

COMPARATIVE STUDY ON THE EFFECTIVENESS OF *MORINGAOLIEFERA*
SEED AND POD EXTRACTS FOR TURBIDITY REMOVAL FROM SURFACE
WATER

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M.ENG DISSERTATION

CIVIL ENGINEERING DEPARTMENT, BAYERO UNIVERSITY, KANO

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WATER

BY

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DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of Dr. Kasim Mohammed and has not been presented anywhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write-up (Abubakar Modibbo Ahmed SPS/13/MCE/00034) were carried out under our supervision.

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APPROVAL

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TABLE OF CONTENTS

Title Page	i
Declaration	ii
Certification	iii
Approval	iv
Acknowledgements	v
Dedication	vii
Table of Contents	viii
List of Tables	xiii
List of Figures	xv
List of Plates	xvii
Abstract	xviii
CHAPTER ONE: INTRODUCTION	
1.1 BACKGROUND	1
1.2 NEED FOR WATER TREATMENT	3
1.3 STATEMENT OF RESEARCH PROBLEM	5
1.4 JUSTIFICATION FOR THE STUDY	6
1.5 AIM AND OBJECTIVES	7
1.5.1 Aim	7
1.5.2 Objectives	7
1.6 SCOPE AND LIMITATION	8
1.6.1 Scope	8

1.6.2 Limitation	8
1.8 CONTRIBUTION TO KNOWLEDGE	8
CHAPTER TWO: LITERATURE REVIEW	
2.1 INTRODUCTION	9
2.2 CHEMICAL COAGULANTS	9
2.2.1 Iron salts	9
2.2.2 Aluminium salts	10
2.2.3 Lime	10
2.2.4 Activated silica	11
2.2.5 Polyelectrolytes	11
2.3 ALUM AS A CHEMICAL COAGULANT	12
2.4 NATURAL MATERIALS USED IN WATER TREATMENT	12
2.5 <i>MORINGA OLEIFERA</i>	13
2.5.1 Description of <i>Moringa oleifera</i>	14
2.5.2 Related species	15
2.6 ACTIVE INGREDIENTS IN <i>MORINGA OLEIFERA</i> SEEDS	16
2.7 TURBIDITY	17
2.7.1 Environmental significance	18
2.7.2 Principle of turbidity	19
2.7.3 Causes of turbidity	19
2.7.4 Some Causes of Water Scarcity	20
2.8 COAGULATION AND FLOCCULATION	21
2.8.1 The coagulation process	21

2.8.2 Flocculation	24
2.8.3 Purpose of Coagulation	26
2.8.4 Factors affecting coagulation/flocculation	28
2.8.5 Health risks associated with chemical coagulation and flocculation	29
2.9 APPLICATIONS OF <i>MORINGA OLEIFERA</i> IN WATER TREATMENT	30
2.9.1 Processing of <i>Moringa oleifera</i> seeds powder and extracting the active Ingredients	31
2.9.2 Use of <i>Moringa oleifera</i> as Coagulant	32
2.9.3 <i>Moringa oleifera</i> as a Primary Coagulant	32
2.9.4 Co-coagulation of <i>Moringa oleifera</i> with alum	36
2.9.5 <i>Moringa oleifera</i> as a Coagulant Aid	37
CHAPTER THREE: MATERIALS AND METHODS	
3.1 MATERIALS	40
3.2 METHODS	40
3.2.1 Sample collection	40
3.2.2 Sample preparation	40
3.2.3 Extraction of oil from the seed and pod powder	40
3.2.4 Preparation of turbid water samples	41
3.2.5 Preparation of Coagulants	41
3.3 COAGULATION TEST	43
3.4 DETERMINATION OF THE OPTIMUM pH	43
3.5 DETERMINATION OF TURBIDITY	44
3.5.1 Calibration of turbidity meter	44

3.5.2 Testing of water sample	45
3.6 DETERMINATION OF pH	45
3.6.1 Calibrating the instrument	45
3.6.2 Testing of sample	46
CHAPTER FOUR: RESULTS AND DISCUSSIONS	
4.1 OPTIMUM DOSE FOR EACH OF THE COAGULANTS	47
4.1.1 Optimum dose of <i>Moringa oleifera</i> seed powder	47
4.1.2 Optimum dose of <i>Moringa oleifera</i> pod extract	49
4.1.3 Optimum dose of <i>Moringa oleifera</i> combined (seed and pod) extract	51
4.2 OPTIMUM pH OF <i>MORINGA OLEIFERA</i> SEED, POD AND COMBINED (SEED AND POD) EXTRACT	54
4.2.1 Optimum pH of <i>Moringa oleifera</i> Seed Extract	54
4.2.2 Optimum pH of <i>Moringa oleifera</i> Pod Extract	56
4.2.3 Optimum pH of <i>Moringa oleifera</i> Combined (seed and pod) Extract	58
4.3 OPTIMUM CONCENTRATION OF <i>MORINGA OLEIFERA</i> (AQUEOUS EXTRACT) SEED, POD AND COMBINATION	60
4.3.1 Optimum concentration of <i>Moringa oleifera</i> seed (aqueous extract)	61
4.3.2 Optimum concentration of <i>Moringa oleifera</i> pod (aqueous extract)	62
4.3.3 Optimum concentration of <i>Moringa oleifera</i> combined (aqueous extract) Powder	63
4.4 COMPARISON ON THE TURBIDITY REMOVAL EFFICIENCIES BETWEEN THE NATURAL COAGULANTS AND THE CONVENTIONAL COAGULANT (ALUM)	64

4.4.1 3% concentration of <i>Moringa oleifera</i> seed, pod, combination and alum on medium and high turbid water	64
4.4.2 6% concentration of <i>Moringa oleifera</i> seed, pod, combination and alum on medium and high turbid water	66
4.4.3 9% concentration of <i>Moringa oleifera</i> seed, pod, combination and alum on medium and high turbid water	68
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS	
5.1 CONCLUSIONS	70
5.2 RECOMMENDATIONS	72
REFERENCES	73
APPENDICES	83

LIST OF TABLES

Table 2.1: Classification of Raw Water Turbidity	18
Table A1: 3% Concentration of <i>Moringa oleifera</i> Seed Extract	83
Table A2: 6% Concentration of <i>Moringa oleifera</i> Seed Extract	83
Table A3: 9% Concentration of <i>Moringa oleifera</i> Seed Extract	83
Table A4: 3% Concentration of <i>Moringa oleifera</i> Seed Extract	84
Table A5: 6% Concentration of <i>Moringa oleifera</i> Seed Extract	84
Table A6: 9% Concentration of <i>Moringa oleifera</i> Seed Extract	84
Table B1: 3% Concentration of <i>Moringa oleifera</i> Pod Extract	85
Table B2: 6% Concentration of <i>Moringa oleifera</i> Pod Extract	85
Table B3: 9% Concentration of <i>Moringa oleifera</i> Pod Extract	85
Table B4: 3% Concentration of <i>Moringa oleifera</i> Pod Extract	86
Table B5: 6% Concentration of <i>Moringa oleifera</i> Pod Extract	86
Table B6: 9% Concentration of <i>Moringa oleifera</i> Pod Extract	86
Table C1: 3% Concentration of <i>Moringa oleifera</i> Combined Extract	87
Table C2: 6% Concentration of <i>Moringa oleifera</i> Combined Seed Extract	87
Table C3: 9% Concentration of <i>Moringa oleifera</i> Combined Seed Extract	87
Table C4: 3% Concentration of <i>Moringa oleifera</i> Combined Extract	88

Table C5: 6% Concentration of <i>Moringa oleifera</i> Combined Extract	88
Table C6: 9% Concentration of <i>Moringa oleifera</i> Combined Extract	88
Table D1: 3% Concentration of Alum	89
Table D2: 6% Concentration of Alum	89
Table D3: 9% Concentration of Alum	89

LIST OF FIGURES

Figure 2.1 Optimum Dosage for a Specific Turbidity Level.	25
Figure 4.1 Dose of 3% Conc. of <i>Moringa oleifera</i> Seed Extract for 495 and 100 NTU	47
Figure 4.2 Dose of 6% Conc. of <i>Moringa oleifera</i> Seed Extract for 495 NTU and 100 NTU	48
Figure 4.3 Dose of 9% Conc. of <i>Moringa oleifera</i> Seed Extract for 495 NTU and 100 NTU	49
Figure 4.4 Dose of 3% Conc. of <i>Moringa oleifera</i> Pod Extract for 495 and 100 NTU	50
Figure 4.5 Dose of 6% Conc. of <i>Moringa oleifera</i> Pod Extract for 495 and 100 NTU	51
Figure 4.6 Dose of 9% Conc. of <i>Moringa oleifera</i> Pod Extract for 495 and 100 NTU	51
Figure 4.7 Dose of 3% Conc. of Combined <i>Moringa oleifera</i> (Seed and Pod) extract for 495 NTU and 100 NTU	52
Figure 4.8 Dose of 6% Conc. of Combined <i>Moringa oleifera</i> (Seed and Pod) Extract for NTU and 100 NTU	52
Figure 4.9 Dose of 9% Conc. of Combined <i>Moringa oleifera</i> (Seed and Pod) Extract for 495 NTU and 100 NTU	53
Figure 4.10 pH of 3% Conc. of <i>Moringa oleifera</i> Seed Extract for 495 and 100 NTU	54
Figure 4.11 pH of 6% Conc. of <i>Moringa oleifera</i> Seed Extract for 495 and 100 NTU	55
Figure 4.12 pH of 9% Conc. of <i>Moringa oleifera</i> Seed Extract for 495 NTU and 100	56
Figure 4.13 pH of 3% Conc. of <i>Moringa oleifera</i> Pod Extract for 495 NTU and 100 NTU	56
Figure 4.14 pH of 6% Conc. of <i>Moringa oleifera</i> Pod Extract for 495 and 100 NTU	57
Figure 4.15 pH of 9% Conc. of <i>Moringa oleifera</i> Pod Extract for 495 and 100 NTU	58
Figure 4.16 pH of 3% Conc. of <i>Moringa oleifera</i> Combined Extract for 495 NTU and 100 NTU	59

Figure 4.17 pH of 6% Conc. of <i>Moringa oleifera</i> Combined Extract for 495 NTU and 100 NTU	59
Figure 4.18 pH of 9% Conc. of <i>Moringa oleifera</i> Combined Extract for 495 NTU and 100 NTU	60
Figure 4.19 Concentration of <i>Moringa oleifera</i> Seed Extract for Medium & High Turbid Water	62
Figure 4.20 Concentration of <i>Moringa oleifera</i> Pod Extract for Medium & High Turbid	63
Figure 4.21 Concentration of <i>Moringa oleifera</i> Combined Extract for Medium & High Turbid Water	64
Figure 4.22 3% Conc. <i>Moringa oleifera</i> Seed, Pod, Combination and Alum for Medium & High Turbid Water	66
Figure 4.23 6% Conc. <i>Moringa oleifera</i> Seed, Pod, Combination and Alum in Medium & High Turbidity Water	67
Figure 4.24 9% Conc. <i>Moringa oleifera</i> Seed, Pod, Combination and Alum in Medium & High Turbid Water	69

LIST OF PLATES

Plate: 2.1 <i>Moringa oleifera</i> Flower	15
Plate: 2.2: <i>Moringa oleifera</i> Pods and Seeds	15

ABSTRACT

The efficiency of *Moringa oleifera* seed, pod and combined (seed and pod) extracts on turbidity removal from surface water was studied. Optimum values of coagulant dose, pH stock concentrations for these coagulants were determined using jar test. Results obtained from jar test experiments revealed that, the optimum doses of *Moringa oleifera* seed extract for 3, 6 and 9% stock solutions were 100, 102, 102 mg/L and 100, 102, 153 mg/L for medium and high turbid waters, respectively. For *Moringa oleifera* pod extract at 3, 6 and 9% stock concentrations, the optimum doses were 200, 198 153 mg/L and 100, 198, 153 mg/L for medium and high turbid waters, respectively. The optimum doses of *Moringa oleifera* combined extract at the same stock solution concentrations were 300, 201, 297 mg/L and 200, 201, 153 mg/L for medium and high turbid waters, respectively. The study also determined the optimum pH of the *Moringa oleifera* seed, pod extracts and their combination to be 6.5, 8.0 and 6.5-7.0. The optimum stock solution concentration for the medium and high turbid waters were respectively found to be 3% with 84 and 98% turbidity removal efficiencies for the seed extract, 6% with 81 and 82% turbidity removal efficiencies for the pod extract, and 6 and 9% with 86 and 95.2% turbidity removal efficiencies for the combined seed and pod extracts. It is therefore, recommended that *Moringa oleifera* pod and combined (seed and pod) extracts can be used as primary coagulants or coagulant aids for turbidity removal from medium and high turbid surface waters.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Safe water and adequate sanitation are fundamental to the health of every human being on the globe, but many people especially in Africa and Asia do not have access to this primary need (Bartram *et al.*, 2005). An important step towards tackling this universal crisis is to understand its extent: how many people lack access to safe drinking-water and sanitation (WHO and UNICEF, 2000).

The Millennium Development Goal 7, Target 7C calls on countries to halve the number of people without access to safe drinking-water and basic sanitation by 2015 (WHO, 2008). Population projections suggest that, an additional 784 million people worldwide will need improved drinking water sources for the MDG target to be met (WHO, 2008). According to the same report, approximately 1.56 billion people gained access to improved drinking-water from 1990 to 2006.

Currently, 87% of the people of the world drink water from improved sources, as compared to 77% in 1990. Improved drinking water coverage in Sub-Saharan Africa is still considerably lower than in other regions. Nevertheless, it has increased from 49% in 1990 to 58% in 2006, which means that an additional 207 million Africans are now using safe drinking water (WHO, 2008).

Regardless of extensive recognition of the importance of improved water and sanitation and heavy investment by international donors and governments in developing countries in extending water supply systems, majority of the population of rural areas still lack right to use to safe drinking water (Rondinelli, 1991). Due to this distressed situation people in rural areas are forced to use traditional sources that are polluted (WHO and UNICEF, 2000). Poor

drinking water and insufficient supplies of water for personal hygiene and poor sanitation are responsible for almost 4 billion cases of diarrhoea each year that cause 2.2 million deaths, mostly among children under the age of five (WHO, 2003). The quality of water has a profound influence on human health, economic and social development of the people.

Water and sanitation improvements, coupled with improvement of personal hygiene can significantly affect the health of the population by reducing a variety of disease conditions such as diarrhoea, intestinal helminths, guinea worm, skin diseases, cholera, trachoma and typhoid (Billig *et al.*, 1999). Studies have reported that diarrhoea, dysentery and malaria are the causes of high rate of mortality in these countries (Verheyen, 1986). Billig *et al.*, (1999) also noted that improvements in health as a result of improved water and sanitation provision can, in turn lead to reduced morbidity and mortality and improved nutritional status.

Water-related diseases cost 443 million school days each year, equivalent to an entire school year for all seven-year-old children in Ethiopia (UNDP, 2006). Almost half of these days are lost due to intestinal parasites transmitted through water and faecal material. According to the same report, more than 150 million children of school going age are severely affected by the intestinal helminths such as roundworm, whipworm and hookworm. In similar study, UNDP 2006 noted that, children with infections are twice as likely to be absent from school as those without and they perform poorly even when in school.

At a very basic level, man requires certain amount of water daily for survival and therefore access to some form of water is essential for life. However, water has much broader influences on health and well being and issues such as the quantity and quality of the water supplied are important in determining the health of individuals and whole communities. However, access may be restricted by insufficient quantity, poor quality and excessive cost relative to the ability and willingness to pay. Thus in terms of drinking water all these issues

must be addressed to protect public health. The quality of water has a great influence on public health; in particular, its microbiological quality. Poor microbiological quality can lead to outbreak of water-related diseases (WHO, 2006).

Turbidity in water is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble coloured organic compounds, phytoplankton and other micro- and macro-organisms (APHA and AWWA, 1989). Turbidity can provide food and shelter to pathogens and if not removed, can promote their re-growth in water distribution system.

Consumption of high turbid water may constitute health risks (WHO, 2006). For many developing countries, coagulation, flocculation and sedimentation (which are the unit processes involved in removing turbidity from water) are relatively expensive processes because of the costs of chemical coagulants and potential risks of chemical pollution resulting from sludge handling and disposal.

About one billion people in developing countries still lack access to safe drinking water and more than six million people (of which 2 million are children) die from diarrhoea every year (Postnote, 2002). The situation persists and it may continue to cause substantial loss of human lives unless it is seriously dealt with at all levels. In developing countries, new treatment plants are expensive to construct, the ability and willingness of domestic consumers to pay for services is minimal, and skills as well as technology are scarce. In order to alleviate these prevailing difficulties, approaches should focus on sustainable water treatment systems that are low-cost, robust and require minimal maintenance and operator skills. Locally available materials can be exploited towards achieving sustainable safe potable water supply.

1.2 NEED FOR WATER TREATMENT

As the case in most parts of sub-Saharan Africa, water demand far outstrips supply in Nigeria. Rural water supply and sanitation projects that are now implemented in several rural

districts in the country by the Community Water and Sanitation Agency (CWSA) are facing certain drawbacks, of which poor management and financial constraints are prominent. The outcome of this is that the few installed water facilities for these communities are unable to suffice the needs of the population.

Rural communities most often rely greatly on ground water provided that it is available in sufficient quantities, and also on surface water which may be contaminated in most cases.

Most of the diseases causing death in the country are related to poor water and sanitation with malaria, diarrhoea and cholera being the most causes of mortality (UNICEF, 2004).

Drinking water treatment involves a number of unit processes depending on the quality of the raw water, and stringent quality requirements recommended by existing guidelines or standards. The cost involved in achieving the desired level of treatment depends, among other things, on the cost and availability of chemicals. Commonly used chemicals for the various treatment units are synthetic organic and inorganic substances. In many places, these are expensive and may have to be imported at high cost. Many of the chemicals are also associated with human health and environmental problems (Crapper *et al.*, 1973; Christopher *et al.*, 1995; Kaggwa, 2001) and a number of them have been regulated for use in water treatment systems.

However, recent studies have pointed out several serious drawbacks of using aluminium salts, such as Alzheimer's disease associated with residual aluminium in treated water and production of large sludge volumes (Ndbigengesere and Narasiah, 1998). There is also the problem of reaction of alum with natural alkalinity present in the water leading to a reduction of pH and low efficiency in coagulation in cold water. Chlorination is the most common disinfection method used, because of its advantages over other methods. One disadvantage of chlorination is that high residual chlorine will bring about unwanted taste and odour.

To overcome these problems or at least supplement the supplies of these chemicals, local materials, in the form of plant extracts, are being considered. The use of locally available organic coagulants may result in a more sustainable, economically viable alternative and remarkably reduce treatment cost (Yung, 2003). The use of natural materials of plant origin to clarify turbid water is not a new idea (Ndabigengesere *et al.*, 1995).

Among the plants that have been tested over the years, powder processed from the seeds of *Moringa oleifera* has been shown to be one of the most effective primary coagulants for water treatment and can be compared to that of Alum (conventional chemical coagulant; Amagloh and Benang, 2009). It was inferred from their reports that the powder has antimicrobial properties. The seed contains 43% oil, 41% protein and 9% carbohydrates (Anhwange *et al.*, 2004). However, the presence of oil and carbohydrates increases the content of organic matter in the treated water. This fact represents a disadvantage for its application at full scale water treatment and highly recommends purification of crude extracts.

It is for this reason this study will want to investigate on the effectiveness of the pods powder in drinking water treatment.

Attention has previously been paid on the efficiency of *Moringa oleifera* seeds in water and wastewater treatment, so this research is intended to compare the coagulating efficiency of *Moringa oleifera* seeds, pods and their combined form (seeds and pods) in drinking water treatment.

1.3 STATEMENT OF RESEARCH PROBLEM

In rural areas, people living in extreme poverty drink highly turbid and microbiologically contaminated water as they lack knowledge of proper drinking water treatment and also cannot afford to use chemical coagulants and disinfectants.

Some drinking water treatment plants in developing countries face a myriad of problems which include large seasonal variation in raw water quality e.g. turbidity, high cost of water treatment chemicals, under or over dosing of chemicals leading supply of poor drinking water. To overcome the problems associated with chemical coagulants, it is necessary to increase the use of natural coagulants for drinking water treatment.

Current operational procedures at many treatment works in developing countries are based on arbitrary guidelines, particularly in relation to the dosage of chemicals. Besides that, there is also the problem of inadequate number of skilled workers and inadequate laboratory facilities to monitor process performances required to operate the plants (Muyibi, 1998).

Although *Moringa oleifera* seeds are the most commonly used natural coagulants by the poor people in the developing world, it is associated with a disadvantage in the preparation of its active crude extract precisely in the process of oil extraction which is tedious. Therefore, it has become imperative to find other natural materials that do not require much time and energy in the preparation of their active crude extract. Hence the use of the pods powder of *Moringa oleifera* may be an alternative.

This research would compare the turbidity removal efficiency of *Moringa oleifera* seeds and pods from surface water. Although many studies have been conducted on potential uses of *Moringa oleifera* seed in drinking water treatment, studies on the use of *Moringa oleifera* pods in drinking water treatment are very rare. This may help in resolving the conflicting interest of traditionally using *Moringa oleifera* seeds in agriculture.

1.4 JUSTIFICATION FOR THE STUDY

People in rural and under developed countries living in extreme poverty are presently drinking highly turbid and microbiologically contaminated water as they lack the knowledge of proper drinking water treatment and also cannot afford to use high cost of chemical

coagulants. *Moringa oleifera* seed is the most common natural coagulant used in water and wastewater treatment which if it is continuously applied in large-scale water and wastewater treatment would negatively affect its application in other sectors such as agriculture.

Therefore, it is necessary to explore other locally available, cheap, under-utilized and environmentally friendly plant materials that can partially or fully replace *Moringa oleifera* seeds.

Previous research by Melesse and Berihun (2013) found that *Moringa oleifera* pods and seeds have similar chemical and mineral composition (though with difference in their concentrations), this is why this study sets out to investigate the potential of using *Moringa oleifera* pods as a substitute for its seeds. This may help in realizing a cheaper and a more sustainable coagulant in water treatment since the pods are usually disposed off as waste.

1.5 AIM AND OBJECTIVES

1.5.1 Aim

The aim of this research work is to evaluate the suitability of using *Moringa oleifera* pod extract for turbidity removal from surface water and to compare it with that of the *Moringa oleifera* seed and combined extract.

1.5.2 Objectives

1. To determine the optimum dosage of *Moringa oleifera* seed, pod and their combination needed to remove turbidity in drinking water treatment.
2. To determine the optimum pH of *Moringa oleifera* seed, pod and their combination.
3. To determine the optimum concentration of stock solution for *Moringa oleifera* seed, pod and combination.

4. To compare the turbidity removal efficiencies of the natural coagulants (seed, pod and their combination) with conventional coagulant (Aluminum Sulphate).

1.6 SCOPE AND LIMITATION

1.6.1 Scope

The scope of this work will cover *Moringa oleifera* seeds and seed- removed pods collected from a farm in Kano, Nigeria and synthetic water of medium and high turbidity will be prepared in accordance with Doerr (2005) classification of raw water turbidity.

1.6.2 Limitation

This study is limited to the use of *Moringa oleifera* pods, seeds and their combination in turbidity removal from synthetic raw water.

1.7 CONTRIBUTION TO KNOWLEDGE

The findings of this research will be useful in developing a cheaper and efficient means of water treatment. Also it will reduce agricultural waste generation by using the pods powder in water treatment. The use of a locally available and producible *Moringa oleifera* bio-coagulant instead of Alum may contribute to cost effective, self-dependent, safest and high quality drinking water treatment in middle- and low-income countries (Nigeria), especially in rural areas.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Water is a valuable natural resource vital for sustaining life. It is in a continuous movement (i.e., hydrological cycle), and is not uniformly distributed in time and space. Due to its multiple benefits and the problems created by its excesses, shortages and quality deterioration, water, as finite resource requires special attention (Pinderhughes, 2004).

Water treatment usually comprises water clarification and disinfection processes (Suarez *et al.*, 2003). In conventional water treatment a series of processes including coagulation, flocculation, sedimentation, filtration and disinfection are often used (AWWA, 1990). A combination of several processes is usually needed to improve the quality of raw water depending on the type of water quality problems present, the desired quality of the treated water, the costs of different treatments and the size of the water system (Kalibbala, 2007).

Methods of water treatment from biological materials will indeed be effective in providing water at a very cheap and affordable price and at all times in every household. One method that has been practised by people in some parts of the developing world is the use of locally available natural coagulants to improve turbidity and reduce bacteria in surface water (Ghebremichael *et al.*, 2005).

2.2 CHEMICAL COAGULANTS

2.2.1 Iron Salts

Iron coagulants include ferric sulphate ($\text{Fe}_2(\text{SO}_4)_3$), ferrous sulphate (FeSO_4) and ferric chloride (FeCl_2). Iron compounds are generally cheaper, produce a heavier floc, and perform over a wider pH range than aluminium coagulants (Tillman, 1996). However, iron coagulants are not used as much as aluminium due to staining equipment, corrosiveness, and they require

more alkalinity than alum. Ferric sulphate is active over a wider pH range (4.0-6.0, 8.8-9.2) than ferrous sulphate (8.8-9.2) and produces heavier flocs which settle more quickly. Ferric chloride reacts in a manner similar to ferrous sulphate but is commonly used as an oxidant. It is effective over a much greater pH range than aluminium sulphate, ferric sulphate, and ferrous sulphate (Skousen *et al.*, 1996).

Although clarifications with iron salts are effective they are not mostly used in conventional treatments due to their colouring effect after coagulation (Peavey *et al.*, 1985).

2.2.2 Aluminium Salts

Common aluminium coagulants include aluminium sulphate (alum), sodium aluminates, and polyaluminium chloride. Dry alum is available in several grades, with a minimum aluminium content expressed as 17 % of Al_2O_3 . Liquid alum is about 49 % solution, or approximately 8.3 % by weight aluminium as Al_2O_3 . Alum coagulation works best for a pH range of 5.5 to 8.0; however, actual removal efficiency depends on competing ions and chelating agent concentrations. Sodium aluminate is an alternative to alum and is available in either dry or liquid forms, containing an excess of base. Sodium aluminate provides a strong alkaline source of water-soluble aluminium, which is useful when adding sulphate ions is undesirable. It is sometimes used in conjunction with alum for controlling pH. Polyaluminum chloride (PAC), another aluminium derivative, is a partially hydrolyzed aluminium chloride solution. Although still not widely used, it has been reported to provide stronger, faster settling flocs than alum in some applications (Hahn and Kunte, 1990).

2.2.3 Lime

This is usually not considered as an effective coagulant because it does not produce flocs like salts of iron and aluminium. It reacts with phosphorous and bicarbonate compounds in water

to adjust pH causing precipitation of calcium carbonate and magnesium hydroxides (Cosidine, 1974).

2.2.4 Activated Silica

The nature of interaction with suspended solids is somehow analogous to that of polyelectrolytes but differs by lacking the long flexible chains and is therefore denser. They are usually referred to as weighting agents that promote settling of flocs. Dosages are about 20-60 % of alum dose used for coagulation. They have been used with or without alum to achieve clarification in lime water-softening plants (Cosidine, 1974).

2.2.5 Polyelectrolytes

Polyelectrolytes are water-soluble organic polymers consisting of repeating units of smaller molecular weights chemically combined to form larger molecules of colloidal size each carrying electrical charges or ionized groups. They can be either natural or synthetic and can be used as both primary coagulants and coagulant aids (Hashimoto *et al.*, 1991). Polyelectrolyte primary coagulants are cationic with high charge density and low molecular weight, while synthetic polyelectrolyte coagulant aids have relatively high molecular weights and facilitate flocculation through inter-particle bridging (Gregory and Duan, 2001). Although polyelectrolytes are more expensive than aluminium and iron salts in terms of material cost, overall operating costs can be lower because of reduced need for pH adjustment, lower sludge volumes, no increase in total dissolved solids in treated water and shorter settling time (Özacar and Şengil, 2003).

However, they are not readily available and also costly for most parts of the developing world. Natural polyelectrolytes such as water-soluble proteins released from crushed seed kernels are potential alternatives to synthetic polyelectrolytes. The merits of natural

polyelectrolytes over synthetic include safety to human health, biodegradability and a wide effective range of flocculation for various colloidal suspensions (Kawamura, 1991)

2.3 ALUM AS A CHEMICAL COAGULANT

Alum ($\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$) is available commercially in industrialized countries in lumps, ground or liquid form. It is a basic product of the reaction between sulphuric acid and a mineral despite such as bauxite. Lump or ground alum whether purified or not contain not less than 9.0 % of available water-soluble aluminium as Al or 17 % as Al_2O_3 (AWWA, 1990). Chemical coagulation with alum like any other form of coagulant is aimed at achieving the following objectives; removal of turbidity (inorganic or organic), removal of harmful bacteria and other pathogens and removal of colour, taste and odour producing substances.

Alum is a relatively inexpensive coagulant if local production is possible. In most developing countries, it is imported at substantially increased cost. Treatment plants in these countries must be designed so that alum consumption may be minimized. The dosage of alum may be reduced in some instances by; direct filtration of low turbidity waters, pre-treating excessively turbid river waters, use of coagulant aids and optimum pH adjustment.

2.4 NATURAL MATERIALS USED IN WATER TREATMENT

Natural materials have been used in water treatment since ancient times, for example the women of Sudan have used the seeds from the *Moringa oleifera* tree for water treatment since the beginning of the 20th century through a technique that comprehended the swirling of seeds in cloth bags with water for a few minutes and let it settle for an hour.(ibid) But lack of knowledge on the exact nature and mechanism by which they work has impeded their wide spread application and they have been unable to compete with the commonly used chemicals. In recent years there has been a resurgence of interest to use natural materials due to cost and

associated health and environmental concerns of synthetic organic polymers and inorganic chemicals. A number of effective coagulants have been identified from plant origin. Some of the common ones include *Moringa oleifera* (Olsen, 1987; Jahn, 1988), nirmali (Tripathi *et al.*, 1976), okra (Al-Samawi and Shokrala, 1996), Cactus latifaira and Prosopis juliflora (Diaz *et al.*, 1999), tannin from ricot, peach kernel and beans (Jahn, 2001), and maize (Raghuwanshi *et al.*, 2002).

2.5 MORINGA OLEIFERA

Moringa oleifera Lam, a medium sized tree species has gained importance due to its multipurpose usage and well adaptability to dry and hot climates of north-western plains, central India and dry regions of peninsular India. (Pandey *et al.*, 2011) The *Moringa oleifera* (MO) tree is a perennial plant that grows very fast, with flowers and fruits appearing within 12 months after planting. The tree grows up to a height of 5–12 meters with branches extending between 30 and 120 cm. (Arnoldsson *et al.*, 2008).

Moringa oleifera, commonly referred to as Moringa, is the most widely cultivated variety of the genus *Moringa*. The tree is somewhat slender with drooping branches that grows to approximately 10 m in height. However, it is normally cut annually to one meter or less, and allowed to re grow, so that pods and leaves remain within reach. Bichi (2013) noted that *Moringaceae* is a single genus family with 14 known species, of these, *Moringa oleifera* Lam (syns. *Moringa pterygosperma* Gaertn) is the most widely known and utilized species.

A native of the sub-Himalayan regions of north-west India, *Moringa oleifera* is now indigenous to many countries in Africa, Arabia, South East Asia, the Pacific and Caribbean Islands; and South America. Commonly known as the 'horse-radish' tree (arising from the taste of a condiment prepared from the roots) or 'drumstick' tree (arising from the shape of the

pods), *Moringa oleifera* has a host of other countries specific vernacular names (*Zogale* in Northern Nigeria), an indication of the significance of the tree around the world.

Rajangam *et al.* (2001) reported that India is the largest producer of *Moringa* with an annual production of 1.1 to 1.3 million tonnes of tender fruits from an area of 380 km². Among the states, Andhra Pradesh leads in both area and production (156.65 km²) followed by Karnataka (102.8 km²) and Tamil Nadu (74.08 km²). In other states, it occupies an area of 46.13 km².

2.5.1 Description of *Moringa oleifera*

NRC (2006) reported that *Moringa* has a tuberous taproot, whose presence helps explain the species' tolerance to drought conditions. Normally umbrella shaped, the tree comes with a lax crown of graceful, airy foliage, whose feathery effect is due to the finely trip innate division of the leaves. The leaves are densely crowded at the tops of the branches. Depending on climate, the foliage is evergreen or deciduous and, from a distance, reminiscent of a legume like *leucaena* or *calliandra*.

In season the tree is enshrouded in creamy white, honey-scented flowers arranged in drooping panicles 10-30 cm long. Flowers are insect pollinated and “require a large number of insect visitations,” with carpenter bees being the most common guests (Bhattacharya and Mandal, 2004). Flowers and fruits (pods) can be produced twice a year; though in many places, flowering and fruiting occur all year-round. The fruits are initially light green, slim and eventually turning dark green and firm. Depending on genotype, they are up to 120 cm long.



Plate: 2.1 *Moringa oleifera* Flower

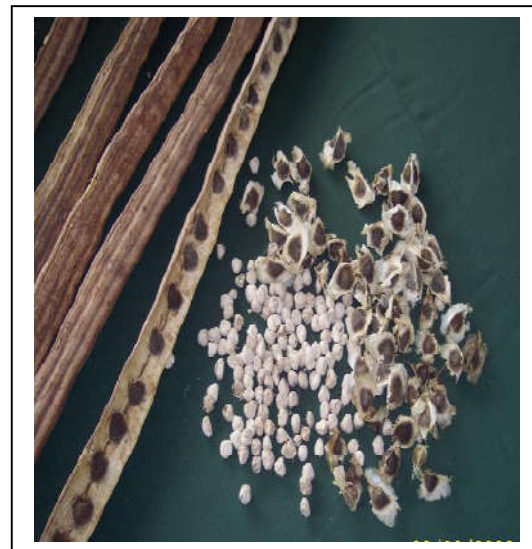


Plate: 2.2: *Moringa oleifera* Pods and Seeds

While most are straight a few are wavy and some curly in shape. In cross-section, most are rectangular but a number are triangular and some are round. Fully matured and dried seeds are surrounded by a lightly wooded shell with three papery wings.

Because of its wide distribution nature, *Moringa* has various common names in various localities. Some of these, according to National Research Council (2006) are: *English*: moringa, horseradish tree, drumstick tree, sujuna, ben tree, ben oil tree; *French*: ben ailé, ben oléifère, benzolive, arbre radis du cheval; *Spanish*: ben, árbol del ben, paraíso, morango, Moringa; *Arabic*: ruwag, alim, halim, shagara al ruwag (Sudan); *Yoruba & Nago*: èwè igbale, èwè ile, èwè oyibo, agun oyibo, ayun manyieninu, ayèrè oyibo; *Fulani*: gawara, konamarade, rini maka, habiwal hausa; *Hausa*: zogalle, zogalla-gandi, bagaruwar maka, bagaruwar masar, shipka hali, shuka halinka, barambo, koraukin zaila, rimi turawa; and *Ibo*: Ikwe oyibo

2.5.2 Related Species

The National Research Council (2006) noted that, out of the 14 *Moringa* species only *Moringa oleifera* has been accorded research and development. The rest remain almost unknown to science. The other 13 species are: *Moringa drouhardii* (Madagascar), *Moringa*

concanensis (mostly India), *Moringa arborea* (northeastern Kenya), *Moringa hildebrandtii* (Madagascar), *Moringa oleifera* (India), *Moringa borziana* (Kenya and Somalia), *Moringa ovalifolia* (Namibia and extreme southwestern Angola), *Moringa peregrina* (Horn of Africa, Red Sea, Arabia), *Moringa longituba* (Kenya, Ethiopia, Somalia), *Moringa stenopetala* (Kenya and Ethiopia), *Moringa pygmaea* (northern Somalia), *Moringa rivae* (Kenya and Ethiopia), *Moringa ruspoliana* (Kenya). NRC (2006) also noted that these other species could provide even better food ingredients, flocculants, antibiotics, oils, or wood; perhaps they have their own unique qualities; but no one knows at present.

2.6 ACTIVE INGREDIENTS IN *MORINGA OLEIFERA* SEEDS

Ndabigengesere *et al.*, (1995) found that the shelled *Moringa oleifera* contains 36.7% proteins, 34.6% lipids, and 5% carbohydrates. The un-shelled *Moringa oleifera* contains 27.1% proteins, 21.1% lipids, and 5.5 carbohydrates. Folkard *et al.* (1989) identified the active ingredient in the *Moringa oleifera* seed to be a Polyelectrolyte. According to Jahn (1988), the *Moringa* flocculants are basic polypeptides with molecular weights ranging from 6,000 to 16,000 daltons. Six polypeptides were identified with their amino acids being mainly glutamic acid, proline, methionine, and arginine. Bina (1991) identified the active ingredient as a polypeptide acting as cationic polymers; and Ndabigengesere *et al.*, (1995; 1998) reported that the active ingredients in an aqueous *Moringa oleifera* extract are dimeric cationic proteins with molecular weights of about 13 000 daltons and iso-electric point of between 10 and 11.

Preliminary studies by Gassenchmidt *et al.* (1995), on the active ingredients of *Moringa oleifera* as a coagulant, have suggested that the active components are cationic peptides of molecular weight between 6.5 – 7.0 kDa. The extract of *Moringa oleifera* was described by Ndabigengesere *et al.* 1995 as dimeric cationic proteins with molecular mass of 12-14 kDa. Tauscher, (1994) mentioned that the sequence of one of the *Moringa oleifera* proteins is

oppositively charged 6 kDa polypeptide. *Moringa oleifera* seed extract was described as water soluble protein with a net positive charge (Nkhata, 2001).

Broin *et al.*, (2002) mentioned that the molecular weight is 6 kDa and that *Moringa oleifera* contains eight (13.1% positively charged amino acids, 7 arginines and 1 histidine) and only one (1.6%) negatively charged residue (aspartic acid). As a consequence, the protein in solution is highly positively charged. Broin *et al.*, (2002) also proposed that the coagulation mechanism mainly relies on patch charge mechanism. Interestingly, according to the same study, this protein is also very rich in glutamine (14- residues, 23%). The high density of glutamine residues could favour floc formation through H-bonding among proteins coating the particles. Kebreab *et al.*, (2005) mentioned that there were no characteristic differences (molecular weight and pI) between the proteins extracted by different methods. In all cases the coagulants were proteins, as determined by the dye binding method and absorbance at 595 nm.

In addition, Kebreab *et al.*, (2005) mentioned that the protein fraction obtained during the research does not consist of a single, homogenous protein, but is a mixture of proteins with similar physical characteristics; and using mass spectrometry analysis of the protein also indicated a dominant protein with molecular weight of 4.75 kDa. Eilert *et al.*, (1981) also identified an active anti-microbial agent in the seeds. When isolated, it was found to be *4 α -4-rhamnosyloxy-benzyl-isothiocyanate*, the only known glycosidic mustard oil at present. The compound is readily soluble in water at 1.3 mol/L and is non-volatile.

2.7 TURBIDITY

The cloudiness of water is referred to as turbidity and has its origin from particles suspended in the water (Cech, 2005). These are natural contaminants and most often consist of mineral particles such as clay and silt or organic flocs. Turbidity is a measure of the cloudiness or

murkiness of water due to suspended particles i.e. organic particles, such as decomposed plant and animal matter, or living biological organisms (example algae) and inorganic particles (silt, clay and natural chemical compounds like calcium carbonate).

Turbidity is the technical term also referring to the cloudiness of a solution and it is a qualitative characteristic which is imparted by solid particles obstructing the transmittance of light through a water sample. Turbidity often indicates the presence of dispersed and suspended solids like clay, organic matter, silt, algae and other micro organisms.

Doerr (2005) classified raw water turbidity in to four different classes as show in Table 2.1
Table 2.1: Classification of Raw Water Turbidity

Raw water turbidity (NTU)	Classification of turbidity
<50	Low
50-150	Medium
150-250	High
>250	Extreme

Source: Doerr, (2005)

2.7.1 Environmental Significance

When turbid water in a small, transparent container such as drinking glass cup is held up to the light, an aesthetically displeasing opaqueness or milky coloration is apparent. The colloidal material which exerts turbidity provides adsorption sites for chemicals and for biological organism that may be harmful. They may be harmful or cause undesirable tastes and odours. Disinfection of turbid water is difficult because of the adsorptive characteristics of some colloids and because the solids may partially shield organisms from disinfectant.

In natural water bodies, turbidity may impart a brown or other colour to water and may interfere with light penetration and photosynthetic reaction in streams and lakes. Turbidity increases the load on slow sand filters. The filter may go out of operation, if excess turbidity exists. Knowledge of the turbidity variation in raw water supplies is useful to determine whether a supply requires special treatment by chemical coagulation and filtration before it

may be used for a public water supply. Turbidity measurements are used to determine the effectiveness of treatment produced with different chemicals and the dosages needed. Turbidity measurements help to gauge the amount of chemicals needed from day-to-day operation of water treatment works.

Measurement of turbidity in settled water prior to filtration is useful in controlling chemical dosages so as to prevent excessive loading of rapid sand filters. Turbidity measurements of the filtered water are needed to check on faulty filter operation. Turbidity measurements are useful to determine the optimum dosage of coagulants to treat domestic and industrial wastewaters. Turbidity determination is used to evaluate the performance of water treatment plants.

2.7.2 Principle of Turbidity

Turbidity is based on the comparison of the intensity of light scattered by the sample under defined conditions with the intensity of the light scattered by a standard reference suspension under the same conditions. The turbidity of the sample is thus measured from the amount of light scattered by the sample taking a reference with standard turbidity suspension. The higher the intensity of scattered light the higher is the turbidity. Formazin polymer is used as the primary standard reference suspension.

2.7.3 Causes of Turbidity

Turbidity can be caused by:

- Organic particles, such as decomposed plant and animal matter, or living biological organisms (example: algae)
- Inorganic particles (silt, clay and natural chemical compounds like calcium carbonate).

Turbidity in surface water bodies usually has organic and inorganic matter. It can be caused

by, heavy rains, flooding and spring runoff, landslides and bank erosion, Algae blooms, people, animals or boats disturbing the waterbed, human activities that disturb land (example: construction), storm water pollution from urban areas.

Shallow or poorly-built wells or springs may be contaminated from surface water, especially during heavy rains or spring runoff. Turbidity in groundwater is mostly inorganic and caused by natural geological factors.

Turbidity is a major problem in water treatment when the water source is surface water but can often be neglected in treatment of groundwater (Knutsson and Morfeldt, 1995).

Turbidity is usually measured in Nephelometric Turbidity Units (NTU). This is an optical measurement, where a light beam is transmitted through the water sample, and the amount of scattered and absorbed light is detected (Hammer and Hammer Jr., 2004). The World Health Organisation allows agricultural water with turbidity below 5 (WHO, 2008).

2.7.4 Some Causes of Water Scarcity

Population increase

In some European countries and in the United States, water consumption has not increased significantly since the 1970s however, in Africa and other developing countries consumption is increasing while water resources are being ruined (Acquah, 1997).

Acquah (1997) also noted that, increase in population has led to an increase in pollution and degradation of the environment raising huge challenges for policy makers. Since this increase is faster than infrastructural development, demand for freshwater in these regions are extremely high. The rapid increase in population and urbanization, particularly the conversion of watersheds into residential facilities and farmlands is leading to depletion of water resources (Goundern, 1997).

Pollution

The quality of freshwater is threatened because of pollution by domestic, industrial and agricultural wastes. The amount of domestic and industrial waste water that flows into the world's rivers in a year amounts to about 450 km³. Farming close to river banks and uncontrolled discharge of waste into freshwaters pose significant threat to water quality in rural and urban areas (Acquah, 1997).

2.8 COAGULATION AND FLOCCULATION

All waters, especially surface waters, contain both dissolved and suspended particles. Coagulation and flocculation processes are used to separate the suspended solids portion from the water. The suspended particles vary considerably in source, composition, charge, particle size, shape, and density. Correct application of coagulation and flocculation processes and selection of the coagulants depend upon understanding the interaction between these factors. The small particles are stabilized (kept in suspension) by the action of physical forces on the particles themselves. One of the forces playing a dominant role in stabilization results from the surface charge present on the particles (Qasim *et al.*, 2000).

Most solids suspended in water possess a negative charge and, since they have the same type of surface charge, they repel each other when they come close together. Therefore, they will remain in suspension rather than clump together and settle out of the water. Coagulation and flocculation occur in successive steps intended to overcome the forces stabilizing the suspended particles, allowing particle collision and growth of floc.

2.8.1 The Coagulation Process

Coagulation is accomplished by the addition of ions having the opposite charge to that of the colloidal particles. Since the colloidal particles are almost always negatively charged, the ions which are added should be cations or positively charged. The coagulating power of an ion is dependent on its valency or the magnitude of the charge. A bivalent ion (+2 charges) is 30 to

60 times more effective than a monovalent ion (+1 charge). A trivalent ion (+3 charges) is 700 to 1000 times more effective than a monovalent ion (Diaz *et al.*, 1999).

Typically, two major types of coagulants are added to water. These are aluminium salts and iron salts. The most common aluminium salt is aluminium sulphate, or alum. When aluminium sulphate is added to water, the aluminium ions enter into a series of complicated reactions. The aluminium ions become hydrated, meaning that water molecules attach themselves to the aluminium ions. In addition, anions present in the water, such as hydroxide and sulphate ions can be attached to the aluminium ions.

These reactions result in large, positively charged species having aluminium ions at their centers. These particles may have charges as high as +4. Following these reactions, a second type of reaction occurs, called flocculation. This reaction involves the bridging of two or more of these large species to form even larger, positively charged ions. A typical species can contain eight aluminum ions, twenty hydroxide ions, and will have a +4 charge. Iron salts behave in a similar manner when added to water.

Once these large polymeric aluminium or iron compounds are formed, the magnitude of their high positive charge allows these species to rapidly move toward the colloid, where they are adsorbed onto the negatively charged surface of the turbidity particle. The coagulant compounds can penetrate the bound water layer because of their high positive charge. This rapid adsorption results in the compression of the electrical double layer, and results in the colloid becoming coated with the coagulant compounds. The net result of this process is that the electrical charges on the particle are reduced. The suspension is now considered to be destabilized, and the particles can be brought together through, among other forces, Brownian movement, and will be held together by the van der Waals forces (Gregory and Duan, 2001).

An additional process occurs which assists this process. As the coagulant continues to undergo the hydrolyzation and olation reactions, progressively larger masses of flocculent material are formed. These compounds can become large enough to settle on their own, and tend to trap turbidity particles as they settle. This is commonly referred to as sweep floc.

Amirtharajah and O'Melia (1990) noted that as the coagulation reactions and destabilization are occurring, the zeta potential at the surface of the colloid is also found to be reducing. Typically, the zeta potential for naturally occurring water may be in the range of 10 to 25 millivolts. As the reactions occur, this zeta potential will be reduced to approximately 5 millivolts. These figures are only examples of what might be considered typical waters. Since all waters exhibit a specific set of characteristics, these numbers will vary. It is interesting to note that the zeta potential does not have to be reduced to zero in order for coagulation to occur, because the forces of attraction can become predominant before complete destabilization occurs.

Hydrophilic colloids participate in the coagulation process in a slightly different way. These colloids tend to attract water molecules to their surfaces. This is also a hydration process, and the water molecules act as a barrier to contact between particles. Also attached to the surfaces are hydroxyl, carboxyl, and phosphate groups, all to which are negatively charged. Coagulant products react chemically with the negatively charged groups attached to the hydrophilic colloids, forming an insoluble product which is electrically neutral and destabilized (Faust and Aly, 1999)

The first step destabilizes the particle's charges. Coagulants with charges opposite those of the suspended solids are added to the water to neutralize the negative charges on dispersed non-settlable solids such as clay and colour-producing organic substances.

Once the charge is neutralized, the small suspended particles are capable of sticking together. The slightly larger particles formed through this process and called microflocs, are not visible to the naked eye. The water surrounding the newly formed microflocs should be clear. If it is not, all the particles' charges have not been neutralized, and coagulation has not been carried to completion. More coagulant may need to be added.

A high-energy, rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Coagulants should be added where sufficient mixing will occur. Proper contact time in the rapid-mix chamber is typically 1 to 3 minutes (Raghuwanshi *et al.*, 2002)

2.8.2 Flocculation

Following the first step of coagulation, a second process called flocculation occurs. Flocculation, a gentle mixing stage, increases the particle size from sub-microscopic microfloc to visible suspended particles.

The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs called pinflocs. The floc size continues to build through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added. Macroflocs are formed. High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the sedimentation process.

Common conventional coagulants used for drinking water production are e.g. aluminium sulphate, ferric chloride, polyaluminium chlorides and synthetic polymers e.t.c. All of these

have in common the ability of producing positively charged ions when dissolved in water, which can contribute to charge neutralization (Kemira, 2003)

Aluminium sulphate and ferric chloride will also react with water to form aluminium or iron hydroxides, thus lowering the pH of the water. The formed hydroxides tend to form polymers, which through a bridging action between contaminants contribute to the flocculation process. The phenomenon where polymers are adsorbed on the surface of two particles and thus joining them together is also known as patch coagulation (Kemira, 2003).

The dosage of coagulant depends on several parameters such as type and concentration of contaminants, pH, temperature etc. It also depends on the way the coagulant is added. Rapid stirring ensures adequate mixing, and so does dosing below the surface. The optimal dosage for specific water is defined as the dosage which gives the lowest turbidity in the treated water (see Figure 2.1). Dosage beyond the optimum point will, apart from obvious disadvantages such as increased aluminium/iron content in the water, also lead to an increase in turbidity (Kalibbala, 2007).

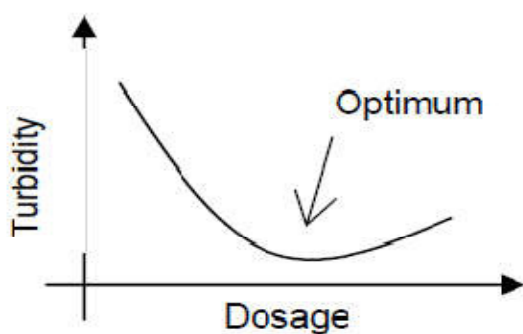


Figure 2.1 Optimum Dosage for a Specific Turbidity Level.

2.8.3 Purpose of Coagulation

Untreated surface waters contain clay, minerals, bacteria, inert solids, microbiological organisms, oxidized metals, organic colour producing particles, and other suspended materials. Some of the microbiological organisms can include Giardia-cysts, pathogenic bacteria, and viruses. Oxidized metals include iron and manganese. All of these materials can inhibit disinfection, cause problems in the distribution system, and leave the water cloudy rather than clear. The purpose of coagulation is to remove these particles. The ability of particles to remain suspended in water is a function of both the particle size and specific gravity.

Turbidity particles can range in size from molecular to 50 microns. Particles which are greater than one micron in diameter are considered silt, and settle out due to their relatively large size and density without the need to coagulate in a matter of seconds or minutes. Colloidal material ranges in size from 0.001 to one micron in diameter. These materials require days to months for complete settling (Amirtharajah and O'Melia, 1990). Since retention times in the water treatment process are generally less than twelve hours, the rate of settling of these colloidal particles must be increased in the water treatment process. This is accomplished in the coagulation process when tiny particles agglomerate into larger, denser particles which will settle more quickly.

These tiny colloidal particles have a very large surface area to mass ratio, and this factor is important in keeping the particles suspended for long periods of time. In fact, the surface area to mass ratio is so high that electric charges and ionic groups become important in keeping the particles suspended. Two types of colloids exist. These are hydrophobic or water hating colloids, and hydrophilic or water loving colloids. Hydrophilic colloids form suspensions easily, and can be difficult to remove (Gregory and Duan, 2001).

These colloids can, however, react chemically with the coagulants commonly added to water under proper conditions. Examples of hydrophilic colloids would be organic colour forming compounds. Hydrophobic colloids do not easily form suspensions. The reactions between hydrophobic colloids and the coagulants commonly added to water are largely physical rather than chemical. Examples of hydrophobic colloids would be clays and metal oxides (Gregory and Duan, 2001).

Coagulation, generally followed by filtration, is by far the most widely used process to remove the substances producing turbidity in water. These substances which normally produce turbidity consist largely of clay minerals and microscopic organisms and occur in widely varying sizes, ranging from those large enough to settle readily to those small enough to remain suspended for very long times.

Coarser components, such as sand and silt, can be removed from water by simple sedimentation. Finer particles, however, will not settle in any reasonable time and must be flocculated to produce the large particles that are settleable. It can be seen that the settling rates of the colloidal and finely divided (approximately 0.001 to 1 micron) suspended matter are so slow that removing them from water by plain sedimentation in tanks having ordinary dimensions is impossible (Faust and Aly, 1999).

The enormous increase of surface area for a given weight of solids as the particles become smaller and more numerous is an important property of colloids. Substances producing colour, as distinct from turbidity, consist either of colloidal metallic hydroxides, iron for example, or of organic compounds having a much smaller particle size. These substances, too, can be removed by coagulation, which serves to agglomerate the very small particles into sizes, which are settleable or can be removed by filter.

2.8.4 Factors Affecting Coagulation/Flocculation

Coagulation and flocculation processes are dependent on numerous inter-related factors, which sometimes make optimisation of the processes cumbersome. Such factors include the characteristics of the water source, raw water pH, alkalinity and temperature, the type of coagulant and coagulant aids and their order of addition, dose rates of coagulants, the degree and time of mixing provided for chemical dispersion and flocs formation. For water with low alkalinity coagulant can consume virtually all of the available alkalinity, hence lowering the pH to a level that hinders effective treatment, while high alkaline waters may require additional chemicals to lower the pH to values favourable for coagulation (Rossi and Ward, 1993; Kalibbala, 2007).

The performance of the hydrolysing metal salts is significantly influenced by the pH of the solution and they have a good coagulation effect within a certain pH range of the water. The coagulation process in water treatment can be modified to facilitate the removal of dissolved organic matter which has been reported to occur optimally at pH 5-6 and at maximum rate at pH 4 (Gregory and Duan, 2001).

Low temperature affects the coagulation and flocculation process by altering the coagulant solubility, increasing the water viscosity and retarding the kinetics of hydrolysis reactions and particle flocculation. Poly-aluminium coagulants are more effective in cold water than alum, as they are pre-hydrolysed. To achieve effective coagulation, proper mixing is also necessary to allow active coagulant species to be transferred onto turbid water particles (Gregory *et al.*, 1997).

Proper mixing after addition of coagulants into raw water facilitates optimum removal of fine particles in the supernatant. This is because very fine particles become transformed into aggregates under good mixing condition (Kan *et al.*, 2002). It is commonly observed that

particles are destabilised by small amounts of hydrolysing metal salts and that optimum destabilisation corresponds with the neutralisation of particle charge.

Larger amounts of coagulants cause charge reversal so that the particles become positively charged and thus restabilisation occurs, which results in elevated turbidity levels. Thus, careful control of coagulant dosage is needed to give optimum destabilisation and this is determined to a large extent by the consistency of raw water quality (Gregory and Duan, 2001).

2.8.5 Health Risks Associated with Chemical Coagulation and Flocculation

Although water treatment chemicals are effective and used worldwide, scientific evidence shows that exposure to chemicals during coagulation with metal salts could be associated with adverse health effects (Driscoll and Letterman, 1995). Aluminium, which is the major component of aluminium sulphate (alum), polyaluminium chloride (PAC) and polyaluminium silica sulphate (PASS), could induce Alzheimer's disease and other similar related problems that are associated with residual aluminium in treated water (AWWA, 1990).

Moreover, monomers of some synthetic organic polymers such as acrylamide have neurotoxicity and strong carcinogenic properties (Hashimoto *et al.*, 1991). Disinfection of the clarified water prevents the growth of microorganisms both in the treatment plant and in the distribution system, thus protecting the public from water-borne diseases. Like chemical coagulants, disinfectants (chlorine in particular) combine with natural organic matter (NOM) that may be present in water to form trihalomethanes (THMs), which are carcinogenic and/or mutagenic by-products.

These THM cannot be removed by conventional treatment methods and thus water to be chlorinated should either be free from natural organics, or if NOM is present an alternative disinfectant should be used (Tokmak *et al.*, 2004).

Alternative disinfectants such as chlorine dioxide, chloramines and ozone are also associated with the formation of disinfection by-products (DBPs) that are toxic compounds and impart objectionable taste and odour (Sadiq and Rodriguez, 2004). Irradiation with ultraviolet (UV) light is a promising alternative method of disinfection but it is expensive and leaves no residue and hence another disinfectant is required to disable bacteria and viruses. In addition, UV light can react with nitrate in water to produce nitrite, the precursor for methaemoglobinaemia in infants (Mole *et al.*, 1999).

The search for disinfectants that are cheap, maintain acceptable microbiological quality and avoid chemical risks is one of the biggest challenges facing the water treatment industry (Bove *et al.*, 2002)

2.9 APPLICATIONS OF *MORINGA OLEIFERA* IN WATER TREATMENT

The traditional use of the *Moringa oleifera* seeds for domestic household water treatment has been well known to certain rural areas in the Sudan (NRC, 2006). In the West Asia, one of the best known uses for Moringa is the use of powdered seeds to flocculate contaminants and purify drinking water (Gassenchmidt, *et al.*, 1995; Olesen, 1987), but the seeds are also eaten green, roasted, powdered and steeped for tea or used in curries (Gassenchmidt, *et al.*, 1995).

This tree has in recent times been advocated as an outstanding indigenous source of highly digestible protein, Ca, Fe, Vitamin C, and carotenoids suitable for utilization in many of the developing regions of the nations where under nourishment is a major concern. These various uses have been documented by many researchers (Fahey *et al.*, 2002; Sampson, 2005; Talalay, *et al.*, 2001). Comprehensive studies have been carried out on the use of *Moringa*

oleifera seeds extract in water treatment by (Fahey, *et al.*, 2002; Kaser, *et al.*, 1990; Okuda, *et al.*, 1999; Muyibi, *et al.*, 2003; Bichi *et al.*, 2012). Below are some of the reviews of the studies.

2.9.1 Processing of *Moringa oleifera* Seeds Powder and Extracting the Active Ingredients

The first stage in the application of *Moringa oleifera* seeds extract in water treatment is the production of *Moringa oleifera* seeds powder. This normally involves manually removing the seed coat and wings, grinding the seeds in to fine powder using a domestic blender or manually using a pestle and a mortar, and sieving. Previous researchers (Muyibi and Evison, 1995a, b) used the grinded powder without sieving. Later researchers (Okuda, *et al.*, 2001; Bichi, *et al.*, 2012) sieved the powder through a 210 µm sieve. The second stage comprises extracting the active ingredients. Previous researchers used mixing in water and filtering through Mosley cloth (Muyibi and Evison, 1995b).

Later researchers use mixing with a stirrer and filtering with whattman filter paper (Muyibi, *et al.*, 2003). Ali (2010) used six different methods: normal aqueous extraction (M1), normal salt extraction (M2), oil removal followed by aqueous extraction (M3), oil removal followed by salt extraction (M4), oil removal followed by aqueous extraction and micro-filtration or cross flow filtration (M5), and oil removal followed by salt extraction and micro-filtration or cross flow filtration (M6).

The extracted bio-active constituents were then applied to determine the method with best results. Ali (2010) found that oil removal followed by salt extraction and micro filtration produced the best result for the application of *Moringa oleifera* in water coagulation. Bichi, *et al* (2012), on the other hand, found that oil removal and aqueous extraction produced the best result for its application in water disinfection.

2.9.2 Use of *Moringa oleifera* as Coagulant

Coagulation is by far the most widely used process to remove the substances producing turbidity in water. These substances normally consists largely of clay minerals and microscopic organisms and occur in widely varying sizes ranging from those large enough to settle readily to those small enough to remain in suspension for a very long time. Colloidal and fine impurities in water possess a certain anticoagulation stability which is due to the presence of hydrate shells or a double electric field around particles.

This anti-coagulation stability of impurities can be disturbed by heating, freezing, addition of electrolytes to water or by the application of a magnetic field. This problem is most often solved by coagulating hydrophilic and hydrophobic impurities. (Nikoladze *et al.*, 1989). The active ingredient in the *M. oleifera* seed has also been identified as a polyelectrolyte (Folkard *et al.*, 1989). Its use for coagulation, co-coagulation, or coagulant aid has been a subject of investigation in many parts of the world. Most of these research works have been documented by, Sani (1990), Ndabigengesere *et al.* (1995), Muyibi and Evison (1996).

2.9.3 *Moringa oleifera* as a Primary Coagulant

Muyibi and Okuofu (1995); and Kaser, *et al.* (1990) have reported the potential use of *Moringa oleifera* seed extracts as a primary coagulant. Madsen *et al.* (1987) in a study carried out in Sudan using the Nile river water found that there was a fall in turbidity, within 1 hour, from 2000 FTU to 1- 2 FTU for the Blue Nile water; from 50 FTU to 10 FTU for the White Nile water and from 300FTU to 10 FTU for the irrigation canal water. Folkard *et al.* (1989), has evaluated the performance of *Moringa oleifera* and *M. Stenopetola* in the flocculation of turbid water with alum.

They found that both *Moringa oleifera* and *M. Stenopetola* gave equivalent performance to alum in the clarification of highly turbid waters. There was, however, a limit to the

effectiveness of the seeds on low turbidity waters, the limit varying depending on the source. In another study carried out in Kano-Nigeria, Sani (1990) reported a 92.99% reduction in turbidity within 2 hours settling period for initial turbidities ranging 205-986 NTU using *Moringa oleifera* dosages of 40 – 400 mg/L depending on initial turbidities. In a similar study by Muyibi and Okuofu (1995) working in Kano-Nigeria, three water samples from Challawa water works, Thomas reservoir and Rimin Gado water were used.

It was found that turbidity removal varied from 26.5% to 45% for Challawa water, 32.5% to 83.3% for Thomas reservoir water, and 27.8% to 49.1% for the Rimin Gado reservoir water. They also noted that for Thomas reservoir water, for example, at initial turbidity of 90 NTU, the turbidity removal was 83% while at 60 NTU initial turbidity, removal dropped to 63%. It was then concluded that, in general, turbidity removal increase with increase in initial turbidity of the raw water sample. These results confirmed the earlier findings by Jahn (1988) and Folkard *et al.* (1989).

Muyibi and Evison (1996) also worked in Kano and used water samples from Challawa and Dambatta waterworks, and Rimin Gado reservoir. The report showed that for Challawa and Dambatta water works water samples, turbidity removals were 36-98.2% and 14.3-99.4% respectively, with the dosage varying from 100 to 450 mg/l and 100 to 250 mg/l, respectively. The optimum dose of *Moringa oleifera* for the two samples was 250 mg/L. For the Rimin Gado reservoir water samples, turbidity removal varied from 17.1-95.7% with the *M. oleifera* dose varying from 100 to 450 mg/L.

It was however, observed that in this case, turbidity removal was probably inhibited by the humic substances and high natural colour of the water samples. Muyibi and Okuofu (1995) noted that since *Moringa oleifera* is a polyelectrolyte (Weber, 1972), it may not be effective as a primary coagulant for low turbidity water because such waters contain low concentration

of colloidal particles, with a low rate of inter particle contact in such systems. This is later confirmed by Muyibi and Evison (1995a).

Nwaiwu and Lingmu (2011) worked on the effect of settling time on turbidity removal using *Moringa oleifera* seed powder and found that 24 hours settling time is the best for treating low and medium turbidity water because better coagulation and higher turbidity removal was achieved at that time. This result contradicts the findings by Katayon *et al.* (2004) and Muyibi and Evison (1995a) which indicated that *Moringa oleifera* seed extract may not be an efficient coagulant for low turbid water. This variation in results may be due to the fact that seeds from different sources (geographic locations) exhibit varying coagulation performance (Narasiah *et al.*, 2002) as a result of different protein contents of the seeds.

Also, Ali *et al.* (2010) found that microfiltered *Moringa oleifera* was good enough to achieve 94.82% turbidity removal for low turbidity (44.2 NTU), they also found that ultrafiltered *Moringa oleifera* was more efficient in reducing the turbidity of a low turbid water at a very low dosage of 0.8 mg/l without altering with the pH of the water this result corroborates the findings by Nwaiwu and Lingmu (2011) and contradicts the findings by Katayon *et al.* (2004) and Muyibi and Evison (1996).

The results of this research work also showed that the processed *Moringa oleifera* seed can be used for river water treatment. A dose of 0.8 mg/L of processed *Moringa oleifera* seed was enough to get residual turbidity of 2.29 NTU for microfiltered and 2.17 NTU for ultrafiltered *Moringa oleifera* seed, while 5 mg/L of aluminium sulphate is needed to treat the same turbidity. The residual turbidity was less than the standard drinking water turbidity of less than 5 NTU. The pH of treated water is very important as the potable water should have pH between 6.5-8.5 according to (WHO, 2006). The pH for water treated with processed *Moringa oleifera* seed was 7.03 for microfiltered and 6.79 for ultrafiltered *M. oleifera* seed,

which is within the standard range, while it was 5.81 for water treated with aluminium sulphate. Therefore, it is important to add the lime to adjust the pH and this is an additional cost for water treatment industry.

In another study conducted by Gidde *et al.*, (2012) to compare the effectiveness of the three coagulants namely; shelled blended, de-oiled powder and protein powder at the same concentration for high, medium and low turbidity water, they found that shelled blended *Moringa oleifera* coagulant was able to achieve 76.4% turbidity removal at an optimum dosage of 70 mg/L for 50 NTU while for 150 and 450 NTU turbidity, the dosage were 120 mg/L and 240 mg/L at 92.33% and 97% percentage turbidity removal respectively. They also found that de oiled powder of *Moringa oleifera* was able to achieve 77.8% turbidity removal at an optimum dosage of 50 mg/L for 50 NTU whilst for 150 and 450 NTU turbidity, the optimum dosage were 90 mg/L and 120 mg/L at 95.86 and 98.11% percentage turbidity removal respectively. The protein powder extract of *Moringa oleifera* was able to achieve 84.4% turbidity removal at an optimum dosage of 20 mg/L for 50 NTU whilst for 150 and 450 NTU turbidity, the dosage were 40 mg/L and 100 mg/L respectively and percentage turbidity removal was 95.86 and 98.11%. The findings by Gidde is in conformity with that of Nwaiwu and Lingmu (2011) and contradicts the findings by Katayon *et al.*, (2004) and Muyibi and Evison (1996) on low turbidity water,

From the results above it could be seen that at 50 NTU, 28.57% reduction in dose in de oiled powder and 71.42% reduction in protein powder were observed, also at 150 NTU the percentage reduction in dose for de oiled powder was 66.66%. Lastly for 450 NTU the percentage reduction in dose for de- oiled powder was 12.5% and 58.38% for protein powder. In a recent study, Patik and Sadgir (2013) used Bentonite clay, kaolin and black cotton soil for preparing turbid water of 50 NTU. *Moringa oleifera* seed suspension was added in concentration of 20, 40, 60 and 80 mg/L. The turbidity of water sample was reduced to 3.4

NTU for a dose of 50 mg/L using alum as coagulant for bentonite clay, the turbidity of water has further reduced to 0.2 NTU for *M.oleifera* seed suspension as coagulant for bentonite clay. In case of kaolin, the turbidity has reduced to 5.1 NTU using 80 mg/L of alum dose. Abnormal behaviour was observed for *Moringa oleifera* as coagulant for kaolin. Turbidity has reduced to 3.7 NTU using 80 mg/L of alum dose for black cotton soil similarly, reduction to 1.3 NTU was observed using 60 mg/L dose of *Moringa oleifera* for black cotton soil.

Most works on the use of *Moringa oleifera* in coagulation employ the parameters used in conventional jar tests to evaluate the coagulating efficiency of the seed extract. However, Muyibi and Evison (1995b) investigated among others, the multiple effects of physical parameters of rapid and slow mixing rates and times on coagulation of turbid water with *Moringa oleifera*. Using the single factor method of optimization and optimum dosage, it was observed that at initial turbidity of 50 NTU (low turbidity), the rapid mix velocity gradient and time was 432/s and 1 min respectively. Also for initial turbidity of 225-750 NTU (moderate to high), the optimum rapid mix velocity gradient and time was 443/s and 4 min respectively. The residual turbidity recorded was less than 10 NTU in all cases. Similarly, the optimum slow mix velocity gradient and time recorded were 149.9/s and 20 min for low turbidity water; and 208.3/s and 25min for medium and high turbidity water.

2.9.4 Co-coagulation of *Moringa oleifera* with Alum

Investigations were carried out on the use of *Moringa oleifera* in conjunction with alum. Folkard *et al.* (1989) reported dramatic improvements in floc characteristics and significant savings in imported alum usage of the order of 50 to 80%. Muyibi and Okuofu (1995) also observed that the flocs formed in conjunctive use were bigger, denser and settled faster after slow mixing, than when alum or *Moringa oleifera* alone were used. Furthermore, rates of floc formation and settling were reported to be comparable to alum in the range of raw water turbidities (26-40 NTU) considered. Saving in alum use in the range of 40-80% was similarly

reported, depending on the raw water and the quality of the product water desired. In the same study, it was noted that as optimum dose of alum was reduced by 80%, 60%, and 40% and the *M. oleifera* seed dose increased by 10 mg/L from 20 mg/L to 50 mg/L, respectively the residual turbidity of the water decreased. In another study, Muyibi and Evison (1996) reported a saving of up to 40% in alum use when *M. oleifera* was used as a co-coagulant. The lowest residual turbidity was recorded at a combination of 30 mg/L alum + 40 mg/L *Moringa oleifera*.

2.9.5 *Moringa oleifera* as a Coagulant Aid

Since *Moringa oleifera* seed extract is a polyelectrolyte, it may be able to function as a coagulant aid, using alum as the primary coagulant (Jahn, 1982). This possibility was a subject of study in recent times. Muyibi and Okuofu (1995) reported that in one investigation, the optimum dose of alum without *Moringa oleifera* was 40 mg/L. When *M. oleifera* was used as a coagulant aid, the optimum dose of *Moringa oleifera* was found to be 10 mg/L while alum was 20 mg/L. The optimum time of application of *Moringa oleifera* was found to be 50 seconds' after slow mixing. It was further noted that the flocs formed were dense and settled faster than with alum alone. The residual turbidity was also found to be much lower than that of alum alone.

Gidde *et al.*, (2012), compared different forms of *Moringa oleifera* extract viz; shelled blended, deoiled and protein powder for turbidity removal and found that at optimum dosage, the percentage turbidity removal increase with initial turbidity in the case of all three coagulants. Also found that among the three forms, protein powder has more removal efficiency than deoiled and shelled blended powder respectively.

In another study Goja and Osman (2013) worked on the efficiency of leaves, seeds and bark of *moringa oleifera* in reducing bacterial load in water and found that the seed extract shows a

great effect in reducing the total coliform count (55.9%) and faecal coliform count (92.5%) as compared to bark (45.0 and 90.7%) and leaf (47.1% and 88.7%) extracts at 3g/100ml respectively. In another study, Wuana *et al.* (2015) investigated and found that moringa oleifera pod husk; Activated and Carbonized at equilibrium shows optimal removal efficiencies of 90.98% at a pH of 5.

Moringa oleifera is a versatile plant that has a wide applicability, solvent extraction using various solvent is not common and is usually more efficient than mechanical process. Since the oil content is hindering its efficiency in drinking water treatment and on the other wing, the oil has wide applicability in other sectors, therefore it is imperative to investigate the suitability of other solvents in the extraction other than the commonly used hexane. Recently Efoevbokhan *et al.* (2015) investigated the suitability of three solvent; Hexane, Isopropyl Alcohol and Petroleum Ether in the extraction of *Moringa oleifera* seed oil from the northern and southern part of Nigeria using soxhlet extractor and found that petroleum ether gave the highest oil yield of 49.38% and 37.57%, next was hexane with 44.94% and 34.71% while isopropyl alcohol gave 36.39 and 28.43% for samples from northern and southern part of Nigeria. They also found that percentage yield of oil from the two samples was found to be dependent on the solvent used, extraction time and the source of the seed sample. From the above finding it could be concluded that petroleum ether is a better solvent for de-fattening and therefore there is a need to check the efficiency of petroleum ether in extraction of oil from *Moringa oleifera* seed.

The findings by Goja and Osman (2013); Wuana *et al.* (2015); Melesse and Berihum, (2013); Efoevbokhan *et al.* (2015) and many other researches will serve as a basis for research.

Although many studies have been carried out on *Moringa oleifera*'s efficiency as a coagulant (Muyibi and Okuofu, 1995; Muyibi and Evison, 1995, 1996), studies on the efficiency of the

pod in turbidity removal on surface water is rare or have not been established yet. This is why this study set out to investigate the efficiency of the pods (seed removed pods) powder in turbidity removal from surface water.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

The materials used in this research work were; *Moringa oleifera* seeds, *Moringa oleifera* pods, Aluminium sulphate and synthetic raw water.

3.2 METHODS

3.2.1 Sample Collection

A good quality, matured and naturally tree dried *Moringa oleifera* seed pods were obtained from Bayero University Farm, Faculty of Agriculture. Completely dried pods were collected from the tree.

3.2.2 Sample Preparation

The seeds were removed manually from the pod, the husk and wings were removed with hands from the seeds to obtain the kernels. The kernels were ground to powder using a manual grinding machine. The powder was stored in an enclosed plastic container prior to extraction.

The seed-removed pods in the above were collected and ground manually using a clean pestle and mortar and sieved with BS sieve no. 250 μm to obtain the fine powder. The powder was stored in an enclosed plastic container prior to extraction.

3.2.3 Extraction of Oil from the Seed and Pod Powder

The oil was extracted from the seeds because the presence of oil in the *Moringa oleifera* seed would affect the coagulation activity (Garcia-fayos *et al.*, 2010).

The soxhlet extraction method was used to extract the oil from *Moringa oleifera* (Ali *et al* 2010). 10 g of *Moringa oleifera* seed powder was weighed with a sensitive weighing balance (ae ADAM Model: AAA 250L, UK) and carefully folded into a fat-free filter paper and a

small fat-free cotton wool placed on top. This was properly tied with a thread at both ends and carefully placed in the extraction thimble and a small cotton wool placed on top. The whole Soxhlet apparatus was then connected after the addition of 300 ml of Petroleum ether (60-80°C, JHD, China). The extraction was then carried out using the heating mantle (Thermo Scientific, Serial No. 10066984/00, UK) evaporating the petroleum ether through three cycles, each cycle for 30 min until the extraction solvent became colourless (Muyibi *et al.*, 2003), and made sure there was continuous flow of water in the condenser. The sample was then removed and air dried at room temperature for 24 hours (AOAC, 1995). This process was repeated until the desired quantity required for the whole experiment was achieved for both the *Moringa oleifera* seed and pod powder.

3.2.4 Preparation of Turbid Water Samples

5 g of kaolin clay was weighed, mixed with 500 mL of tap water in a beaker. Mixed clay sample was allowed to soak for 24 h. Suspension was then stirred for 10 minutes with a magnetic stirrer (Model: BS 5000PART11, England) so as to achieve uniform and homogeneous sample. Resulting suspension was then used as stock solution for preparation of turbid water samples. The stock sample of kaolin clay was diluted with tap water to get desired raw water turbidity for daily experiment (Gidde *et al.*, 2012).

For the purpose of this research, synthetic water with high turbidity (495 NTU) and medium turbidity (100 NTU) were diluted.

3.2.5 Preparation of Coagulants

In this section four coagulants were prepared; three are natural coagulants while the fourth is a conventional coagulant. Coagulant 1 (*Moringa oleifera* seed powder), coagulant 2 (*Moringa oleifera* pod powder), coagulant 3 (combination of 50% of *Moringa oleifera* seed and 50% of *Moringa oleifera* pod powder) and coagulant 4 (Aluminium Sulphate).

i. Coagulant 1

3%, 6% and 9% (w/v) of *Moringa oleifera* seed powder were separately dissolved in beakers containing 100 mL of distilled water and stirred for ten minutes using a magnetic stirrer (Model: BS 5000PART11, England) to release the active components (Jahn, 1988). The resulting suspension was then filtered through a muslin cloth and re-filtered through a filter paper (Watman No.1, England) to give stock solutions with approximate concentrations of 30,000 mg/L, 60,000 mg/L and 90,000 mg/L. These stock solutions were used in the experiment. The stock solution was prepared fresh for use on daily basis, since deterioration sets in if stored for more than two days at room temperature (Muyibi and Evinson, 1994).

ii. Coagulant 2

3%, 6% and 9% (w/v) of the *Moringa oleifera* pod powder were separately dissolved in three different 250 mL capacity beakers containing 100 ml of distilled water each and stirred for ten minutes using a magnetic stirrer (Model: BS 5000PART11, England) to release the active components (Jahn, 1988). The resulting suspension was then filtered through a muslin cloth and re-filtered through a filter paper (Watman No.1, England) that gave stock solutions with approximate concentrations of 30,000 mg/L, 60,000 mg/L and 90,000 mg/L. The stock solutions were used in experiments.

iii. Coagulant 3

3% ,6% and 9% (w/v) of the *Moringa oleifera* combined (seed and pod) powder were separately dissolved in 250 mL capacity beakers containing 100 ml of distilled water and stirred for ten minutes using a magnetic stirrer (Model: BS 5000PART11, England) to release the active components (Jahn, 1988). The resulting suspension was filtered through a muslin cloth and re-filtered through a filter paper (Watman No.1, England) to give stock solutions with approximate concentrations of 30,000 mg/L, 60,000 mg/L and 90,000 mg/L.

The stock solution was prepared fresh for use when needed, since deterioration sets in if stored for more than two days at room temperature (Muyibi and Evinson, 1994)

iv. Coagulant 4

3, 6 and 9% (W/V) of Aluminium Sulphate (laboratory Grade) were separately dissolved in 250 mL capacity beakers containing 100 ml of distilled water and stirred for ten minutes using a magnetic stirrer (Model: BS 5000PART11, England). The resulting suspension was filtered through a filter paper (Watman No.1, England), to give stock solutions with approximate concentrations of 30,000 mg/L, 60,000 mg/L and 90,000 mg/L.

3.3 COAGULATION TEST

Jar test is commonly use in measuring coagulation activity. Jar test for this study was carried out using a Flocculator (Model: PEF, Serial No.PEF003/11, Spain) which consists of six (6) beakers. Each of the 1000 mL capacity beakers were filled with raw water with identical turbidity level. Varying dosage of the coagulants (0, 1.7, 3.3, 6.7, 10, 13.3 ml) were applied to the beakers. The water samples were agitated simultaneously and different rotational speeds were varied accordingly. After 4 minutes of rapid mixing (125 rpm), the stirring speed was then lowered (40 rpm) and this rate were kept for 25 minutes allowing simulation of different mixing intensities and resulting flocculation process. The propellers were then stopped completely and the sample was allowed to settle for 1h (Muyibi *et al.*, 2003). After 1h settling time, supernatant was collected from each beaker and residual turbidity was measured which served as the basis for determining the efficiency of each of the coagulants. This procedure was followed in testing the efficiencies of all the coagulants for both turbid waters. For reliable and valid results every experiment was performed in duplicate.

3.4 DETERMINATION OF THE OPTIMUM pH

Jar test was performed to determine the effect of pH on *Moringa oleifera* performance. To each of the 1000 mL capacity beaker, raw water with identical turbidity were filled to

capacity in five beakers. Using 1 molar solution of either HCl or NaOH, the pH value of the water sample in each of the five beakers were adjusted to (the WHO pH range for drinking water) 6.5, 7.0, 7.5, 8.0 & 8.5. The optimum dosage for each coagulant at various concentrations and for both turbid waters obtained in SECTION 4.1 during the coagulation test were used, jar test was then performed similar to (Muyibi *et al.*, 2003). The optimum pH was determined based on the pH value with highest turbidity removal efficiency. This process was performed for all the three natural coagulants for both turbid waters. For reliability and accuracy in the results, all experiments were performed in duplicate.

3.5 DETERMINATION OF TURBIDITY

3.5.1 Calibration of Turbidity Meter (Portable Turbidity, Model: SGZ-200BS, England)

The standard solution was used to calibrate the instrument and the detection range was adjusted to 1000 NTU.

Step 1

Distilled water was added to the sample cell up to the horizontal mark and was wiped gently with soft hand towel. The sample cell was then covered and placed in to the turbidity meter such that the vertical mark on the sample cell coincides with the mark on the turbidity meter and the dial cap placed. Then using the set zero knobs, the reading on the turbidity meter was adjusted to zero.

Step 2

A 400NTU standard solution was added to the sample cell up to the horizontal mark and wiped gently with soft hand towel. The sample cell was covered and inserted in to the slotter such that the vertical mark on the sample cell coincides with the mark on the turbidity meter and the dial cap placed. The stable reading on the turbidity meter was observed and recorded, when the stable reading on the instrument is not 400 NTU, using the calibration knob the

reading was adjusted to 400 NTU. This procedure was repeated three times prior to the main experiment.

3.5.2 Testing of Water Sample

To the sample cell, the water sample was added up to the horizontal mark, wiped gently with soft hand towel, covered and inserted in to the slotter of turbidity meter such that the vertical mark on the sample cell coincides with the mark on the turbidity meter with the dial cap placed for auto sensing by the meter. The stable reading on the screen of the turbidity meter was observed and the value is recorded as the turbidity. This procedure was followed to test the turbidity in all the water samples.

$$T_1 - T_2 \times 100$$

T_1 = initial turbidity of the raw water

T_2 = Final turbidity after treatment

3.6 DETERMINATION OF pH

3.6.1 Calibrating the Instrument (Model pHS-25, China)

The buffer solutions with values pH of 9.2, 7.0 and 4.0 were used to calibrate the pH meter used in this research.

Step 1

In a 100 mL beaker, a buffer solution with pH value of 9.2 was placed and mixed with a magnetic stirrer to achieve uniform and homogeneous solution. The electrode of the pH meter was then inserted in to the beaker containing the stirred buffer solution. The stable reading on the screen of the meter was observed. When the instrument was not showing pH value of 9.2, using the calibration knob the pH was adjusted to read 9.2. The electrode was removed from the buffer, rinsed with distilled water and then wiped gently with soft hand towel.

Step 2

In a 100 mL beaker, a buffer solution with pH value of 7.0 was placed and mixed with a magnetic stirrer to achieve uniform and homogeneous solution. The electrode of the pH meter was then inserted in to the beaker containing the stirred buffer solution. The stable reading on the screen of the meter was observed. When the pH value on the screen is not equal to 7.0, using the calibration knob the pH is adjusted to 7.0. The electrode was then removed from the buffer, rinsed with distilled water and then wiped gently with soft hand towel.

Step 3

In a 100 mL beaker, a buffer solution with pH value of 4.0 was placed and mixed with a magnetic stirrer to achieve uniform and homogeneous solution. The electrode of the pH meter was then put in to the beaker containing the stirred buffer solution. The stable reading on the screen of the meter was observed. When the instrument was not showing a pH value of 4.0, using the calibration knob the pH value was adjusted to read to 4.0. The electrode was removed from the buffer and rinsed with distilled water and then wiped gently with soft hand towel until dried.

3.6.2 Testing of Samples

In a clean beaker containing the water sample, the electrode was carefully placed and the stable reading displayed on the screen of the meter was recorded. The electrode was then removed out of the water sample, rinsed with distilled water and wiped with soft hand towel until dried. This procedure was followed in testing the pH for all the water samples.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Jar test experiments with different *Moringa oleifera* coagulant forms (seed, pod and combined extract) were performed. These coagulants were prepared by using a standard preparation method as discussed in Chapter Three. Initially the optimum dosage for each coagulant was determined, this was the dosage of coagulant corresponding to the lowest residual turbidity in NTU or highest turbidity removal in percentage.

4.1 OPTIMUM DOSE FOR EACH OF THE COAGULANTS

4.1.1 Optimum Dose of *Moringa oleifera* Seed Powder

a. Concentration of *Moringa oleifera* Seed Powder (3% w/v)

Figure 4.1 represent the results obtained when different doses of 3% concentration of *Moringa oleifera* seed extract were used to treat high and medium turbid waters (495 NTU and 100 NTU). Turbidity removal efficiencies of 97.6% and 81.4% for both turbid waters were achieved at same optimum dosage of 100 mg/L. This result corroborates with the findings of Sani (1990), Muyibi and Okufor (1995) who reported a 92.99% reduction in turbidity for water with initial turbidity ranging 205-986 NTU using *Moringa oleifera* dosages of 40 – 400 mg/L.

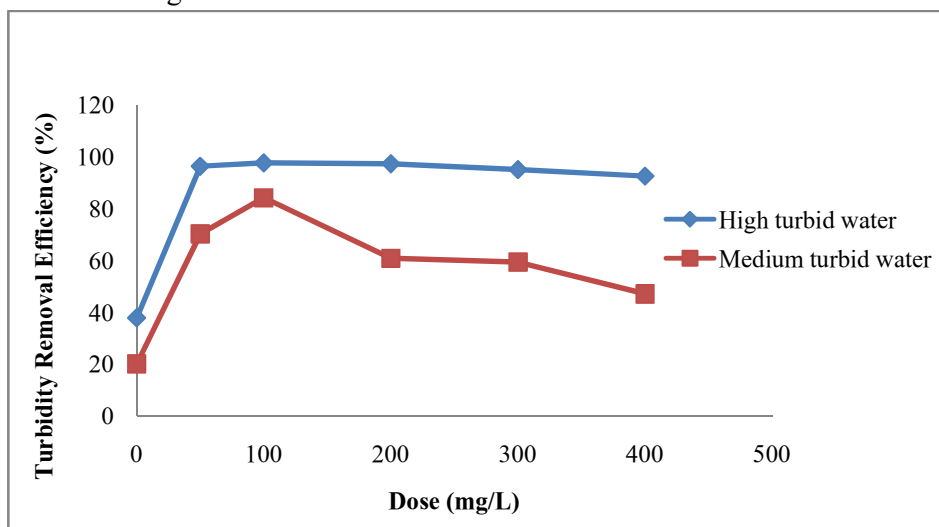


Figure 4.1: Dose of 3% Conc. of *Moringa oleifera* seed extract for 495 and 100 NTU

b. Concentration of *Moringa oleifera* Seed Powder (6% w/v)

It can be observed that 6% concentration of *Moringa oleifera* seed extract achieved turbidity removal efficiencies of 92% and 73.2% for high and medium turbid waters at a common optimum dose of 102 mg/L as shown in Figure 4.2. From the result obtained, it can be clearly stated that, the optimum dose of *Moringa oleifera* seed for waters with initial turbidity ranging between 100-500 NTU is somewhat the same.

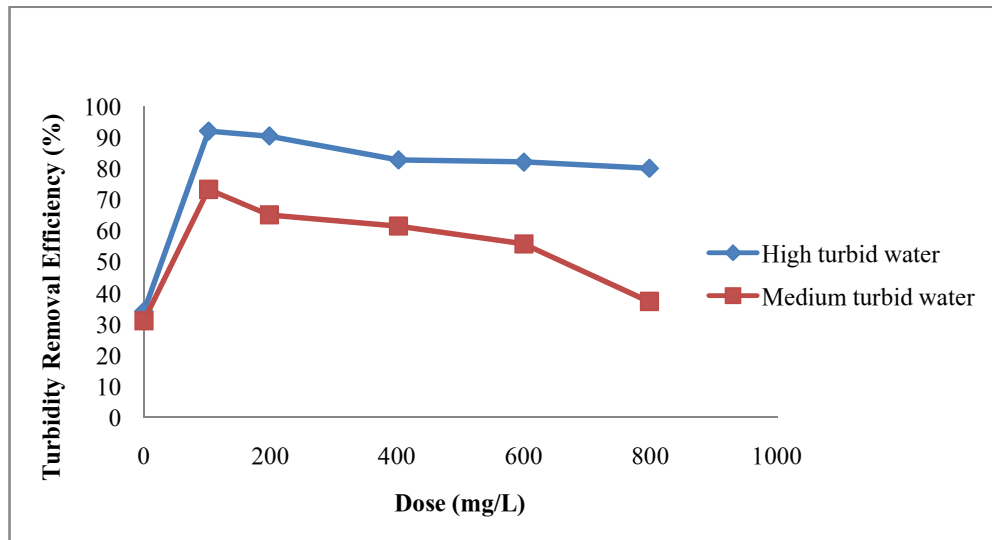


Figure 4.2: Dose of 6% Conc. of *Moringa oleifera* Seed Extract for 495 NTU and 100 NTU

c. Concentration of *Moringa oleifera* Seed Extract (9% w/v)

Figure 4.3 shows the results of coagulation with 9% concentration of *Moringa oleifera* seed extract. From the result it can be clearly seen than a turbidity removal efficiency of 95.8% was achieved at an optimum dose of 153 mg/L for water with initial turbidity of 495 NTU whereas 51.5% turbidity removal efficiency was achieved with the same optimum dose for water with initial turbidity of 100 NTU. These results agree with the findings of Muyibi and Okufo (1995) who noted that since *Moringa oleifera* is a polyelectrolyte, it may not be effective as a primary coagulant for low/medium turbidity water because such waters contain low concentration of colloidal particles, with a low rate of inter particle contact in such systems.

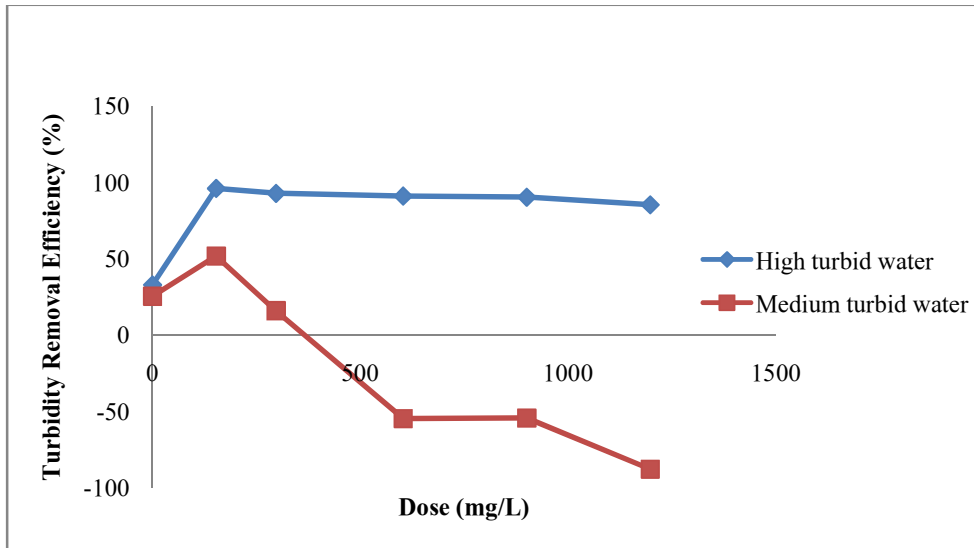


Figure 4.3: Dose of 9% Conc. of *Moringa oleifera* Seed Extract for 495 NTU and 100 NTU

4.1.2 Optimum Dose of *Moringa oleifera* Pod Extract

a. Concentration of *Moringa oleifera* Pod Powder (3% w/v)

The optimum dose of a coagulant is that dosage which yields the highest turbidity removal efficiency in percentage (%) or least residual turbidity in NTU. From Figure 4.4, it can be seen that, the optimum dose for 3% concentration of *Moringa oleifera* pod extract for high turbidity water (495 NTU) was 100 mg/L with 76.4% turbidity removal efficiency whilst for medium turbidity water (100 NTU), the optimum dose was found to be 200 mg/L with 80.0% turbidity removal efficiency. From the results obtained it can be deduced that 3% concentration of *Moringa oleifera* pod extract is more effective in turbidity removal from medium turbid water than high turbid water. The result obtained in this study is in consonance with 75-200 mg/L range of optimum dosage (Folkard *et al.*, 2005).

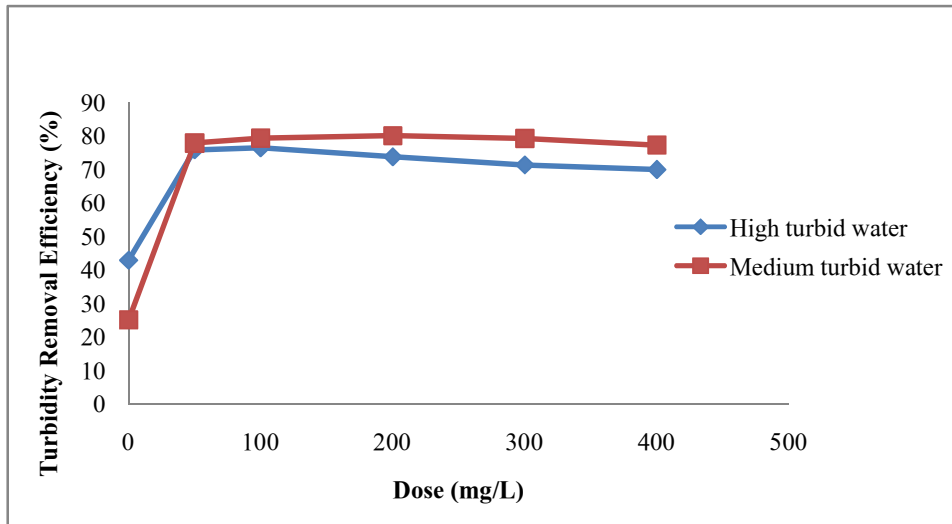


Figure 4.4: Dose of 3% Conc. of *Moringa oleifera* Pod Extract for 495 and 100 NTU

b. Concentration of *Moringa oleifera* Pod Extract (6% w/v)

Figure 4.5 below explain the results obtained when 6% concentration of *Moringa oleifera* pod extract was used to treat raw water with initial turbidity of 495 and 100 NTU, 84.3 and 81.1% turbidity removal efficiencies were achieved at an optimum dosage of 198 mg/L for both turbid waters as shown in the Figure 4.5. This same value of optimum dose for both high and medium turbidity water could be due to fact that, medium turbidity water contains less colloidal particles with low rate of inter particle contact as a result exerts higher dose of the coagulants for effective coagulation process (Muyibi and Evison, 1995a).

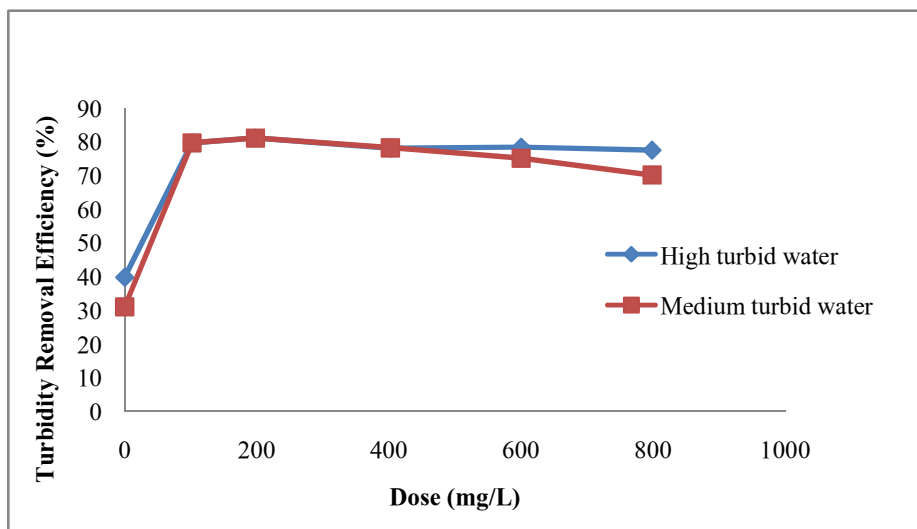


Figure 4.5: Dose of 6% Conc. of *Moringa oleifera* Pod Extract for 495 and 100 NTU

c. Concentration of *Moringa oleifera* Pod Powder (9% w/v)

Figure 4.6 shows the result of coagulation with 9% concentration of *Moringa oleifera* Pod extract. From the results it can be seen that, 74.5% and 80.8% turbidity removal were recorded at same optimum dose of 153 mg/L for both 495 NTU and 100 NTU respectively.

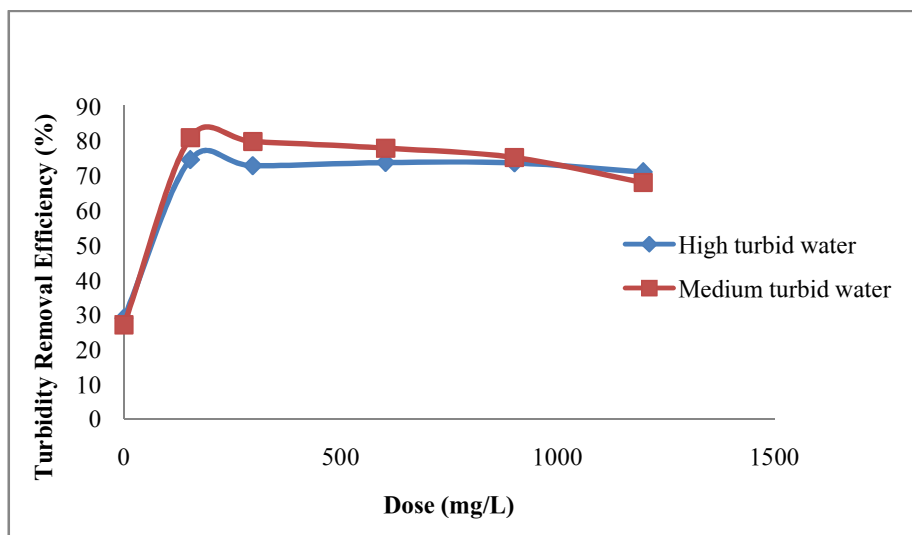


Figure 4.6: Dose of 9% Conc. of *Moringa oleifera* Pod Extract for 495 and 100 NTU

4.1.3 Optimum Dose of *Moringa oleifera* Combined (Seed and Pod) Extract

a. Concentration of *Moringa oleifera* Combined (Seed and Pod) Extract (3% w/v)

The results of jar test experiment with 3% concentration of combined (seed and Pod) extract are presented in figure 4.7. The result revealed that, when different range of dosages of *Moringa oleifera* combined extract were applied to raw waters with initial turbidity of 495 NTU and 100 NTU their optimum doses were found to be 200 mg/L and 300 mg/L with 95.2% and 85.1% turbidity removal efficiencies respectively. From the results, it can be seen that 3% concentration of the combined extract is more effective in turbidity removal from high turbid water this is because with lower dosage higher turbidity removal efficiency were achieved with high turbid water.

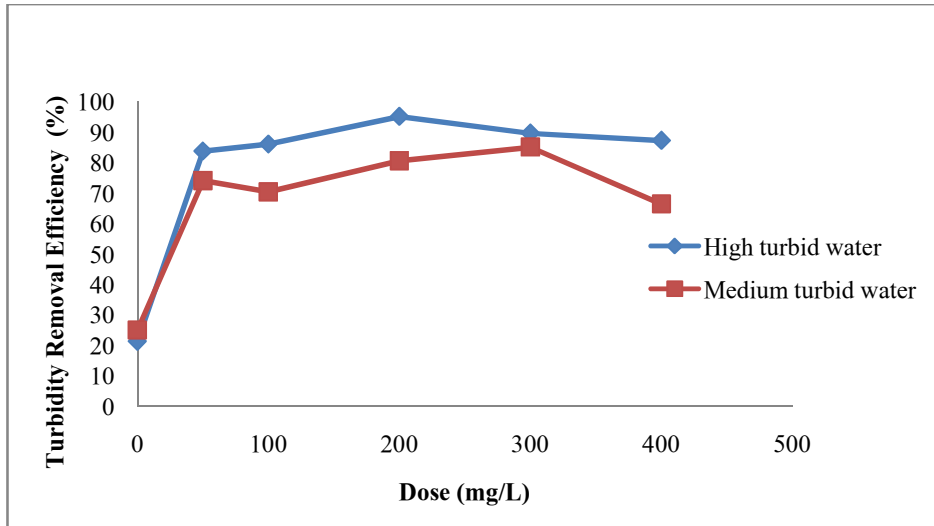


Figure 4.7: Dose of 3% Conc. of Combined *Moringa oleifera* (Seed and Pod) Extract for 495 NTU and 100 NTU

b. Concentration of *Moringa oleifera* Combined (Seed and Pod) Extract (6% w/v)

The figure below represents the results obtained when different dosages of 6% concentration of *Moringa oleifera* combined extract were employed in treating water with 495 and 100 NTU. It can be observed that the highest turbidity removal efficiency of 87.3% was recorded at an optimum dose of 102 mg/L, for the high turbid water whereas for the medium turbid water 85.6% was achieved as the highest turbidity removal efficiency at an optimum dose of 402 mg/L as illustrated in Figure 4.8.

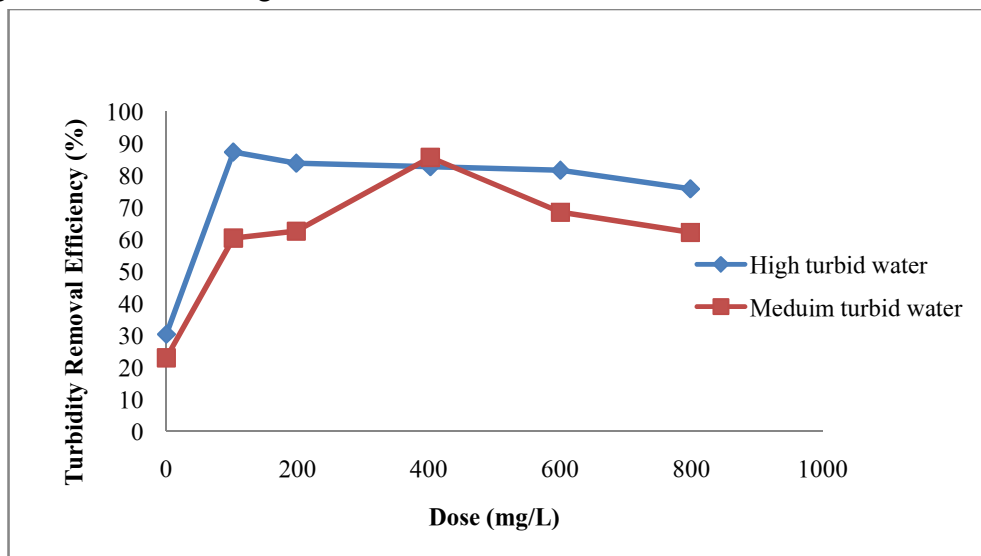


Figure 4.8: Dose of 6% Conc. of Combined *Moringa oleifera* (Seed and Pod) Extract for 495 NTU and 100 NTU

c. Concentration of *Moringa oleifera* Combined (Seed and Pod) Extract (9% w/v)

Increasing the concentration of the stock solution to 9%, turbidity removal efficiencies of 95.5% and 70.6% were accomplished for water with initial turbidity of 495 NTU and 100 NTU at optimum dosages of 153 mg/L and 297 mg/L respectively. It is obviously seen that, increasing the concentration of the stock solution increased the removal efficiency in high turbidity water of 495 NTU and vice versa with medium turbidity water of 100 NTU. From the result of this study, it can be inferred that with low dosage of 9% concentration of *Moringa oleifera* combined extract, high turbidity removal efficiency was recorded in high turbid water while with medium turbid water, low turbidity removal efficiency at high dosage of the extract. This could be because medium turbidity water contains less colloidal particles with low rate of inter-particle contact as a result exerts higher dose of the coagulants for effective coagulation process. The details can be seen in Figure 4.9.

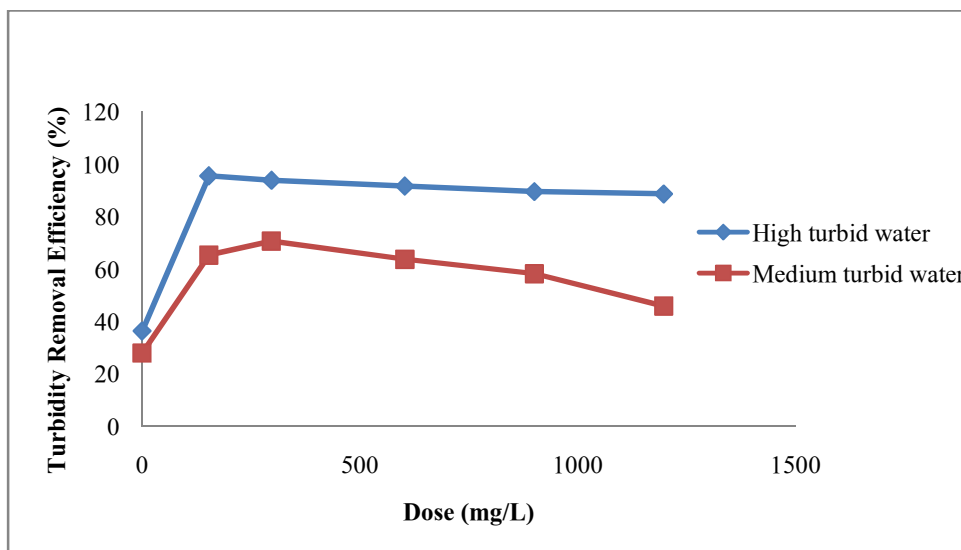


Figure 4.9: Dose of 9% Conc. of *Moringa oleifera* Combined (Seed and Pod) Extract for 495 NTU and 100 NTU

4.2 OPTIMUM pH OF *MORINGA OLEIFERA* SEED, POD AND COMBINED (SEED AND POD) EXTRACT

In this section, the optimum doses obtained in Section 4.1 for each of the coagulants at 3%, 6% and 9% was used to treat both the high and medium turbid water at different pH values.

4.2.1 Optimum pH of *Moringa oleifera* Seed Extract

a. Concentration of *Moringa oleifera* Seed Powder (3% w/v)

Figure 4.10 shows the turbidity removal efficiencies of 3% concentration of *Moringa oleifera* seed extract when used to treat high and medium turbid waters with different initial pH values. When the optimum dose was applied to the high turbid water with different initial pH values, it was observed that *Moringa oleifera* has less treatment ability in water with pH ranging from 7- 8.5 as compared to its best turbidity removal efficiency of 97.7% attained at the pH of 6.5. Therefore, the optimum pH value is 6.5. A similar trend was observed when medium turbid water with different initial pH values were treated with the optimum dose, with the highest turbidity removal efficiency recorded at 76.4%. This result is in consonance with previous studies on the optimum pH range of *Moringa oleifera* seed extract for turbidity removal (Cohen & Hannah, 1971).

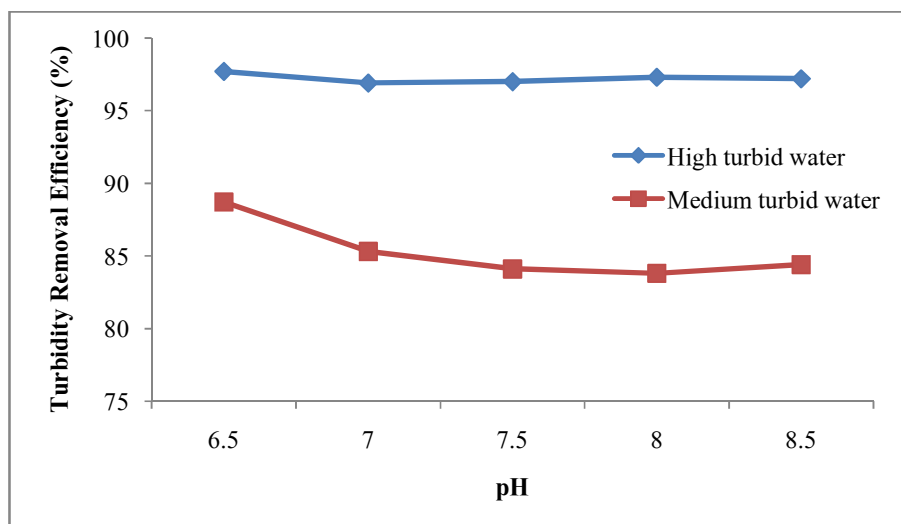


Figure 4.10: pH of 3% Conc. of *Moringa oleifera* Seed Extract for 495 NTU and 100 NTU

b. Concentration of *Moringa oleifera* Seed Powder (6% w/v)

The results obtained when the optimum dose of 6% concentration of *Moringa oleifera* seed was used to treat high and medium turbid waters with pH ranging from 6.5-8.5 are presented in Figure 4.11. For high turbid water, it was found that at the optimum dose the *Moringa oleifera* seed extract had limited turbidity removal ability in pH ranges of 7 to 8.5 likewise for medium turbid water. The optimum pH was found to be 6.5 for both turbid waters as the highest turbidity removal efficiencies occurred at that pH.

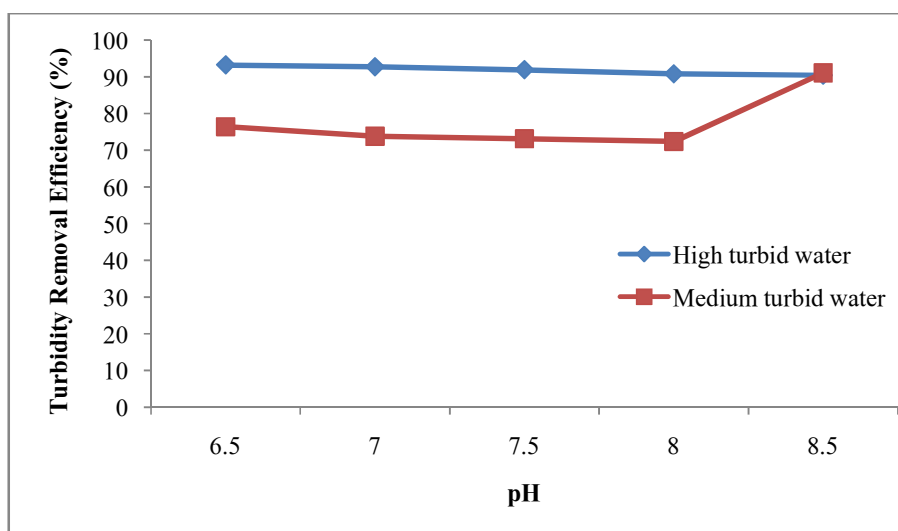


Figure 4.11: pH of 6% Conc. of *Moringa oleifera* Seed Extract for 495 NTU and 100 NTU

c. Concentration of *Moringa oleifera* Seed Powder (9% w/v)

When the optimum doses of 9% concentration of *Moringa oleifera* seed obtained in Section 4.1 were used to treat raw waters (495 and 100 NTU) with pH values adjusted within the WHO standard for drinking water, the results obtained are illustrated in Figure 4.12. For the high turbid water, it can be observed that low turbidity removal capability occurred at pH of 7 and 7.5, a better removal efficiency occurred at pH values of 8 and 8.5 while the best turbidity removal efficiency of 96.3% can be seen to have occurred at the pH of 6.5. In the case of the medium turbid water, marginal turbidity removal efficiency occurred across the pH ranges with the best turbidity removal ability of 56.1% occurring at pH of 6.5.

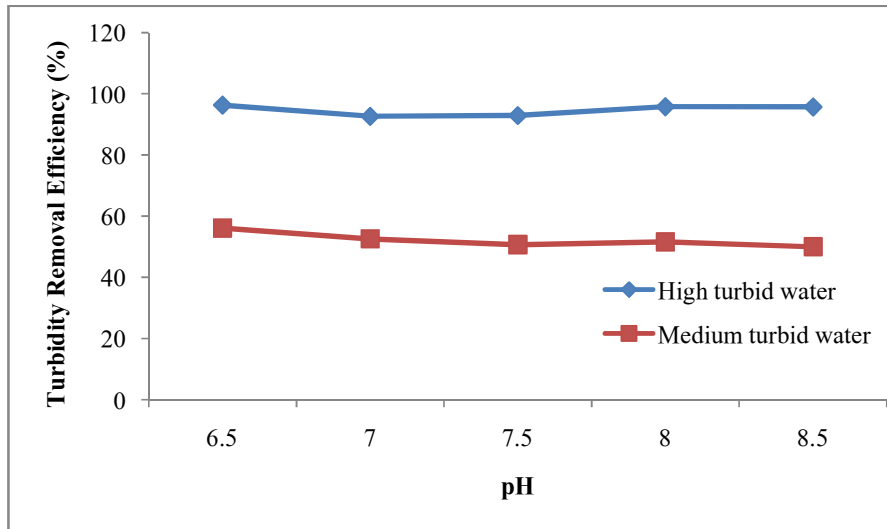


Figure 4.12: pH of 9% Conc. of *Moringa oleifera* Seed Extract for 495 NTU and 100 NTU

4.2.2 Optimum pH of *Moringa oleifera* Pod Extract

a. Concentration of *Moringa oleifera* Pod Powder (3% w/v)

The results presented on Figure 4.13 represent the optimum pH of 3% concentration of *Moringa oleifera* pod extract for high and medium turbid waters. After treating with the optimum dosages for both turbid waters, a similar trend was observed. It shows that *Moringa oleifera* pod extract has less treatment capability at pH range of 6.5-7, it can be said that the optimum pH for *Moringa oleifera* pod lies exactly at the pH of 8 as the highest turbidity removal efficiencies were observed there for both high and medium turbid waters respectively.

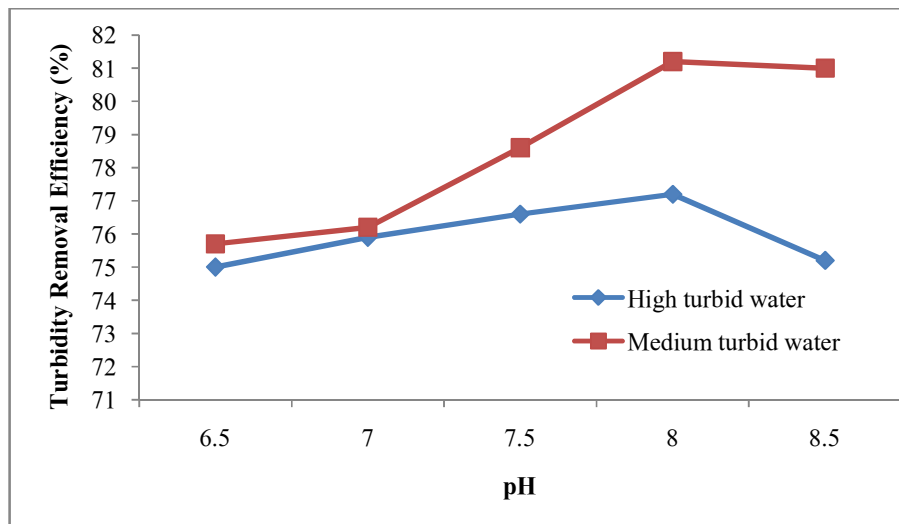


Figure 4.13: pH of 3% Conc. of *Moringa oleifera* Pod Extract for 495 NTU and 100 NTU

b. Concentration of *Moringa oleifera* Pod Powder (6% w/v)

The result obtained when the optimum doses of 6% concentration of *Moringa oleifera* pod extract were used to treat raw waters with initial turbidity of 495 NTU and 100 NTU are illustrated in Figure 4.14. It can be clearly seen that the optimum dose was not effective in turbidity removal at pH ranges 6.5-7.5 for both turbid waters. The highest turbidity removal efficiency for the high turbid water occurred at the pH of 8 which is the optimum pH, whereas for medium turbid water the optimum pH was found to be 8.5.

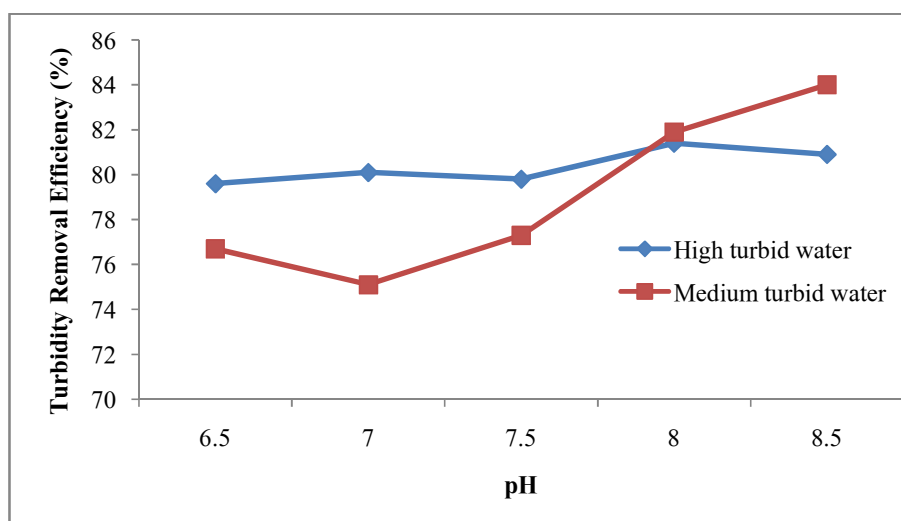


Figure 4.14: pH of 6% Conc. of *Moringa oleifera* Pod Extract for 495 NTU and 100 NTU

a. Concentration of *Moringa oleifera* Pod Powder (9% w/v)

Figure 4.15 represent the results of optimum pH of 9% concentration of *Moringa oleifera* pod extract when used treat high and medium turbid waters. When five 0.3 L capacity beaker filled with raw water with identical turbidity of 495 NTU with their pH values adjusted within the range of 6.5, 7, 7.5, 8 and 8.5 were treated with the optimum dosage of 153 mg/L of 9% concentration of *Moringa oleifera* pod extract, higher turbidity removal efficiencies were recorded in the beakers with pH values of 8 and 8.5 with that of pH 8 being the highest. When the same procedure was repeated for water with initial turbidity of 100 NTU, the highest turbidity removal efficiency was found to be at pH of 8. From the results, it can be deduced that the optimum pH for both turbid waters is 8.

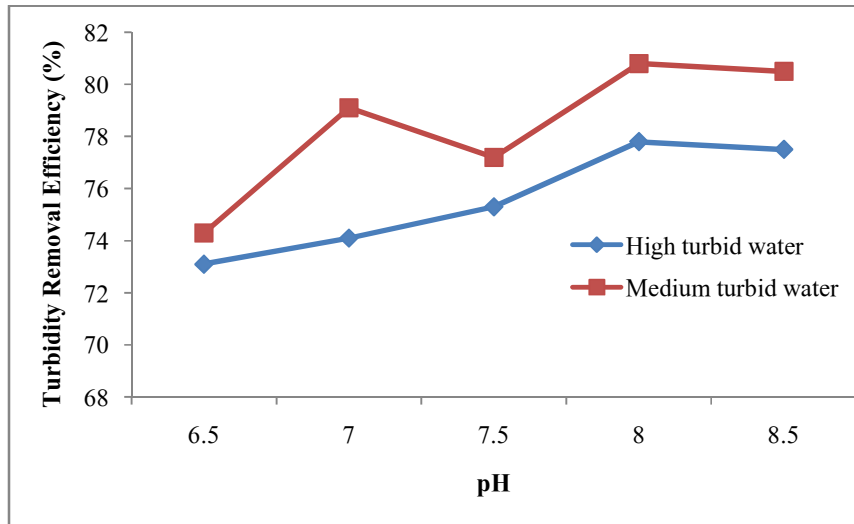


Figure 4.15: pH of 9% Conc. of *Moringa oleifera* Pod Extract for 495 NTU and 100 NTU

4.2.3 Optimum pH of *Moringa oleifera* Combined (Seed and Pod) Extract

a. Concentration of *Moringa oleifera* Combined Powder (3% w/v)

The results obtained when the optimum doses of 3% concentration of *Moringa oleifera* combined (seed and pod) extract were used to treat 450 and 100NTU raw water with their pH values adjusted from 6.5 to 8.5 are illustrated on Figure 4.16. For the high turbid water, it can obviously be seen that at pH of 6.5, good turbidity removal efficiency was observed to have occurred, increasing the pH value to 7 (neutral zone) better turbidity removal efficiency was achieved. At pH ranges of 7.5, 8 and 8.5 turbidity removal capabilities lower than that obtained at pH of 7 were achieved. A similar pattern of trend (same as that of high turbid water) was observed when 3% concentration of *Moringa oleifera* combined (seed and pod) extract was used to treat medium turbid water. The pH of 7 yielded the highest turbidity removal efficiency for both turbid waters respectively.

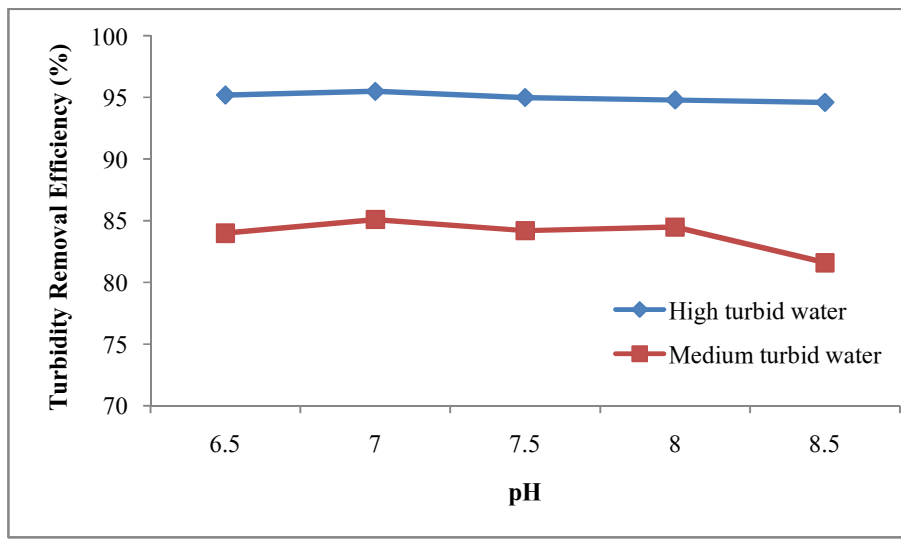


Figure 4.16: pH of 3% Conc. of *Moringa oleifera* Combined Extract for 495 NTU and 100 NTU

b. Concentration of *Moringa oleifera* Combined Powder (6% w/v)

The results presented in Figure 4.17 represents the optimum pH of 6% concentration of *Moringa oleifera* combined (seed and pod) extract used to treat raw water with initial turbidity of 495 and 100 NTU . From the result it can be seen that for high turbid water, at pH of 6.5 turbidity removal efficiency was low, increasing the pH to 7 higher removal ability was attained. Further increase in the pH values to 7.5, 8 and 8.5 resulted in a slight decrease in the removal efficiencies. For medium turbid water, highest removal efficiency occurred at the pH value of 6.5, increasing the pH values to 7, 7.5, 8 and 8.5 lower removal efficiencies with marginal difference were obtained. Therefore, the highest turbidity removal efficiencies for both 495 and 100 NTU waters occurred at pH values of 7 and 6.5 respectively.

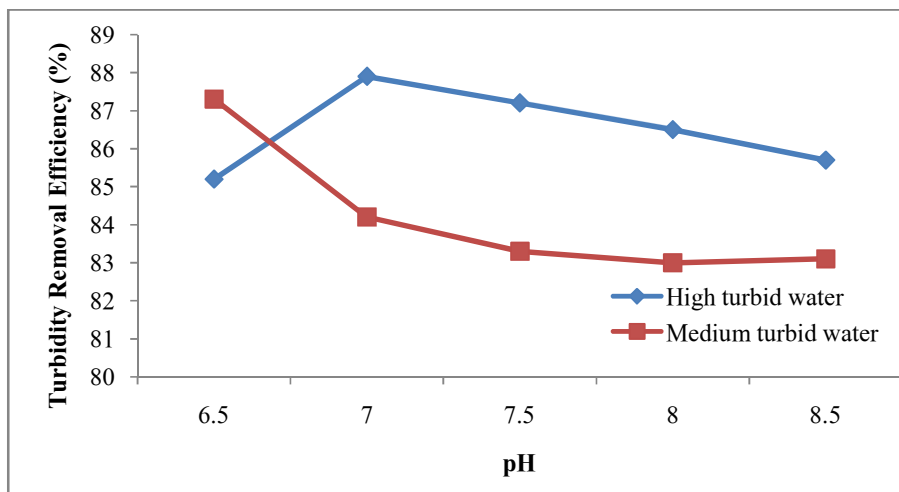


Figure 4.17: pH of 6% Conc. of *Moringa oleifera* Combined Extract for 495 NTU and 100 NTU

c. Concentration of *Moringa oleifera* Combined Powder (9% w/v)

The results illustrated on figure 4.18 depict the optimum pH when 9% concentration of *Moringa oleifera* combined (seed and Pod) extract was employed to treat high and medium turbid waters at different pH values. For high turbid water, at pH value of 6.5, a good turbidity removal efficiency was recorded, increasing the pH value to 7, better removal efficiency was achieved. As the pH value is increased further the turbidity removal efficiency keeps decreasing with the least removal efficiency recorded at pH of 8.5. The same pattern of trend was observed when the optimum dose was applied to treat medium turbid water at different pH values, with highest turbidity removal efficiency occurring at pH of 7 and the lowest at pH of 8.5 as illustrated in Figure 4.18.

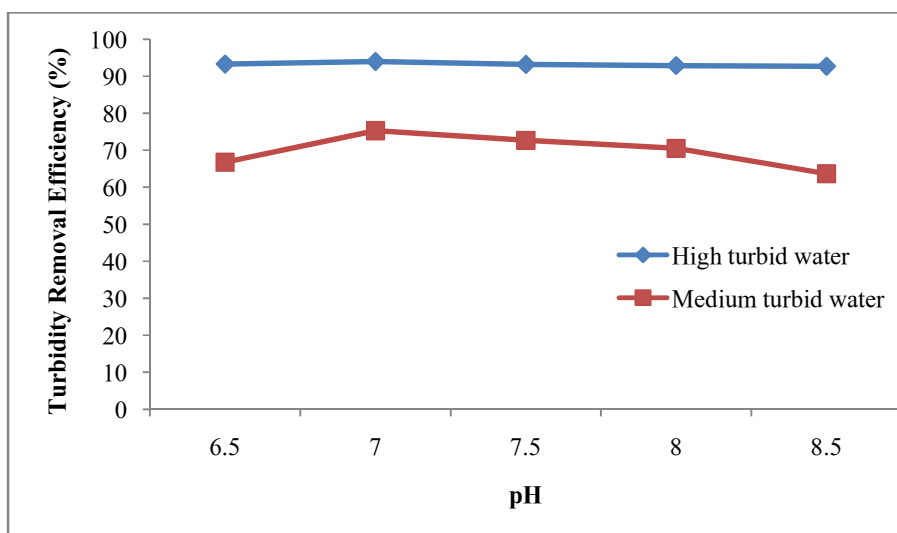


Figure 4.18: pH of 9% Conc. of *Moringa oleifera* Combined Extract for 495 NTU and 100 NTU

4.3 OPTIMUM CONCENTRATION OF *MORINGA OLEIFERA* (AQUEOUS EXTRACT) SEED, POD AND COMBINATION

The optimum concentration of a coagulant (aqueous extract) is the concentration which gives the best turbidity removal efficiency usually expressed in percentage (%) or that concentration that yields lowest residual turbidity in Nephelometric turbidity unit (NTU) after

treatment. In this research three different concentrations (3%, 6% and 9%) were prepared and similar range of doses in millimetres for each of the concentrations were applied to treat high and medium turbid water.

4.3.1 Optimum Concentration of *Moringa oleifera* Seed (Aqueous Extract)

The jar test result when medium turbid water with initial turbidity of 100 NTU was treated with 3% concentration of *Moringa oleifera* seed extract revealed that 84.1% turbidity removal efficiency was recorded. The percentage turbidity removal efficiency dropped to 73.2% when 6% concentration of the seed extract was used to treat raw water with the same turbidity, turbidity removal efficiency further dropped to 51.5% when higher concentration of *Moringa oleifera* seed extract (9%) was used to treat raw water with same initial turbidity. Therefore a total of 38% reduction in turbidity removal efficiency was observed when 3% concentration of aqueous extract of *Moringa oleifera* was increased to 9%. This shows that at lower concentration of aqueous extract (3%) *Moringa oleifera* seed performs better in terms of turbidity removal from medium turbid water than at higher concentrations (6% and 9%) as shown in Figure 4.19.

It can be clearly seen that the aqueous extract of 3% concentration of the seed gives the highest turbidity removal efficiency with 97.6% for high turbid water with initial turbidity of 495 NTU, followed by 9% concentration with an average turbidity removal of 95.8% for the same raw water turbidity. 6% concentration of the seed extract gave the least turbidity removal efficiency when compared to 9% and 3% concentrations. The result obtained in this study revealed that *Moringa oleifera* seed is more effective in turbidity removal from water with high initial turbidity which corroborate with the findings of Muyibi and Okufo (1995). The details of the results are presented in Figure 4.19.

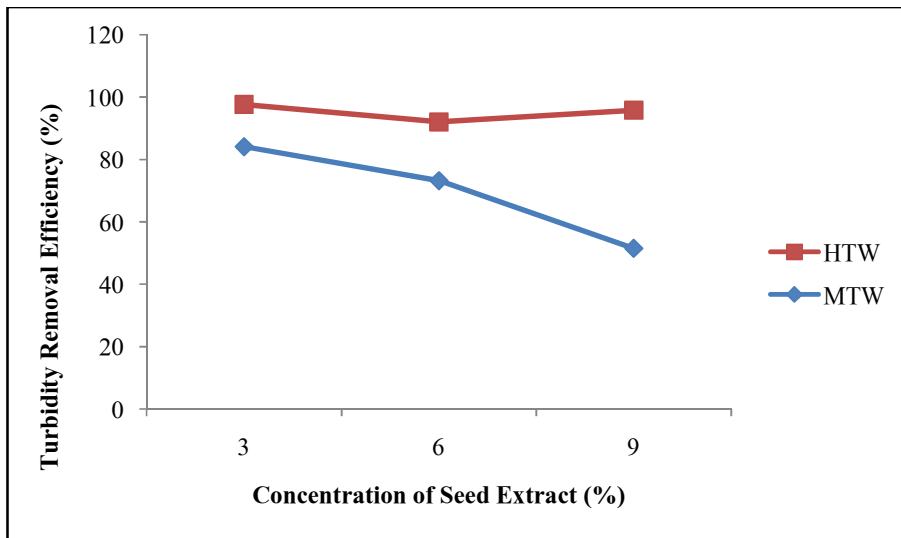


Figure 4.19: Concentration of *Moringa oleifera* Seed Extract for Medium & High Turbid Water

4.3.2 Optimum Concentration of *Moringa oleifera* Pod (Aqueous Extract)

The results obtained when raw water sample of 100 NTU was treated with different concentration (3%, 6% and 9%) of *Moringa oleifera* pod extracts at different dosages are represented in Figure 4.20. Hence, from the result obtained it can be seen that 3% concentration of the aqueous extract recorded 80% turbidity removal efficiency while 6% concentration of the aqueous extract a higher turbidity removal efficiency of 81.1% was recorded and lastly with a higher concentration of 9% *Moringa oleifera* pod extract, turbidity removal efficiency of 80.8% was achieved. Thus, from the result obtained in this research 6% concentration of *Moringa oleifera* pod extract was found to be the optimum concentration for turbidity removal from water with initial turbidity of 100 NTU.

When raw water with initial turbidity of 495 NTU was treated with different concentrations of *Moringa oleifera* pod extract, the results obtained are depicted in Figure 4.20. It can be seen clearly that when the aqueous extract of 9% concentration of pod powder was flocculated at high and low speeds (rpm) and allowed to settled for 1 hour the highest turbidity removal efficiency was found to be 74.5%, reducing the concentration of aqueous

extract to 6% a higher turbidity removal efficiency of 81.6% was attained and lastly when 3% concentration of the pod aqueous extract was used, 76.4% turbidity removal efficiency was achieved. It can be deduced from the result that 6% concentration aqueous extract gave the optimum turbidity removal efficiency. Furthermore the figure below shows that *Moringa oleifera* pod is more effective on medium turbid water than high turbid water.

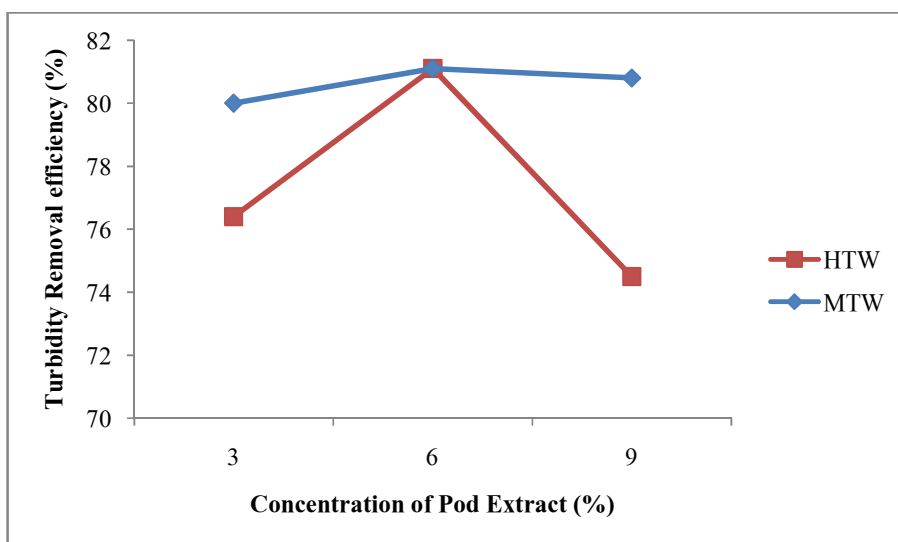


Figure 4.20: Concentration of *Moringa oleifera* Pod Extract for Medium & High Turbid Water

4.3.3 Optimum Concentration of *Moringa oleifera* Combined (Aqueous Extract) Powder

The results obtained when raw water with initial turbidity of 100 NTU was treated with 3% concentration of *Moringa oleifera* combined extract revealed that a high turbidity removal efficiency of 85.1% was achieved. Increasing the concentration of the *Moringa oleifera* extract to 6% a higher turbidity removal efficiency of 85.6% was attained, a decrease in the turbidity removal efficiency was observed when the concentration was further increased to 9%. The details of the results are illustrated in the Figure 4.21. The decrease in turbidity removal efficiency with increase in the concentration could be due to the fact that low/medium turbidity water contains less negative colloidal particles and the high concentration

of coagulants yields higher positive charges which will neutralise all the negative charges with the remaining positively charged coagulants adding turbidity to the water.

Figure 4.21 depicts the results of turbidity removal efficiencies when different concentrations (3%, 6% and 9%) of *Moringa oleifera* combined extract were used to treat raw water with initial turbidity of 495 NTU. It can be seen that, 3% concentration was able to achieve 95.2% turbidity removal efficiency, increasing the concentration to 6% the turbidity removal efficiency decreased to 87.3% and a further increase in the concentration (9%) gave the highest and most satisfactory turbidity removal efficiency of 95.5%.

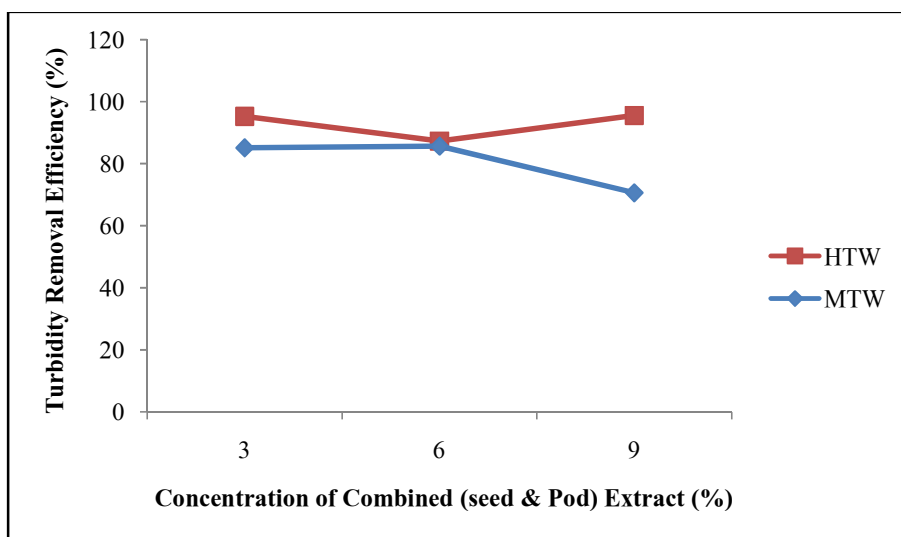


Figure 4.21: Concentration of *Moringa oleifera* Combined Extract for Medium & High Turbid Water

4.4 COMPARISON ON THE TURBIDITY REMOVAL EFFICIENCIES BETWEEN THE NATURAL COAGULANTS AND THE CONVENTIONAL COAGULANT (ALUM)

4.4.1 3% (w/v) Concentration of *Moringa oleifera* Seed, Pod, Combination and Alum on Medium and High Turbid Water

The results obtained when 3% concentration of *Moringa oleifera* seed, pod, combination and Alum were employed at different dosages to treat raw water with initial turbidity of 100 NTU

are presented in Figure 4.22. *Moringa oleifera* seed was able to achieve 84.1% turbidity removal efficiency at an optimum dose of 50 mg/L while at an optimum dose of 200 mg/L, *Moringa oleifera* pod extract was able to accomplish 80% turbidity removal efficiency from the same raw water (100 NTU). Similarly combined (seed and pod) extract yielded turbidity removal efficiency of 85.1%, at an optimum dose of 300 mg/L, a value slightly above the one obtained by the seed extract. The conventional coagulant (alum) gave the highest turbidity removal efficiency of 95.6% at an optimum dose of 100 mg/L.

From the results presented in Figure 4.22, it shows that at optimum dose of 50 mg/L, 3% concentration of *Moringa oleifera* seed extract was able to achieve 97.6% turbidity removal efficiency, a lower turbidity removal efficiency of 76.4% was observed when 100 mg/L of the pod powder was used to treat raw water of 495 NTU and *Moringa oleifera* combined (seed and pod) extract was able to achieve a turbidity removal efficiency of 95.2% at an optimum dose of 400 mg/L. Comparing the removal efficiencies of the three natural coagulants with conventional coagulant (alum) it can be seen that aluminium sulphate gave the highest turbidity removal efficiency of 99.9% at an optimum dose of 100 mg/L. It can be deduced that except for the *Moringa oleifera* pod extract all the coagulants (*M. oleifera* seed, combined and Alum) shows higher turbidity removal efficiency in high turbid water than that in low turbid water. It was observed that for all the natural coagulants the removal efficiencies dropped with decrease in initial turbidity of the raw water although an increase in removal efficiency with decrease in turbidity was observed with the *Moringa oleifera* pod extract. Aluminium Sulphate gave the highest in terms of turbidity removal efficiency while *Moringa oleifera* pod powder gave the lowest

Although the residual turbidities obtained after treating the water with the natural coagulant were above standard drinking water turbidity of 5 NTU (WHO) further filtration could yield

higher removal efficiency value same as that of the conventional coagulant as it was reported by Nwaiwu and Bello (2011)

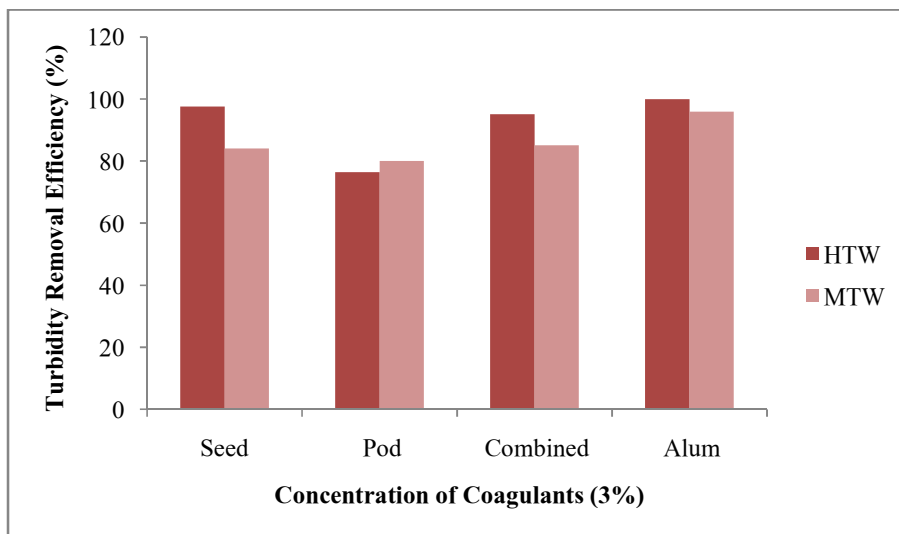


Figure 4.22: 3% Conc. *Moringa oleifera* Seed, Pod, Combination and Alum for Medium & High Turbid Water

4.4.2 6% (w/v) Concentration of *Moringa oleifera* Seed, Pod, Combination and Alum on Medium and High Turbid Water

Figure 4.23 represents the turbidity removal efficiencies of 6% concentration of four coagulants (*Moringa oleifera* seed, pod, combined (seed and pod) and aluminium sulphate (Alum) on water with an initial turbidity of 100 NTU. *Moringa oleifera* seed was able to remove 73.2% of the initial turbidity of the raw water, *Moringa oleifera* pods was able to achieve 81.1% turbidity removal efficiency while a total of 85.6% turbidity removal efficiency was recorded with the same concentration of the combined (seed and Pod) extract. Aluminium sulphate has the highest turbidity removal efficiency with 98.6% when compared to the natural coagulants. Similarly, it can be deduced that the efficiency of *Moringa oleifera* seed and the combined (seed and pod) decreases with decrease in turbidity of the raw water and also the concentration while with the *Moringa oleifera* pod extract, an increase in the turbidity removal efficiency with decrease in the initial turbidity of the raw water was

observed. Thus, in terms of turbidity removal efficiency, Aluminium sulphate has the highest while *Moringa oleifera* seed extract gave the lowest removal efficiency as shown below.

The results of the coagulation of high turbidity water of 495 NTU revealed that *Moringa oleifera* seed extract at an optimum dose of 102 mg/L achieved 92.0% turbidity removal efficiency while at 198mg/L optimum dose a total of 81.1% turbidity removal efficiency was attained by *Moringa oleifera* Pod extract, *Moringa oleifera* combined extract achieved turbidity removal efficiency of 87.3% at an optimum dose of 102 mg/L. Aluminium sulphate on the other hand attained a remarkable turbidity removal efficiency of 99.9% at an optimum dose same as that of *Moringa oleifera* seed extract. The results of this study disagree with the findings of Nwaiwu and Bello (2011), they found that with a particular weight of *Moringa oleifera* seed extract accomplishes more treatment than an equal weight of aluminium sulphate. The lower turbidity removal efficiency of the pod powder extract on high turbidity water could be attributed to its lower composition of the active ingredient responsible for coagulation as compared to the seed (Melesse and Berihun, 2013). The details of the results are presented in the Figure 4.23.

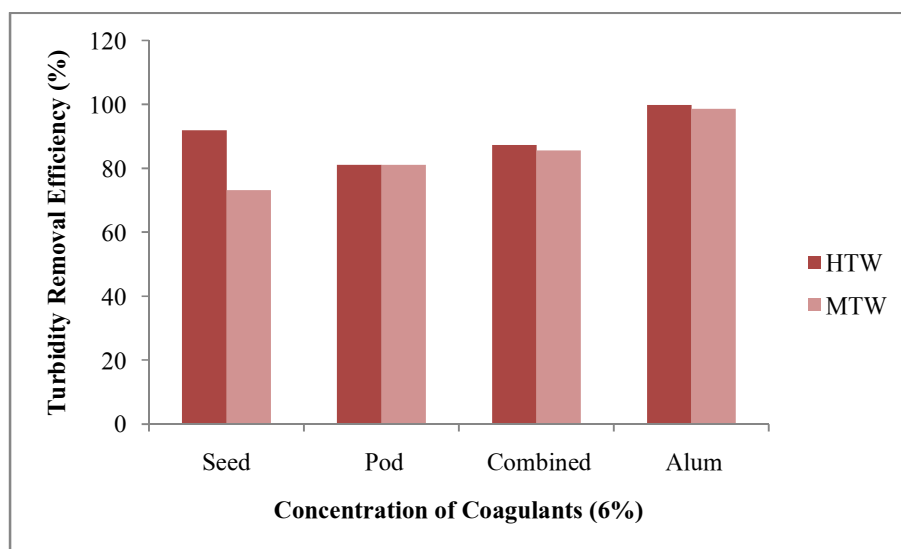


Figure 4.23: 6% Conc. *Moringa oleifera* Seed, Pod, Combination and Alum in Medium & High Turbidity Water

4.4.3 9% (w/v) Concentration of *Moringa oleifera* Seed, Pod, Combination and Alum on Medium and High Turbidity Water

When 9% concentrations of *Moringa oleifera* seed, Pod, combined (seed and pods), and Aluminium sulphate were differently prepared and applied in a range of dosages to treat raw water with initial turbidity of 100 NTU, the results obtained are illustrated in Figure 4.23. At an optimum dose of 153 mg/L, *Moringa oleifera* seed extract was able to achieve turbidity removal efficiency of 51.5%, *Moringa oleifera* pod extract was able to remove 80.8% of the initial turbidity, the combined (seed and Pod) extract at an optimum dose of 297 mg/L, recorded 70.6% turbidity removal efficiency and lastly aluminium sulphate yielded 96.3% turbidity removal efficiency at an optimum dosage of 153 mg/L. It can obviously be seen that at this concentration (9%), *Moringa oleifera* seed extract is least effective while the *Moringa oleifera* pod extract gave the highest turbidity removal efficiency as compared to the other two natural coagulants, Aluminium sulphate gave the best turbidity removal efficiency at same optimum dosage with that of the *Moringa oleifera* pod extract.

Increasing the concentrations of the stock solution to 9% for all the coagulants, *Moringa oleifera* seed extract was able to achieve turbidity removal efficiency of 95.8% at an optimum dose of 153 mg/L, *Moringa oleifera* pod extract gave 74.5% turbidity removal efficiency at 153 mg/L. The combined (seed and pod) extract recorded similar removal efficiency as to that of the seed extract at the same optimum dose with that of *Moringa oleifera* seed extract, lastly aluminium sulphate gave the highest turbidity removal efficiency as compared to the natural coagulants with turbidity removal efficiency of 99.6% at the same optimum dose with that of the three natural coagulants as shown in Figure 4.24. The lower figure of turbidity removal efficiency attained with *Moringa oleifera* pod extract as compared to the other coagulants could be due to its lower concentration of the active proteins that are responsible for coagulation.

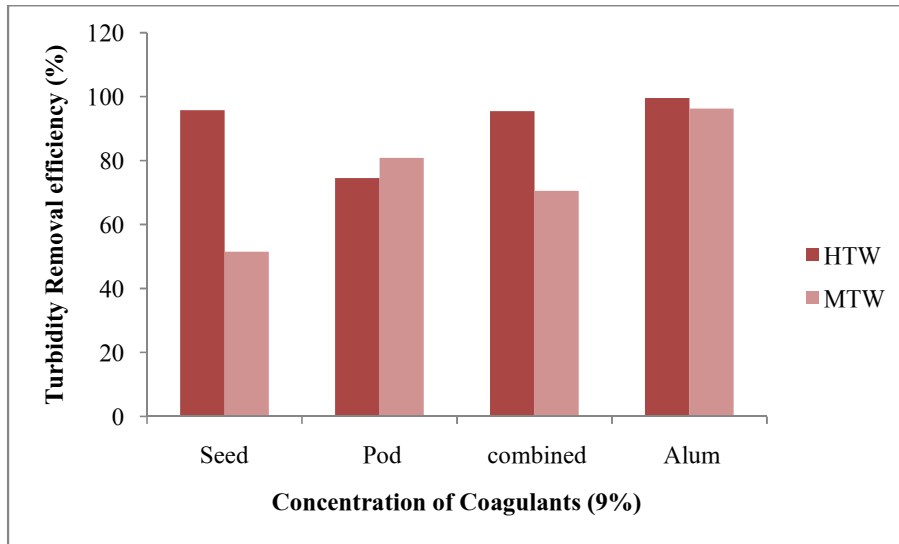


Figure 4.24: 9% Conc. *Moringa oleifera* Seed, Pod, Combination and Alum in Medium & High Turbid Water

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the results obtained in this research, it can be concluded that;

1. The optimum doses of 3%, 6% and 9% concentrations of *Moringa oleifera* seed powder for medium and high turbid waters were found to be the same with 100 mg/L, 102 mg/L and 153 mg/L respectively. For *Moringa oleifera* pod powder, the optimum doses of 3%, 6% and 9% concentrations for medium turbid water were found to be 200 mg/L, 198 mg/L and 153 mg/L while that of high turbid water were found to be 100 mg/L, 198 mg/L and 153 mg/L. Lastly for the *Moringa oleifera* combined powder, the optimum doses of 3%, 6% and 9% concentrations were 300 mg/L, 201 mg/L and 297 mg/L for medium turbid water and for the high turbid water were 200 mg/L, 201 mg/L and 153 mg/L
2. Best turbidity removal efficiencies for all concentrations of *Moringa oleifera* seed extract and for both high and medium turbid waters were recorded at pH value of 6.5, while at pH value of 8 the best turbidity removal efficiencies was found for all concentrations of *Moringa oleifera* pod extract for both turbid waters. Lastly for *Moringa oleifera* combined extract, at all the concentrations for both turbid waters, highest turbidity removal efficiencies were recorded at the pH value of 7 except for 6% concentration for medium turbid water which was recorded at the pH of 6.5. Therefore it can be concluded that the optimum pH of *Moringa oleifera* seed and pod extracts are 6.5 and 8 respectively, while for *Moringa oleifera* combined extract the optimum lies from pH range of 6.5- 7.0.
3. The optimum concentration of *Moringa oleifera* seed extract for medium and high turbid waters were found to be 3% with 84.1 and 97.6 percentage turbidity removals

respectively. For *Moringa oleifera* pod extract, 6% was found to be the optimum concentration with 81.1 and 81.6 percentage turbidity removals for both medium and high turbid waters respectively. Lastly for *Moringa oleifera* combined powder, 6% and 9% were found to be the optimum concentrations with 85.6% and 95.2% as the turbidity removal efficiencies for medium and high turbid waters respectively. Based on this research, it can be concluded that *Moringa oleifera* seed performs better at lower concentration (3%), *Moringa oleifera* pod extract performs better at 6% concentration for both turbid waters and lastly for *Moringa oleifera* combined extract 6% and 9% concentration are the best for medium and high turbid waters respectively.

4. At all the concentrations (3%, 6% and 9%) for both turbid waters, the natural coagulants (specifically *Moringa oleifera* seed and combined extract) were able to achieve higher removal efficiency slightly below that attained by alum except for 9% concentration of *Moringa oleifera* seed extract which gave a low removal efficiency of 51.1% for medium turbid water as compared to 96.3% achieved by alum at same concentration for same turbid water. Although all the waters treated with the natural coagulants had residual turbidities above the WHO recommended standard (did not meet standard) for drinking water of 5 NTU, further filtration may yield better results with residual turbidities below the WHO standard for drinking water. In addition higher removal efficiencies could be achieved by the natural coagulants if the settling time was extended due to fact that, aluminium sulphate settles faster than the natural coagulants. It can be concluded that *Moringa oleifera* pod and combined (seed and pod) extract are very effective in turbidity removal from water with medium and high initial turbidity.

5.2 RECOMMENDATIONS

1. There is a need for further filtration of water treated with all the natural coagulants since none of their residual turbidities met the WHO standard for drinking water.
2. There is need for public education and enlightenment on the use of *Moringa oleifera* seed, pod and their combination in water clarification through organizing workshops, seminars, conferences and the media in all district assemblies and regions of Nigeria.
3. Government and private organizations should invest more in *Moringa oleifera* cultivation since it has the potential of reducing cost of water treatment and can help improve water quality for rural dwellers.
4. *Moringa oleifera* pod is recommended for use in water treatment by rural dwellers.
5. Further research work need to be carried out on the following areas;
 - Isolation of the active extract compound responsible for coagulation in *Moringa oleifera* pod.
 - The effect of storage condition of *Moringa oleifera* pod powder or its aqueous extract on turbidity removal from surface water.
 - Further work on varying the ratios of combined *Moringa oleifera* seed and pod should be carried out in order to get the best combined ratio of *Moringa oleifera* seed and pod powder.
 - The effect of settling time on turbidity removal from surface water using *Moringa oleifera* pod powder.
 - Use of the crude extract of *Moringa oleifera* pod in water treatment without oil extraction.

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APPENDIX A: RAW DATA ON WATER TREATMENT USING *MORINGA OLEIFERA* SEED EXTRACT

Table A1: 3% Concentration of *Moringa oleifera* Seed Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	308	37.8	80	20
1	50	18.2	96.3	29.8	70.2
2	100	12.1	97.6	15.9	84.1
3	200	13.5	97.3	39.3	60.8
4	300	24.7	95.0	40.8	59.3
5	400	37.0	92.5	53.0	47.0

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table A2: 6% Concentration of *Moringa oleifera* Seed Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	326	34.1	69	31
1	102	39.7	92.0	26.8	73.2
2	198	47.4	90.4	35.0	65.0
3	402	85.7	82.7	38.6	61.4
4	600	89.1	82.0	44.3	55.7
5	798	98.8	80.0	62.8	37.2

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table A3: 9% Concentration of *Moringa oleifera* Seed Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	333	32.7	74.8	25.2
1	153	20.8	95.8	48.5	51.5
2	297	36.6	92.6	84.3	15.7
3	603	45.4	90.8	155	-55

4	900	49.1	90.1	154.6	-54.6
5	1197	74.0	85.1	188.1	-88.1

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table A4: 3% Concentration of *Moringa oleifera* Seed Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	11.2	11.3
2	7.0	15.2	14.7
3	7.5	14.7	15.9
4	8.0	13.5	16.2
5	8.5	13.8	15.6

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

Table A5: 6% Concentration of *Moringa oleifera* Seed Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	33.5	23.6
2	7.0	36.0	26.2
3	7.5	40.2	26.9
4	8.0	45.3	27.6
5	8.5	47.5	29.0

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

Table A6: 9% Concentration of *Moringa oleifera* Seed Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	18.2	43.9
2	7.0	36.6	47.4
3	7.5	35	49.3
4	8.0	20.9	48.4
5	8.5	21.3	50

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

APPENDIX B: RAW DATA ON WATER TREATMENT USING *MORINGA OLEIFERA* POD EXTRACT

Table B1: 3% Concentration of *Moringa oleifera* Pod Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	283	42.8	75	25
1	50	119.7	75.8	22.2	77.8
2	100	116.7	76.4	20.7	79.3
3	200	130.1	73.7	20.0	80
4	300	142.3	71.3	20.8	79.2
5	400	148.6	69.9	22.8	77.2

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table B2: 6% Concentration of *Moringa oleifera* Pod Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	298	39.8	61	39
1	102	79.7	83.9	20.3	79.7
2	198	77.5	84.3	18.9	81.1
3	402	78.1	84.2	21.8	78.2
4	600	78.4	84.2	24.9	75.1
5	798	81.1	83.6	29.9	70.1

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table B3: 9% Concentration of *Moringa oleifera* Pod Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	352	28.9	73	27
1	153	126.1	74.5	19.2	80.8
2	297	134.4	72.8	20.3	79.7
3	603	130.4	73.7	22.2	77.8
4	900	130.9	73.6	24.9	75.1

5	1197	143.4	71.0	32.1	67.9
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RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table B4: 3% Concentration of *Moringa oleifera* Pod Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	123.7	24.3
2	7.0	119.2	23.8
3	7.5	115.6	21.4
4	8.0	113.0	18.8
5	8.5	122.8	19.0

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

Table B5: 6% Concentration of *Moringa oleifera* Pod Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	101	23.3
2	7.0	98.6	24.9
3	7.5	99.8	22.7
4	8.0	92.3	18.1
5	8.5	94.5	16.0

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

Table B6: 9% Concentration of *Moringa oleifera* Pod Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	133.4	16.0
2	7.0	128.0	14.9
3	7.5	122.5	15.8
4	8.0	109.8	15.5
5	8.5	111.6	18.4

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

APPENDIX C: RAW DATA ON WATER TREATMENT USING *MORINGA OLEIFERA* COMBINED (SEED & POD) EXTRACT

Table C1: 3% Concentration of *Moringa oleifera* Combined Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	390	21.2	75	25
1	50	80.4	83.8	25.9	74.1
2	100	68.8	86.1	29.6	70.4
3	200	23.9	95.2	19.4	80.6
4	300	50.9	89.7	14.9	85.1
5	400	62.7	87.3	33.6	66.4

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table C2: 6% Concentration of *Moringa oleifera* Combined Seed Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	345	30.3	77	23
1	102	62.9	87.3	39.6	60.4
2	198	80.4	83.8	37.4	62.6
3	402	85.5	82.7	14.4	85.6
4	600	90.9	81.6	31.5	68.5
5	798	119.6	75.8	37.8	62.2

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table C3: 9% Concentration of *Moringa oleifera* Combined Seed Extract

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	345	30.3	72	28
1	153	22.4	95.5	34.7	65.3
2	297	30.6	93.8	29.4	70.6
3	603	41.4	91.6	36.3	63.7
4	900	52.2	89.5	41.9	58.1

5	1197	56.5	88.6	54.2	45.9
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RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTLWTW: Residual Turbidity for Medium Turbid Water

RELWTW: Removal Efficiency for Medium Turbid Water

Table C4: 3% Concentration of *Moringa oleifera* Combined Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	23.8	16
2	7.0	22.5	14.9
3	7.5	24.7	15.8
4	8.0	25.5	15.5
5	8.5	26.8	18.4

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

Table C5: 6% Concentration of *Moringa oleifera* Combined Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	73.5	12.6
2	7.0	60.1	15.8
3	7.5	63.4	16.7
4	8.0	67	17
5	8.5	70.9	16.9

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

Table C6: 9% Concentration of *Moringa oleifera* Combined Extract

S/N	pH	RTHTW (NTU)	RTMTW (NTU)
1	6.5	33.2	33.2
2	7.0	29.7	24.7
3	7.5	33.7	27.3
4	8.0	34.9	29.5
5	8.5	36.3	36.3

RTHTW: Residual Turbidity for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

APPENDIX D: RAW DATA ON WATER TREATMENT USING ALUMINIUM
SULPHATE (ALUM)

Table D1: 3% Concentration of Alum

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	333	32.7	80	20
1	50	5.75	98.8	6.2	93.8
2	100	0.45	99.9	4.1	95.9
3	200	1.2	98.8	8.0	92.0
4	300	6.8	98.6	11.5	88.5
5	400	16.7	96.6	16.9	83.1

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table D2: 6% Concentration of Alum

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	345	30.3	77	23
1	102	0.7	99.9	1.4	98.6
2	198	6.2	98.7	3.5	96.5
3	402	7.4	98.5	8.6	91.4
4	600	11.8	97.6	15.4	84.6
5	798	13.8	97.2	16.7	83.3

RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water

Table D3: 9% Concentration of Alum

S/N	Dose (mg/L)	RTHTW (NTU)	REHTW (%)	RTMTW (NTU)	REMTW (%)
	0	345	30.3		
1	50	1.8	99.6	3.7	96.3
2	100	6.2	98.7	8	92
3	200	20	96	9.1	90.9
4	300	19.3	96.1	12.9	87.1

5	400	21	95.8	19.7	80.3
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RTHTW: Residual Turbidity for High Turbid Water

REHTW: Removal Efficiency for High Turbid Water

RTMTW: Residual Turbidity for Medium Turbid Water

REMTW: Removal Efficiency for Medium Turbid Water