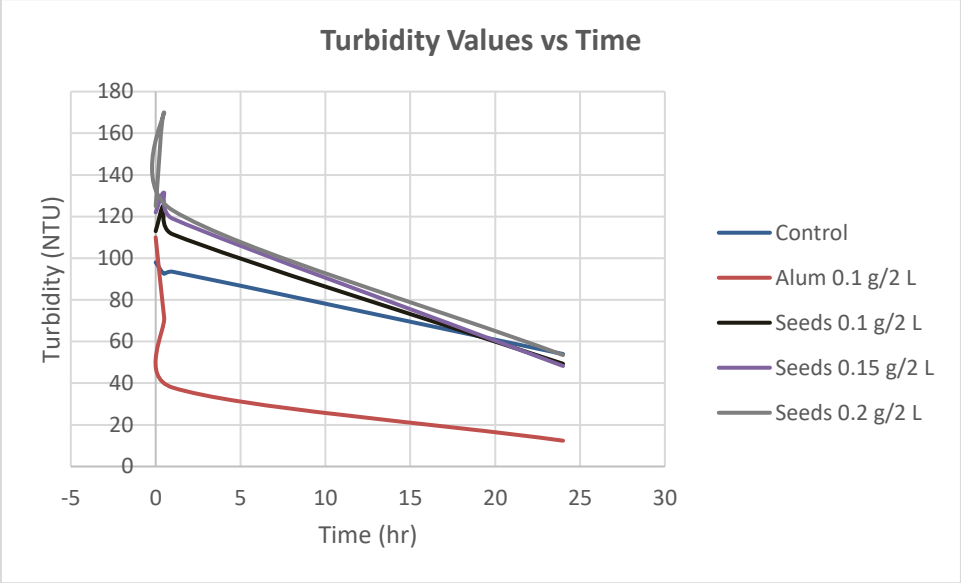

Figure 7: Turbidity Values vs Time using Moringa Seeds in Jar Test Analysis.

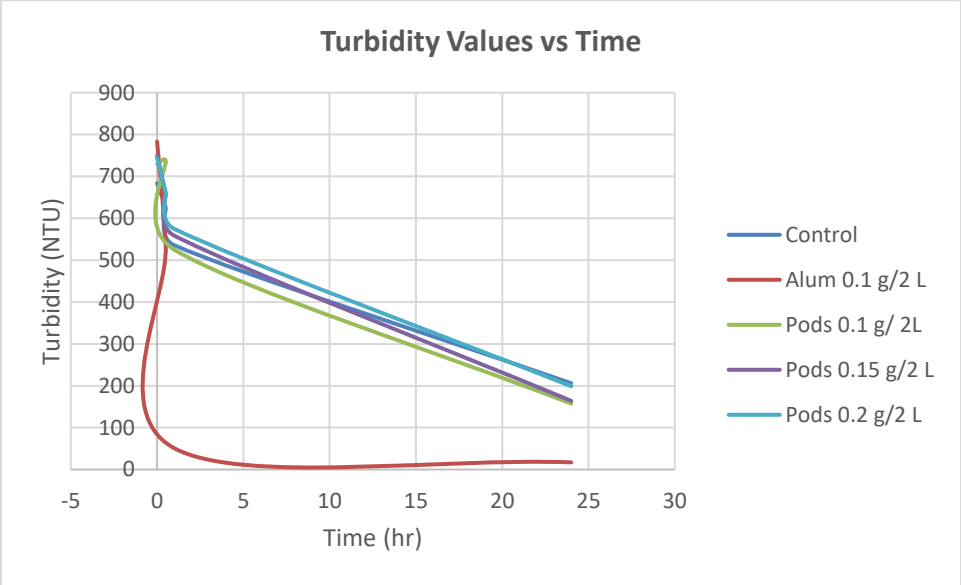

Figure 8: Turbidity Values vs Time using Moringa Dry Pods in Jar Test Analysis.

As it was shown in the figures, Alum had a significant and noticed effect on the turbidity reduction, where Moringa seeds and pods had the same attitude of control solution. That was proved more obviously by finding the turbidity removal percentage for each solution. From **Figure 9** and **Figure 10**, The turbidity removal for Alum was 88.7% and 97.8%, where Moringa samples performed close results to the control solution which recorded turbidity reduction of 44.8% and 69.8%.

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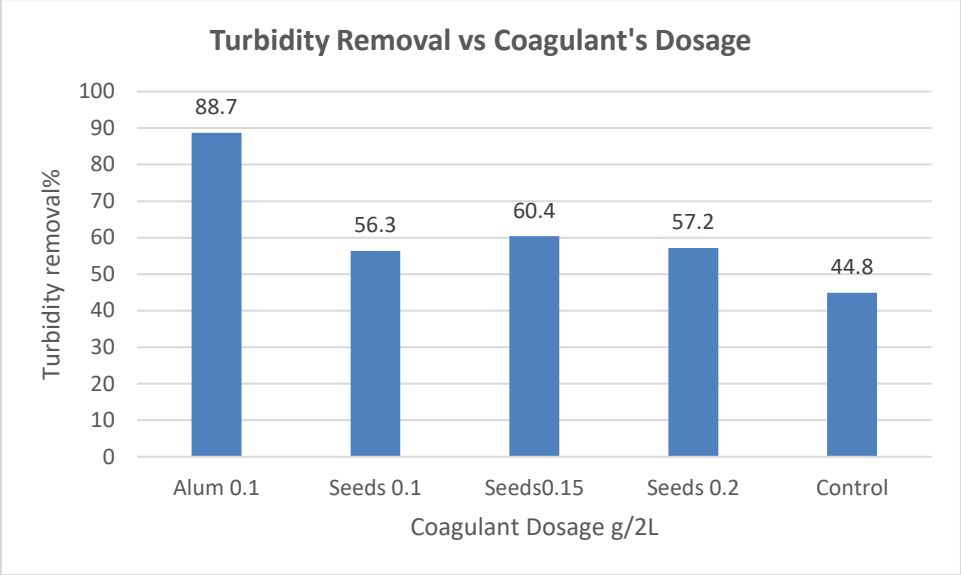

Figure 9 : Turbidity Removal of Alum, Moringa Seeds and Control Solutions Using Jar Test Analysis.

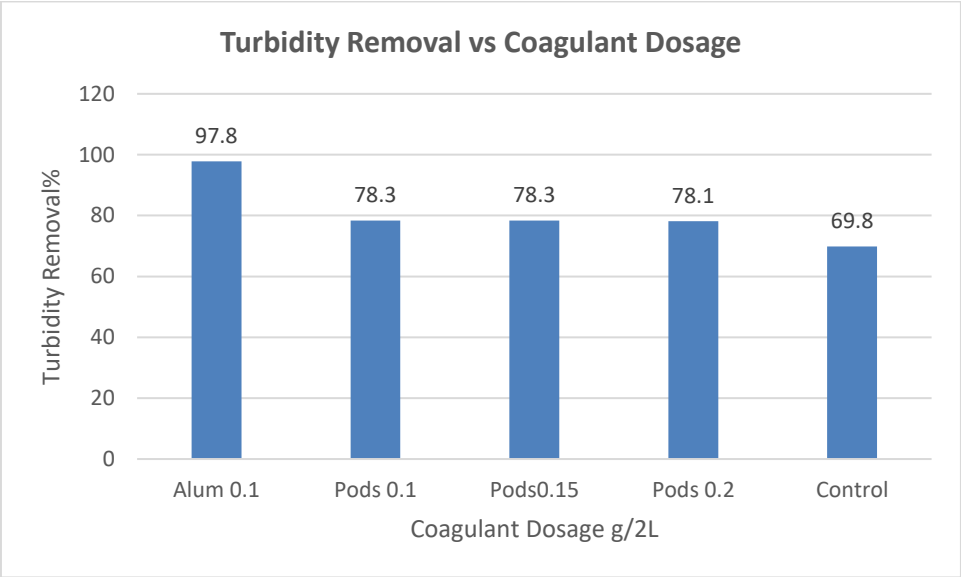

Figure 10: Turbidity Removal of Alum, Moringa Dry Pods and Control Solutions Using Jar Test Analysis.

The sample of calculations of turbidity removal were detailed in the appendices. **Table A 8** and **Table A 9** show the results (sample of calculation section).

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5.2.1.2 With pre-treatment

- **Pre-experiments:**

Due to the non-effective performance of both Moringa seeds and pods in the previous experiments. Extraction of the active coagulant material in Moringa samples was accomplished using 1µ NaCl solvent, it was proved from the literature that salt extraction increases the protein content of Moringa Oleifera which is the main cause of its coagulation activity. The performance of the extracted Moringa seeds and pods was evaluated using plastic bottles experiment with 0.05 g/0.5 L dosage. It was found that the behavior of turbidity variations was the same for the three solutions as shown in **Table 7** and **Figure 11**. However, when the dosages were increased to be 0.3 g/0.5 L for seeds and pods, it was found that the turbidity varies from 212 NTU to 10.9 NTU using seeds after 24 hrs. of settling. That gave a significant effect compared with dry pods which had the same attitude as control solution. That was approved in **Table 8** and **Figure 12**.

Table 7: Turbidity Values using 0.05 g/0.5 L of Treated Moringa Samples.

		Turbidity values (NTU)		
Time (hr.)	Amount (g)	Control	Seeds	Pods
0		78	81	85
0.5	0.05	40	34	40
24		45	34	38

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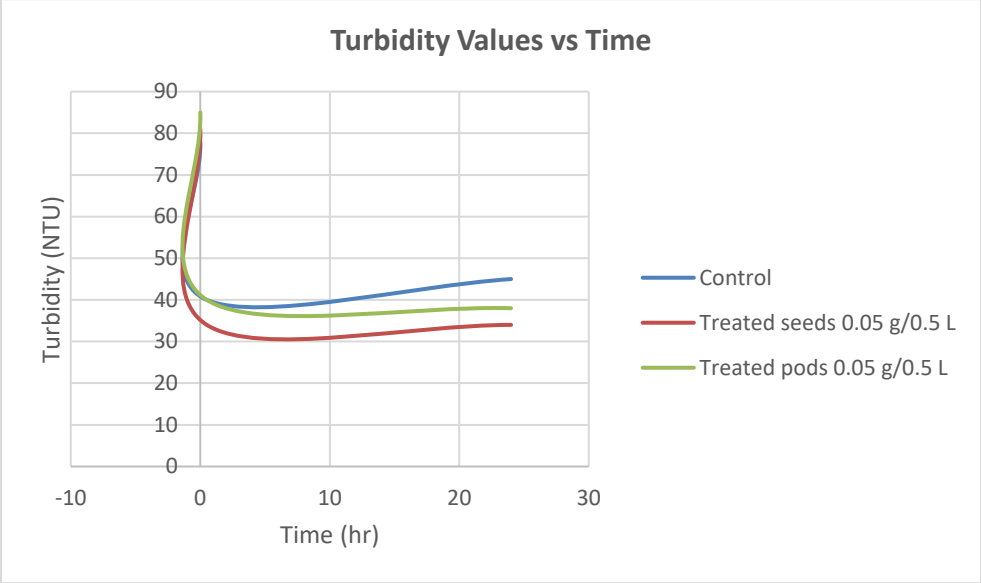

Figure 11: Turbidity Values vs Time using 0.05 g/0.5 L of Treated Moringa Samples.

Table 8: Turbidity Values using 0.3 g/0.5 L of Treated Moringa Samples.

		Turbidity values (NTU)		
Time (hr.)	Amount (g)	Control	Seeds	Pods
0		193	212	216
0.5	0.3	42.6	14.26	43.6
24		38	10.9	29.5

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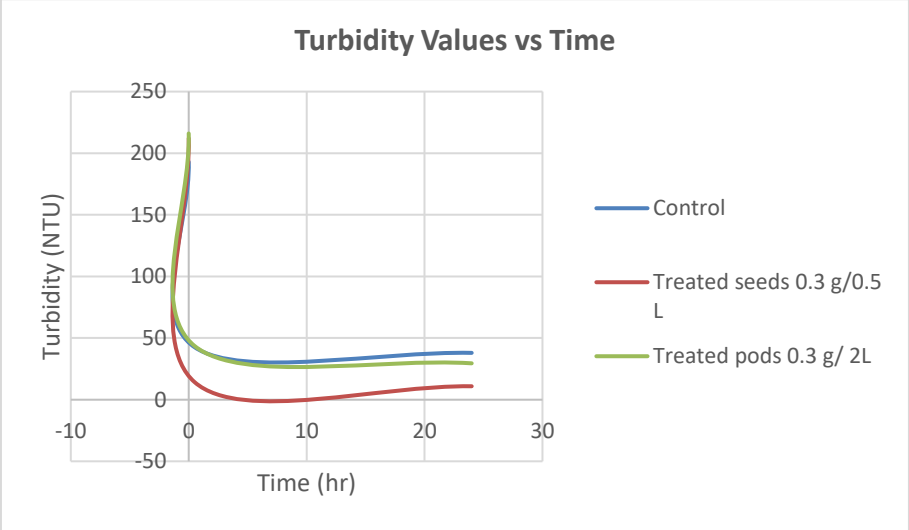

Figure 12: Turbidity Values vs Time using 0.3 g/0.5 L of Treated Moringa Samples.

- **Jar test analysis:**

The extracted seeds were conducted to jar test experiment using higher dosages (0.6, 0.9 and 1.2) g/L. Alum suspension was used for comparison at 0.6 g/L . The raw data were documented in **Table A 7** in the appendices (sample of calculation section), where the following **Table 9** gives the summary of the results.

Table 9: Variation in Turbidity Values Using Treated Moringa Seeds in Jar Test Analysis.

	Turbidity Values (NTU) in 1 L				
Time(hr.)	Control	Alum 0.6 g	seeds 0.6 g	seeds 0.9 g	seeds 1.2 g
0	110	112	106	100	102
0.5	90.5	141.5	90	86.5	84
1	109	57.5	67.5	65.5	67.5
24	69.5	32	31.5	31.4	28

Figure 13 below, shows the convergent coagulation performance of both Alum and Moringa seeds using 0.6 g/L in 24 hrs., the first coagulant had reduced the turbidity from 112 to 32 NTU where the

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second one applied a reduction from 106 to 31.5 NTU. However, that could be more clear by measuring the turbidity removal percentages for each solution as described in **Figure 14**. It was found that Alum and first Moringa seeds solution had almost the same turbidity removal of 71.4% and 70.2% which made a difference of 1.2% only. Additionally seeds extract of 1.2 g/L dosage gave the highest turbidity removal of 72.5% . What concerns in these results, that the turbidity reduction of control solution is represented in 36.8% which proved that the coagulation efficiency of Moringa seeds differs from the settling nature of quarry's water.

Table A *10* shows the detailed results of turbidity removal in sample of calculation section in the appendices.

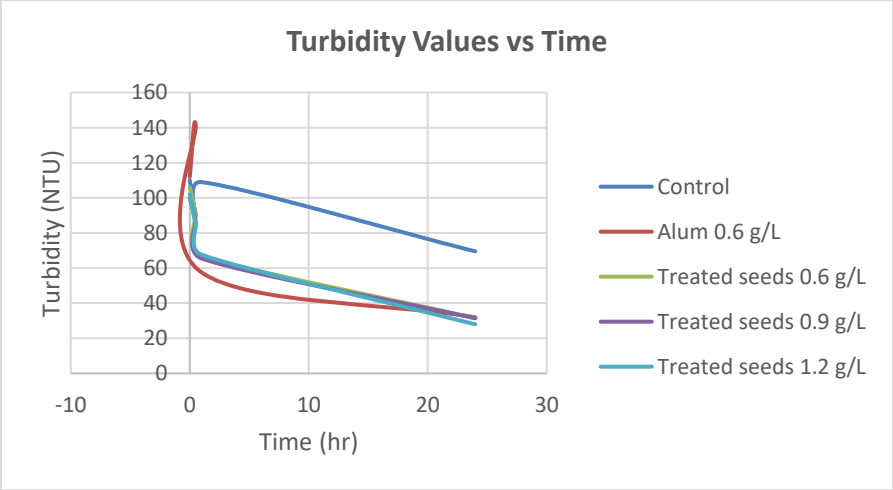

Figure 13: Turbidity Values vs Time using Treated Moringa Seeds in Jar Test Analysis.

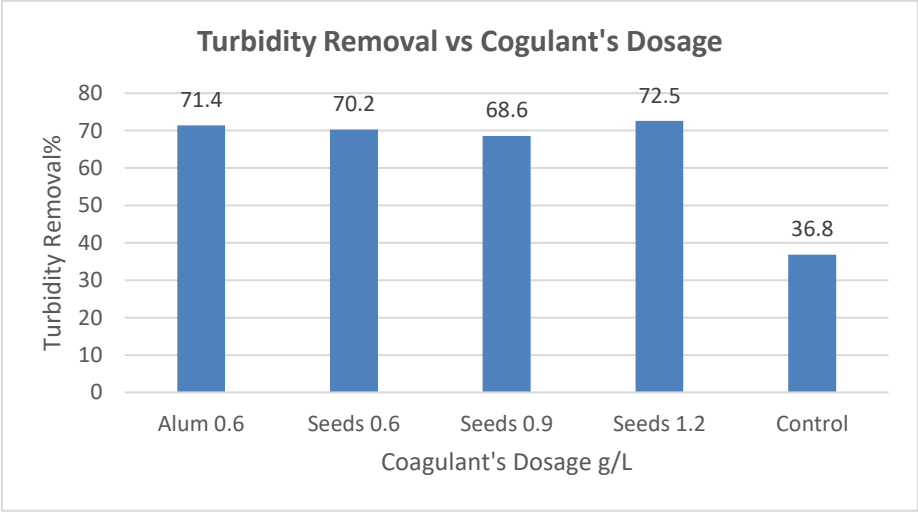

Figure 14: Turbidity Removal of Alum and Moringa Treated Seeds and Control Solutions Using Jar Test Analysis.

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The discussed results explain the coagulation efficiency of Moringa Oleifera seeds extracted with NaCl at optimum dosage of 0.6 g/L with convergent turbidity reduction with Alum in a period of one day. Moreover, seeds coagulation activity was higher than dry pods.

Since one of our objectives was to reuse the treated quarry's water in the stones' washing, it was found that quarries change the used quarry's water every six months until it blocks the pipes with resulted $CaCO_3$ sludge which may place some blocking problems. For that, using treated quarry's water with low turbidity values of 31.5 NTU can solve this problem. Moreover, the resulted Moringa-$CaCO_3$ sludge has less environmental side effects than Alum which causes disposal problems. However, it was found from the literature that 1 kg of Alum costs US1$ where US2$ for 1 kg of Moringa (Katayon et al., 2006), that made Moringa's cultivation more expensive but it would be cost effective for further environmental issues. In addition, turbidity of tap water was measured to be 11 NTU which could be achieved by applying the sedimentation process for other days and maybe with some modifications. However, unequal initial turbidity values in the different applied experiments were due to the nature of quarry's water which is used in washing the stones in a cumulative way. That resulted in variation of its turbidity with time.

Seeds were extracted from its oil content using hexane to evaluate its coagulation performance in a defatted form. This would minimize the organic matter left in the treated water, moreover it would be considered cost effective since the waste will be used in the coagulation experiments, where oil which is considered as an alternative for the olive oil will be kept for further food and medical applications. Using defatted seeds in coagulation experiments was not applied.

5.2.2 Juice clarification

Other experiment was conducted to test the coagulation efficiency of Moringa in juice clarification. Aloe Vera juice was used to conduct the experiment simply to judge non-treated Moringa coagulation. The following **Table 10** and **Figure 15** summarize the results.

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Table 10: Turbidity values (NTU) of Aloe Vera juice Using Moringa Samples.

Time(hr.)	Blank	Seeds	Pods
0	1472	1476	1476
0.5	1195	578	1019

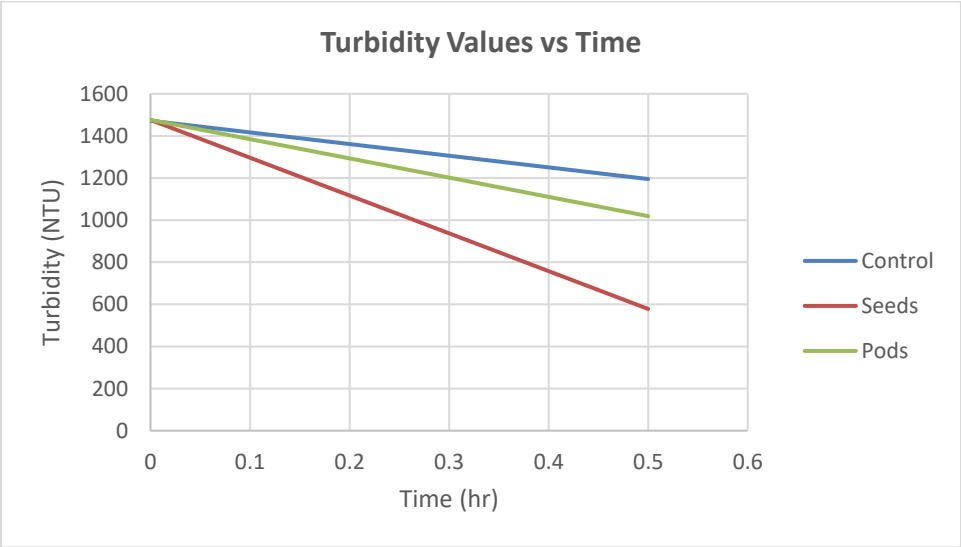

Figure 15: Turbidity Values vs Time using Moringa Samples in Aloe vera juice.

Results proved the significant effect of Moringa seeds in turbidity reduction. That was noticed obviously by measuring the turbidity percentages. It was found that Moringa seeds reduced turbidity from 1476 NTU to 578 NTU to achieve a percentage of 60.8% in a period of only 30 min followed by dry pods 30.9% and 18.8% for control solution. These results are presented in the following **Figure 16** and are given in details in **Table A 11** at sample of calculation section in the appendices.

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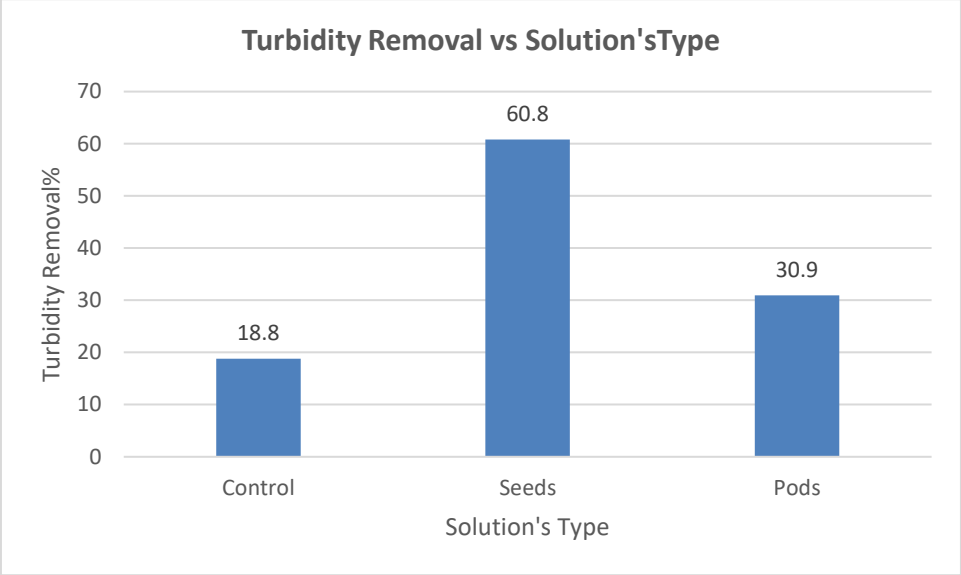

Figure 16: Turbidity Removal Percentage in Jojoba juice.

These percentages gave an indication that Moringa Oleifera worked better at high initial turbidity values even without treatment which proves the literature, moreover that confirmed that seeds have higher coagulation activity than dry pods. The performance of Aloe Vera juice clarification is represented in **Figure 17**.

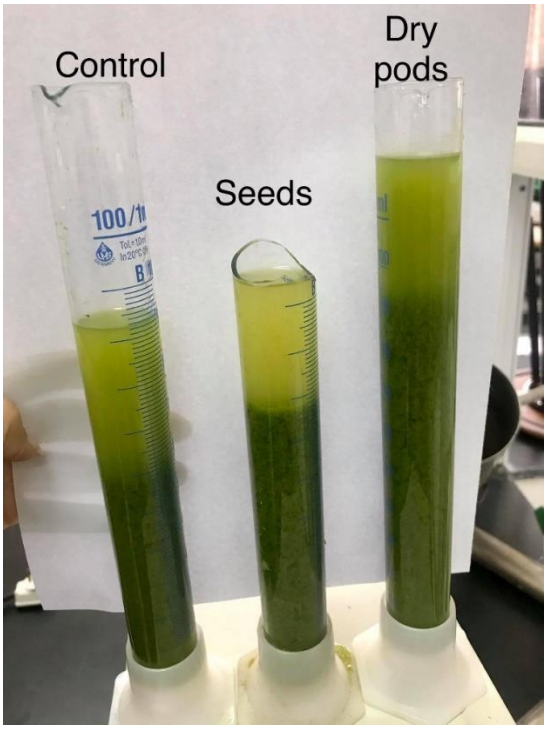

Figure 17: Aloe Vera Clarification Experiment.

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6 Chapter Six: Conclusion and Recommendations

The objective of this project was successfully achieved by studying the drying nature of Moringa Oleifera leaves. The mechanism of this process was determined by identifying drying rates' values during moisture content variation at two temperature ranges; ambient temperature and at (55-60) °C. For each experiment, drying characteristic curves were presented. Drying rate equations were derived from characteristic curves data. Moringa Oleifera was easily and rapidly dried, in which four days were enough for drying at covered area in spite of low drying temperature. The air velocity was not measured but The wind speed was about 2 m/s. When the drying process was conducted at higher but safe drying temperature (55-60)°C, 2.5 hrs. were enough to dry with higher drying rates. This temperature range was easily attained the transparent plastic covered place with no need to pay for energy. For that, Drying is inevitable and elementary step for further handling of any medicinal herb. One can't get powder for using herb as nutrient, medicine or coagulant without previous drying.

On the other hand, the objective of using Moringa Oleifera as a natural coagulant to treat and reuse quarry's water was also achieved by applying its seeds and dry pods into simple pre-experiments and jar test analysis. It was found that extracted Moringa Oleifera samples using 1 µ NaCl solution had significant coagulation efficiency compared with non-treated Moringa samples which had no effect. Moreover, it was proved that treated Moringa seeds had coagulation activity higher than Moringa dry pods with final turbidity value of 31.5 NTU in a period of 24 hrs. Additionally, extracted Moringa seeds had proved a convergent coagulation performance as Alum by having a turbidity removal of 70.2% at optimum dosage of 0.6 g/L in a period of one day. A problem of unequal initial turbidity values for quarry's water was faced. However, non-treated Moringa seeds have succeeded in reducing the turbidity of Aloe Vera juice with 60.8% where 30.9% for dry pods in a period of 30 min. These values gave an indication that Moringa Oleifera works better at high initial turbidity values because of the high presence of particles to form nuclei that are required for flocs formation.

However, using treated quarry's water as an alternative of tap water needs some modifications, since the measured turbidity value of tap water was found to be 11 NTU which is considered relevant for the final resulted turbidity value of 31.5 NTU. That would be achieved by applying more sedimentation time.

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What concerns in using Moringa seeds as a natural coagulant is the large increase of organic matter due to the presence of fatty acidic compounds which limits the storage period for not more than 24 hrs. Moreover, it cannot be used in large scale fields. For that it was recommended to apply adsorption process which is considered cost consuming (Ghebremichael, 2005). The alternative is to use Moringa seeds in a defatted form by using selected extraction solvents such as hexane. Based on the previous facts and the non-influencing performance of Moringa on treated water pH, it is recommended to use Moringa in water treatment process which can minimize the adsorption time.

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8 Appendices

8.1 Apparatus

- **Turbidity Meter:**

Turbidity meter device is used in an aqueous solution to detect suspensions in it, where it works by way of infrared or by USEPA technology, the turbid liquid is characterized by the opposite of light and dispersion that gives information about the degree of turbidity.

The degree of turbidity is expressed in NTU (Nephelometric Turbidity Units), the turbidity gives an indication of the type of water under test and whether it is suitable for certain applications or not, these indicators depend on the presence of organic or inorganic substances, the degree of turbidity depends on the quantity and density of suspensions, where these suspensions can be living creatures, pollutants, minerals, and organic matter present in the water whether this water is surface, groundwater, wastewater. Measurement of turbidity is one of the important tests conducted in water purification plants, food production plants, and others, the degree and standards of turbidity it is differs according to the application used (PCE, 2020).

Figure A 1: Turbidity Meter Apparatus (amazon, 2020) .

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❖ **Jar Test:**

The objective of the laboratory jar test is to determine the minimum amount of needed coagulant in any settling (deposition) as standard device for settling by using coagulants. Water to be treated is placed in four or six jars and the chemical substance to be used for water treatment is placed in each bowl with stirring. The container with the lowest amount of chemical substance used with deposition is considered the appropriate amount for its treatment.

Procedure

1) Fill the jars with 1,000 ml of water to be treated.
2) Mix the beakers at 150 rpm for 2 minutes.
3) Place chemical substance with jars of different quantities.
4) Increase the mixing speed to100-125 rpm for 2 minutes.
5) reduce mixing speed to 30rpm.
6) Close the mixer and wait for stability occur for 30 minute (SNF, 2020).

Figure A 2: Jar Test Apparatus (labopolis, 2020).

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8.2 Figures

Figure A 3: Used Turbidity Meter.

Figure A 4: Filter Paper of 125 mm Pore Size.

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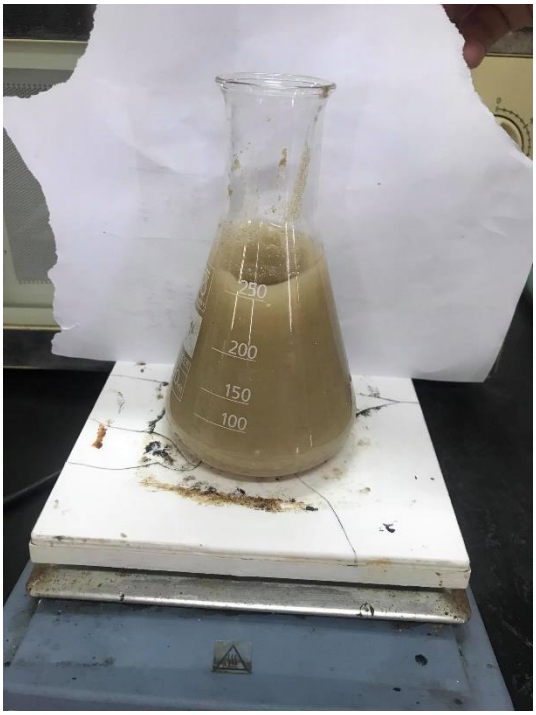

Figure A 5: Stirring of Moringa-NaCl Suspension using Hot Plate.

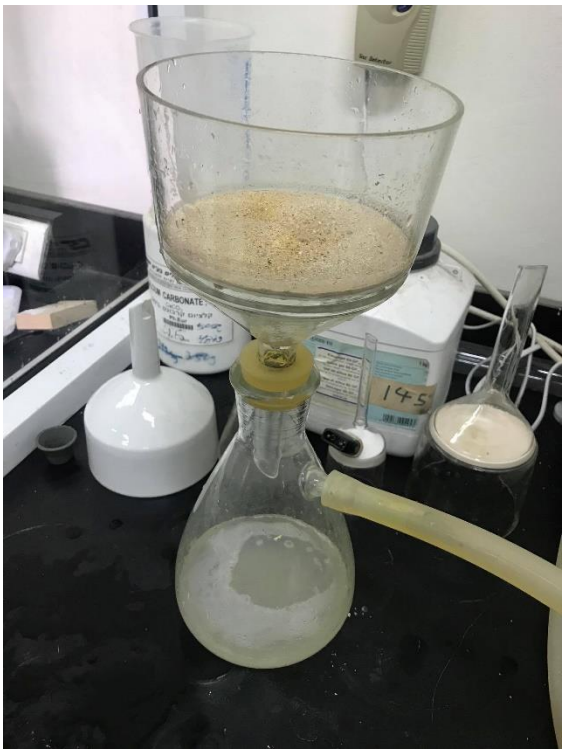

Figure A 6: Buckner Funnel.

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Figure A 7: Coagulation Experiment of Treated Moringa Using Plastic Bottles.

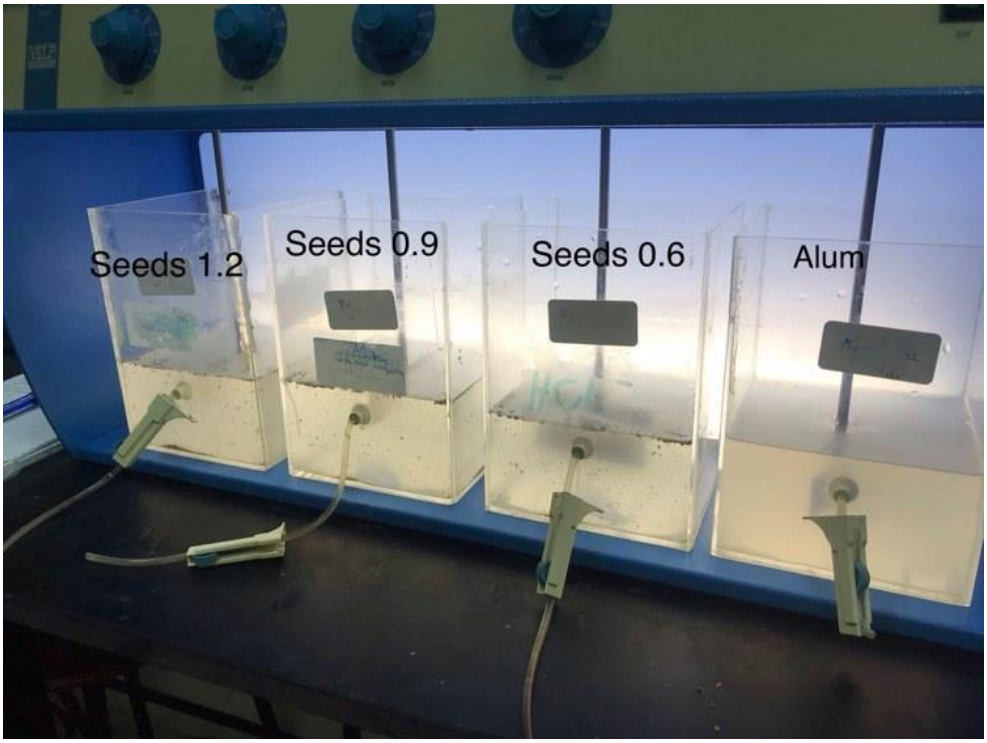

Figure A 8: Jar Test Analysis Using Treated Moringa Seeds.

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8.3 Sample of Calculations

8.3.1 Drying Experiment

- **Determination of moisture content values during drying.**

Moisture content value was determined for each weight based on the dry solid weight W_s which is the smallest dry content achieved. For T =22 °C at W = 500 g the calculation were as the following:

$$Xt = \frac{W - W_s}{W_s}$$

$$Xt = \frac{500 * 10^{-3} - 70 * 10^{-3}}{70 * 10^{-3}}$$

$$Xt = 6.14 \frac{kg\ H_2O}{kg\ dry\ solid}$$

The results for the two experiments are summarized in **Table A 1** and **Table A 2**.

Table A 1: Moisture Content Values During Drying at T= 22 °C.

Weight (g)	X_t (kg H_2O/kg dry solid)
500	6.14
350	4.00
205	1.92
140	1.00
115	0.64
90	0.28
78	0.11
74	0.05
72	0.02
70	0.00
71	0.01

`

Table A 2: Moisture Content Values During Drying at T= 55-60 °C.

Weight (g)	X_t (kg H_2O/kg dry solid)
200	6.40
160	4.92
122	3.14
70	1.59
48	0.77
38	0.40
35	0.29
33	0.22
31	0.14
29	0.07
28	0.03
27	0.00
27.6	0.02

- **Determination of drying rate:**

Drying rate values were determined based on the following equation:

$$R = \frac{-L_s}{A_s} * \frac{dx}{dt}$$

A_s is the area of drying plate, where L_s is the last achieved drying weight assuming 13% moisture content. At T= 22 °C:

$L_s = 0.071 * (1 - 0.13)$

$L_s = 0.061\ kg\ dry\ solid$

`

Where $\frac{dx}{dt}$ values are the slopes of the tangents of moisture content vs time plots. The equation of the first tangent for the first experiment was determined by taking two points set on the line [(0,6),(35,0.7)] as the following:

$$X = A(t - t_0) + B$$

Where A is the slope and B is the intercept of moisture equation line. The values of a and b are read out directly from **Figure 1**.

$$X = \frac{(0.7 - 6)}{(35 - 0)}(t - 0) + 6$$

$$X = -0.15t + 6$$

So

$$R = \frac{-0.061}{(0.3 * 0.3)} * -0.15$$

$$R = 0.10 \frac{kg\ H_2O}{h.m^2}$$

Same calculations were applied to the second tangent using the points [(35,0.7),(100,0)] and the ended up equation was:

$$X = -0.01t + 1.076$$

$$R = 7 * 10^{-3} \frac{kg\ H_2O}{h.m^2}$$

Calculations were repeated for the second experiment. The results of drying rate values for the two experiments are presented in **Table A 3** and **Table A 4**.

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Table A 3: Drying Rate Values at T = 22 °C.

Weight (g)	Ls (kg)	A (m2)	dx/dt	R (kg $H_2O/m^2.h$)
500	0.061	0.09	- 0.15	0.10
350			- 0.15	0.10
205			- 0.15	0.10
140			- 0.15	0.10
115			- 0.01	$7*10^{-3}$
90			- 0.01	$7*10^{-3}$
78			- 0.01	$7*10^{-3}$
74			- 0.01	$7*10^{-3}$
72			- 0.01	$7*10^{-3}$
70			- 0.01	$7*10^{-3}$
71			- 0.01	$7*10^{-3}$

Table A 4: Drying Rate Values at T = 55-60 °C.

Weight (g)	Ls (kg)	A (m2)	dx/dt	R (kg $H_2O/m^2.h$)
200	0.024	0.0177	- 9.86	13.38
160			- 9.86	13.38
112			- 9.86	13.38
70			- 9.86	13.38
48			- 9.86	13.38
38			- 0.41	0.55
35			- 0.41	0.55
33			- 0.41	0.55
31			- 0.41	0.55
29			- 0.41	0.55
28			- 0.41	0.55
27			- 0.41	0.55
27.6			- 0.41	0.55

- **Determination of falling drying rate equations:**

Falling drying rate equation for ambient temperature experiment was determined using two sets of points on the straight line [(0,0.01, (1, 0.11)] as the following using the line equation:

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$$R = A(X - X_0) + B$$

where A is the slope and B is intercept of rate equation line. The values of a and b are read out directly from **Figure 3**.

$$R = \frac{(0.11 - 0.01)}{(1 - 0)}(X - 0) + 0.01$$

$$R = 0.1X + 0.01.$$

The drying rate equation for T =55-60 °C at falling drying period is determined from **Error! Reference source not found.** in the same manner and the ended up equation was:

$$R = 17.37X$$

The comparison of falling drying rates for the two experiments was checked using the resulted straight line equations at X =0.5 $\frac{kg\ H_2O}{kg\ dry\ solid}$ as the following:

$$R = 0.1X + 0.01$$

$$R = 0.1(0.5) + 0.01$$

$R = 0.06\ \frac{kg\ H_2O}{h.m^2}$ at T = 22 °C

Where

$$R = 17.37X$$

$$R = 17.37(0.5)$$

$R = 8.68\ \frac{kg\ H_2O}{h.m^2}$ at T = 55-60 °C

`

8.4 Coagulation experiments

The results of the jar test analysis for non-treated and treated Moringa were presented in the following **Table A 5**, **Table A 6** and **Table A 7**.

Table A 5: Turbidity Values (NTU) Using non-Treated Moringa Seeds in Jar Test Analysis (effect of increasing concentration).

		Time									
		0	0.5 hr.			1 hr.			24 hr.		
Type	Dose g/2L	0 min	Trial 1	Trial 2	Avg (NTU)	Trial 1	Trial 2	Avg (NTU)	Trial 1	Trial 2	Avg (NTU)
Control	..	98	92	93	92.5	94	93	93.5	56	52	54
Alum	0.1	110	74	69	71.5	37.8	38	37.9	13.12	11.66	12.39
Moringa seeds	0.1	113	125	126	125.5	106	117	111.5	47.64	51	49.32
Moringa seeds	0.15	122	130	133	131.5	118	120	119	51	45.5	48.25
Moringa seeds	0.2	125	170	170	170	128	118	123	56	51	53.5

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Table A 6: Turbidity Values (NTU) Using non-Treated Moringa Dry Pods in Jar Test Analysis (effect of increasing concentration).

		Time									
		0	0.5 hr.			1 hr.			24 hr.		
Type	Dose g/2L	0 min	Trial 1	Trial 2	Avg (NTU)	Trial 1	Trial 2	Avg (NTU)	Trial 1	Trial 2	Avg (NTU)
Control	..	684	614	636	625	524	547	535.5	205	207	202
Alum	0.1	783	595	475	535	58	43.61	50.805	21	13.42	17.21
Moringa pods	0.1	729	753	722	737.5	548	556	552	133	182	157.5
Moringa pods	0.15	749	660	656	658	564	553	558.5	135	193	164
Moringa pods	0.2	744	667	655	661	589	560	574.5	207	191	199

Table A 7: Turbidity Values (NTU) Using Treated Moringa Seeds in Jar Test Analysis (effect of increasing concentration).

		Time									
		0	0.5hr.			1 hr.			24 hr.		
Type	Dose g/2L	0 min	Trial 1	Trial 2	Avg (NTU)	Trial 1	Trial 2	Avg (NTU)	Trial 1	Trial 2	Avg (NTU)
Control	..	110	107	109	108	103	105	104	70	69	69.5
Alum	0.6	112	141	142	141.5	57	58	57.5	35	29	32
Moringa seeds	0.6	106	94	86	90	66	69	67.5	31	32	31.5
Moringa seeds	0.9	100	90	83	86.5	66	65	65.5	31.99	30.88	31.435
Moringa seeds	1.2	102	85	83	84	67	68	67.5	29.23	26.77	28

`

Turbidity removal for control solution in non-treated Moringa was calculated using the following equation:

$$Turbidity\ removal\% = \frac{Initial\ Turbidity - Final\ Turbidity}{Initial\ Turbidity} * 100\%$$

$$Turbidity\ removal\% = \frac{684 - 139}{684} * 100\%$$

$$Turbidity\ removal\% = 79.6\%$$

The calculations were repeated for all solutions in treated and non-treated Moringa Samples and the results were presented in **Table A 8**, **Table A 9** and **Table A *10***.

Table A 8: Turbidity Removal Values Using non-Treated Moringa Seeds.

Type	Turbidity removal %
Alum 0.1 g/2 L	88.7
Seeds 0.1 g/2 L	56.3
Seeds0.15 g/2 L	60.4
Seeds 0.2 g/ 2L	57.2
Control	44.8

Table A 9: Turbidity Removal Values Using non-Treated Moringa Dry Pods.

Type	Turbidity removal %
Alum 0.1 g/2 L	97.8
Pods 0.1 g/2 L	78.3

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Pods0.15 g/ 2L	78.3
Pods 0.2 g/ 2L	78.1
Control	69.8

Table A 10: Turbidity Removal Values using Treated Moringa Seeds.

Type	Turbidity removal %
Alum 0.6 g/L	71.4
Seeds 0.6 g/L	70.2
Seeds 0.9 g/L	68.6
Seeds 1.2 g/LL	72.5
Control	36.8

Same calculations were applied for Aloe vera clarification, **Table A 11** summarized that.

Table A 11: Turbidity Removal Values in Aloe Vera Clarification.

Type	Turbidity removal %
Control	18.8
Seeds	60.8
Pods	30.9