INVESTIGATION OF *MORINGA OLEIFERA* USED AS NATURAL COAGULANT IN WATER TREATMENT PROCESS

NUTTAPHON PHUAPRASERT

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF ENGINEERING
(ENVIRONMENTAL AND WATER RESOURCE ENGINEERING)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2015

Thesis
entitled

INVESTIGATION OF *MORINGA OLEIFERA* USED AS NATURAL COAGULANT IN WATER TREATMENT PROCESS

……………………………………
Mr. Nuttaphon Phuaprasert
Candidate

……………………………………
Visiting Prof. Ranjna Jindal,
D.Tech.Sc. (Environmental Engineering)
Major advisor

……………………………………
Lect. Nawatch Surinkul,
D.Eng. (Environmental Engineering)
Co-advisor

……………………………………
Lect. Kritsanat Surakit,
D.Eng. (Water Resources Engineering)
Co-advisor

……………………………………
Prof. Patcharee Lertrit,
M.D., Ph.D. (Biochemistry)
Dean
Faculty of Graduate Studies
Mahidol University

……………………………………
Visiting Prof. Ranjna Jindal,
D.Tech.Sc. (Environmental Engineering)
Program Director
Master of Engineering Program in
Environmental and Water Resource
Engineering
Faculty of Engineering
Mahidol University

Thesis
entitled

INVESTIGATION OF *MORINGA OLEIFERA* USED AS NATURAL COAGULANT IN WATER TREATMENT PROCESS

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Engineering
(Environmental and Water Resource Engineering)
on
April 8, 2015

……………………………………
Mr. Nuttaphon Phuaprasert
Candidate

……………………………………
Mr. Madawala Liyanage Duminda
Jayaranjan,
D.Eng. (Environmental Engineering)
Chair

……………………………………
Visiting Prof. Ranjna Jindal,
D.Tech.Sc. (Environmental Engineering)
Member

……………………………………
Lect. Nawatch Surinkul,
D.Eng. (Environmental Engineering)
Member

……………………………………
Lect. Kritsanat Surakit,
D.Eng. (Water Resources Engineering)
Member

……………………………………
Prof. Patcharee Lertrit,
M.D., Ph.D. (Biochemistry)
Dean
Faculty of Graduate Studies
Mahidol University

……………………………………
Lect. Worawit Israngkul, M.D.
Dean
Faculty of Engineering
Mahidol University

ACKNOWLEDGEMENTS

I am deeply indebted to my main advisor, Visiting Prof. Dr. Ranjna Jindal for the successful completion of my master dissertation research and preparation of this thesis. Her patience and kindness, as well as the academic expertise and very useful advices have been invaluable to me. I am very grateful to my co-advisors, Dr. Nawatch Surinkul and Dr. Kritsanat Surakit for their intensive suggestions and vital help. My thanks go out to Dr. Madawala Liyanage Duminda Jayaranjan for accepting to be the thesis defense committee chairman and for providing useful suggestions for improvement. I am also thankful to all my lecturers at Mahidol University for their support and assistance extended to me.

I express my thanks to Mahidol University for providing all the facilities for my masters study in Environmental and Water Resources Engineering Program. I am deeply grateful to Metropolitan Waterworks Authority (MWA) for giving the opportunity to pursue the graduate studies with financial support throughout this research and convey my special thanks to the laboratory of Bangkhen Water Treatment Plant as well as Department of Water Quality, MWA for assisting me in the laboratory analyses for my dissertation research.

I would also like to extend my thanks and appreciation to all my friends for their kind help. Finally, I am extremely grateful to my family, which has been a constant source of emotional and moral support. This study would certainly not have been possible without them. Special thanks to my parents who took care of me. Lastly, I would like to take this opportunity to thank my beloved wife who has always been my pillar of strength, joy, and guiding light.

I dedicate the usefulness of this thesis to my family and to all the teachers who have taught and inspired me since my childhood.

Nuttaphon Phuaprasert

INVESTIGATION OF *MORINGA OLEIFERA* USED AS NATURAL COAGULANT IN WATER TREATMENT PROCESS

NUTTAPHON PHUAPRASERT 5636392 EGEW/M

M. Eng. (ENVIROMENTAL AND WATER RESOURCE ENGINEERING)

THESIS ADVISORY COMMITTEE: RANJNA JINDAL, Ph.D., NAWATCH SURINKUL, Ph.D., KRITSANAT SURAKIT, Ph.D.

ABSTRACT

The present study was mainly aimed at using *Moringa oleifera* (*M. oleifera*) as a coagulant and evaluating its effectiveness as compared to alum, as well as assessing the use of *M. oleifera* as co-coagulant along with alum in water treatment process. Actual raw water, collected from intake of Bangkhen Water Treatment Plant (WTP), located in Bangkok, Thailand, was used for this study. The effectiveness of *M. oleifera* as a coagulant or co-coagulant was evaluated via jar tests.

The efficiency of *M. oleifera* extraction by using different solvents including distilled water, 0.5M NaCl, 0.5M NaOH was investigated. Distilled water was found to provide a high turbidity removal with no change in coagulated water quality, e.g. conductivity, pH and alkalinity; thus, it was the most suitable solvent for *M. oleifera* extraction. It was also found that the optimum parameters for the coagulation process using *M. oleifera* extraction, including the slow mixing speed and the sedimentation time were 50 rpm and 45 min, respectively; whereas for alum the optimum slow mixing speed and the sedimentation time were 50 rpm and 15 min, respectively. Moreover, the optimum dosage of *M. oleifera* for treating low and medium turbidity raw water was found to be 80 and 70 mg/L, respectively; whereas for alum the optimum dosage to treat low to medium turbidity raw water was 20 mg/L.

In terms of turbidity removal as well as reduction in organic matter, expressed as UV absorbance at 254 nm, alum outperformed *M. oleifera*. However, pH and alkalinity of treated water coagulated with alum were significantly affected. In addition, the coagulation process performance of the *M. oleifera* used along with alum as a co-coagulant was investigated for different dosages of alum. The results showed that a combination of 80 mg/L of *M. oleifera* along with 5 mg/L of alum was enough to improve the efficiency of turbidity removal by reducing the sedimentation time by almost half as compared to that with *M. oleifera* alone. In addition, various physic-chemical parameters, including turbidity, pH, chloride, sulfate, heavy metals, etc., were analyzed in the water after being treated by *M. oleifera*, alum, and the combination of two. The values of all the parameters were considerably lower than WHO guidelines for drinking water quality. Moreover, due to some concern about increased organic matter in treated water with *M. oleifera* as a coagulant or co-coagulant, the formation potential of trihalomethanes (THMs) were also evaluated and were also found to be lower than WHO guidelines for drinking water quality. Based on the results of this study, it could be concluded that although *M. oleifera* seemed to be less efficient as compared with alum in terms of dosage and sedimentation time, it could be used as an effective natural coagulant along with a small dosage of alum as co-coagulant in water treatment process.

KEY WORDS: MORINGA OLEIFERA / NATURAL COAGULANT / ALUM /
WATER TREATMENT / TURBIDITY

114 pages

งานวิจัยสารสกัดจากเมล็ดมะรุม ซึ่งใช้เป็นสารตกตะกอนจากธรรมชาติในกระบวนการผลิตน้ำ
INVESTIGATION OF *MORINGA OLEIFERA* USED AS NATURAL COAGULANT IN WATER TREATMENT PROCESS

ณัฐพล พัวประเสริฐ 5636392 EGEW/M

วศ.ม. (วิศวกรรมสิ่งแวดล้อมและทรัพยากรน้ำ)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์ : รันจนา จินดัล, Ph.D. , ณวัชร สุรินทร์กุล, Ph.D. , กฤษณัส สุรกิตย์, Ph.D.

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์คือการใช้สารสกัดจากเมล็ดมะรุมในการตกตะกอน และประเมินประสิทธิภาพของสารดังกล่าวโดยเปรียบเทียบกับสารส้ม รวมถึงการใช้สารสกัดจากเมล็ดมะรุมร่วมกับสารส้มในการตกตะกอนในกระบวนการบำบัดน้ำ ผ่านการใช้วิธีตกตะกอนเลียนแบบธรรมชาติ (Jar test) ตัวอย่างน้ำที่ใช้ในการทดลองคือน้ำดิบก่อนเข้ากระบวนการผลิตน้ำ ณ โรงงานผลิตน้ำบางเขน กรุงเทพมหานคร

จากการศึกษาประสิทธิภาพของสารสกัดจากเมล็ดมะรุมโดยใช้ตัวทำละลายที่แตกต่างกัน เช่น น้ำกลั่น โซเดียมคลอไรด์ และโซเดียมไฮดรอกไซด์ พบว่า น้ำกลั่นเป็นตัวทำละลายที่เหมาะสมที่สุดสำหรับการสกัดสารจากเมล็ดมะรุม โดยสามารถลดความขุ่นได้ดี และไม่มีเปลี่ยนแปลงคุณภาพน้ำด้านอื่นๆ เช่น ค่าความเป็นกรด-ด่าง และค่าความเป็นด่าง นอกจากนี้ ยังพบว่าสภาวะที่เหมาะสมสำหรับกระบวนการตกตะกอนเลียนแบบธรรมชาตินั้น สารสกัดจากเมล็ดมะรุมใช้ความเร็วในการผสมช้าและเวลาการตกตะกอนคือ 50 รอบต่อนาทีและ 45 นาทีตามลำดับ ในขณะที่สารส้มอยู่ที่ 50 รอบต่อนาทีและ 15 นาทีตามลำดับ และปริมาณที่เหมาะสมของสารสกัดจากเมล็ดมะรุม สำหรับใช้กับน้ำดิบที่มีความขุ่นต่ำและปานกลางเป็น 80 และ 70 มิลลิกรัมต่อลิตร ตามลำดับ ในขณะที่สารส้มใช้เพียง 20 มิลลิกรัมต่อลิตร สำหรับน้ำดิบที่มีทั้งความขุ่นต่ำและปานกลาง

จากการเปรียบเทียบประสิทธิภาพของสารสกัดจากเมล็ดมะรุมและสารส้ม พบว่า สารส้มยังคงมีประสิทธิภาพที่ดีกว่า ในด้านการกำจัดความขุ่นและการลดสารอินทรีย์ในน้ำ (จากค่าการดูดกลืนแสงที่ 254 นาโนเมตร) อย่างไรก็ตาม สารส้มส่งผลต่อค่าความเป็นกรด-ด่างและค่าความเป็นด่างของน้ำอย่างเห็นได้ชัด นอกจากนี้ เมื่อใช้สารสกัดจากเมล็ดมะรุมร่วมกับสารส้ม พบว่าประสิทธิภาพการตกตะกอนสูงขึ้น ซึ่งสารสารส้ม 5 มิลลิกรัมต่อลิตร (ร่วมกับสกัดจากเมล็ดมะรุม 80 มิลลิกรัมต่อลิตร) เพียงพอที่จะเพิ่มประสิทธิภาพในการกำจัดความขุ่นและลดเวลาการตกตะกอนลงเกือบครึ่งหนึ่งเมื่อเทียบกับการใช้มะรุมเพียงอย่างเดีย จากการเปรียบเทียบคุณสมบัติทางกายภาพ-เคมี ของน้ำที่ผ่านการตกตะกอนจากสารสกัดจากเมล็ดมะรุม สารส้ม และใช้สารทั้งสองร่วมกัน เช่น ค่าความเป็นกรด-ด่าง ค่าคลอไรด์ ซัลเฟต และค่าโลหะหนัก เป็นต้น พบว่า ค่าดังกล่าวอยู่ในเกณฑ์ค่าแนะนำคุณภาพน้ำดื่มขององค์การอนามัยโลกทั้งหมด ยิ่งไปกว่านั้น เนื่องจากสารสกัดจากเมล็ดมะรุมส่งผลต่อการเพิ่มขึ้นของสารอินทรีย์ในน้ำ จึงได้มีการวิจัยเพิ่มเติมเกี่ยวกับศักยภาพที่ก่อให้เกิดสารไตรฮาโลมีเทนซึ่งเป็นสารก่อมะเร็ง พบว่า ค่าดังกล่าวยังอยู่ในเกณฑ์ขององค์การอนามัยโลกเช่นกัน กล่าวโดยสรุปคือ แม้สารสกัดจากเมล็ดมะรุมจะมีประสิทธิภาพที่ด้อยกว่าสารส้ม แต่ยังสามารถใช้เป็นสารตกตะกอนที่มีประสิทธิภาพได้ และประสิทธิภาพยิ่งสูงขึ้นเมื่อใช้ร่วมกับสารส้มในปริมาณเพียงเล็กน้อย

114 หน้า

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF ABBREVIATIONS

Abbreviations and symbols

%	Percent
% w/w	Percent weight by weight
% w/v	Percent weight by volume
°C	Degree (s) Celcius
μm	Micrometer (s)
μS/cm	microsiemen (s) per centimeter
AAS	Atomic absorption spectrophotometer
$AgNo_3$	Silver nitrate
Alum / $Al_2(SO_4)_3$	Aluminum sulfate
$AlCl_3$	Aluminum chloride
Avg	Average
AWWA	American Water Works Association
$BaCl_2$	Barium chloride
BOD	Biochemical Oxigen Demand
C. arietinum	*Cicer arietinum*
$CaCO_3$	Calcium carbonate
$CHCl_3$	Chloroform
$CHBrCl_2$ / BDCM	Bromodichloromethane
$CHBr_2Cl$ / DBCM	Dibromochloromethane
$CHBr_3$	Bromoform
cm	Centimeter (s)
COD	Chemical oxygen demand
conc.	Concentration
E. coli	*Escherichia coli*
EDTA	Ethylenediaminetetraacetic acid
et al.	Et alii, and others
Expt.	Experiment (s)

LIST OF ABBREVIATIONS (cont.)

Abbreviations and symbols

$FeCl_3$	Ferric chloride
$Fe_2(SO_4)_3$	Ferric sulphate
Fig	Figure
g	Gram (s)
GC	Gas chromatograph
GC-ECD	Gas chromatograph with electron capture detector
GF-AAS	Graphite furnace atomic absorption spectrophotometer
h	Hour(s)
H_2SO_4	Sulfuric acid
H_3PO_4	Phosphoric acid
IARC	International Agency for Research on Cancer
ICP-OES	Inductively coupled plasma optical emission spectrometer
JECFA	The Joint FAO/WHO Expert Committee on Food Additives
K_2CrO_4	Potassium chromate
KCl	Potassium chloride
kDa	kilodalton (s)
kg	kilogram (s)
KI	Potassium iodide
km	Kilometer (s)
KNO_3	Potassium nitrate
L	Liter (s)
M	Molar
M. oleifera	*Moringa oleifera*
mg/L	Milligram (s) per liter
min	Minute (s)
mL	Milliliter (s)
mm	Millimeter (s)
MPN	Most probable number

LIST OF ABBREVIATIONS (cont.)

Abbreviations and symbols

MWA	Metropolitan Waterworks Authority
N	Normality
$Na_2S_2O_3$	Sodium thiosulfate
Na_2SO_3	Sodium sulfite
NaCl	Sodium chloride
$NaNO_3$	Sodium nitrate
NaOCl	Sodium hypochlorite
NaOH	Sodium hydroxide
ND	Not detected / Non-detectable
Nm	nanometer (s)
NTU	Nephelometric turbidity units
P. vulgaris	*Phaseolus vulgaris*
PAC / PACl	Polyaluminum chloride
PAS	Polyaluminum sulphate
PTWI	Provisional tolerable weekly intake
rpm	Round (s) per minute
S. potatorum	*Strychnos potatorum*
SD	Standard deviation
Sed.	Sedimentation
THMFP	Trihalomethane Formation Potential
THMs	Trihalomethanes
TIS	Thai Industrial Standard
TOC	Total organic carbon
Turbid	Turbidity
WHO	World Health Organization
WTP	Water Treatment Plant
USEPA	United States Environmental Protection Agency
UV	Ultraviolet

LIST OF ABBREVIATIONS (cont.)

Abbreviations and symbols

UV/Vis	Ultraviolet-visible

CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Water is definitely the most vital element among the natural resources. Water from all sources must have some form of treatment before consumption. One of the problems with water treatment system is the turbidity of raw water. The turbidity of the raw water is usually reduced via the process of coagulation to get clean and safe water. Inorganic coagulants and/or polymers, namely aluminum sulfate ($Al_2(SO_4)_3$ or alum), ferric chloride ($FeCl_3$) and poly-aluminum chloride (PAC) are typically used to aid coagulation.

Effectiveness of these chemicals in coagulation is well-known. However, there are some drawbacks associated with the use of these coagulants including i) significant increase in pH of treated water; ii) the large sludge volume obtained from treatments using aluminum salts leading to disposal problems (Ndabigengesere and Narasiah, 1998); iii) residual aluminum-based coagulants such as alum and poly-aluminum chloride (PAC) possibly inducing Alzheimer disease; and iv) aluminum's role as causative agent in neurological disease like 'per-senile dementia' (WHO, 2011; Bhatia et al., 2007).

It can be seen that many of the chemical coagulants are associated with human health and environmental problems. Hence, it is desirable to replace these with natural coagulants for water treatment to counteract the above mentioned problems.

A variety of plant materials have been reported to be used as source of natural coagulants such as *Nirmali*, *Okra*, red bean, sugar and red maize, *Moringa oleifera (M. oleifera)*, *Cactus latifera*, and seed powder of *Prosopis juliflora*. These natural coagulants might prove to be a very good alternative to chemical coagulants in water purification process due to their abundant source, low cost, environmental friendly nature and good biodegradability (Asrafuzzaman et al., 2011).

Among various plant materials to be used as natural coagulants, the *M. oleifera* seeds have become very popular. These seeds are increasingly being recognized as effective coagulants for water treatment process due to the fact that the tree is locally available in the tropical region and has several other uses. *M. oleifera* seed in diverse extracted and purified forms has proven to be effective for removal of turbidity while generating reduced sludge volumes in comparison to alum (Ndabigengesere and Narasiah, 1998). In addition, it softens hard waters (Muyibi and Evison, 1995a), and act as effective adsorber of cadmium (Sharma et al., 2006; Kituyi et al., 2013). It has been found that the active component of the dried crushed seeds (powder) of *M. oleifera* is a soluble protein which acts as natural cationic polyelectrolyte that causes coagulation in turbid water (Ndabigengesere et al., 1995). *M. oleifera* has been ranked as one of the best plant extracts for water purification.

Worldwide, *M. oleifera* has received various levels of interest from a number of researchers assessing its potential as a primary coagulant. However, there is very limited published data to derive a direct comparison between the effectiveness of a natural coagulant (such as *M. oleifera*) and the conventional chemical coagulants (such as alum and ferric chloride) while treating the actual raw water. In view of this, the present study mainly aimed at using *M. oleifera* as a natural coagulant and evaluating its effectiveness as compared to alum, as well as assessing the use of *M. oleifera* as a co-coagulant along with alum in water purification process. Raw water, collected from intake of Bangkhen Water Treatment Plant (WTP), located in Bangkok, Thailand, was used for this study.

1.2 Background Information

Alum is one of the most commonly used coagulants in coagulation-flocculation process in Bangkhen WTP, Metropolitan Waterworks Authority (MWA). However, it significantly affects pH of treated water. Consequently, to prevent corrosion problem, the low pH of treated water needs to be adjusted by the addition of alkalinity in form of bicarbonate or lime which increases the sludge volume as well as the treatment costs. Besides being voluminous, the sludges of alum are gelatinous, acidic, and difficult to dissolve in water and to dispose of in the environment.

Moreover, the cost of sludge treatment and disposal being proportional to the sludge volume become very costly (Ndabigengesere and Narasiah, 1998). In addition, some studies have reported that residual aluminum in water may induce Alzheimer disease. Aluminum has also been indicated to be a causative agent in neurological disease like 'per-senile dementia' (WHO, 2011; Bhatia et al., 2007).

Moringa oleifera (*M. oleifera*) is a multipurpose tree native to Northern India but is now widely found throughout the tropics. It is full of nutrients and vitamins. This multipurpose tree is also used as traditional medicines and helps to purify drinking water (Bhatia et al., 2007). The capable of *M. oleifera* seeds as an effective coagulant in water treatment is owing to its water soluble cationic proteins in the seeds (Ndabigengesere et al., 1995). In coagulation process, *M. oleifera* does not change the pH and conductivity of the treated water. Compared to alum, *M. oleifera* seeds in water treatment do not need pH adjustment and do not lead to corrosion in distribution system. Thus, avoid the cost for conditioning water after the treatment. Therefore, the cost of chemicals used for pH adjustment can be reduced. Moreover, the sludge volume when use *M. oleifera* as coagulant is less than that of alum and do not cause any disposal problem. Furthermore, the benefits of *M. oleifera* sludge are biodegradable organics and no heavy metals; therefore, the sludge can be used as a fertilizer. *M. oleifera* seed is recommended as a suitable resource material for water purification because it has excellent properties as an environmental friendly coagulant (Ndabigengesere and Narasiah, 1998).

Metropolitan Waterworks Authority (MWA) is responsible for clean disinfected water production, transmission and distribution to people living in Bangkok, Nonthaburi and Samut Prakan. There are four water treatment plants, namely, Bangkhen WTP, Samsen WTP, Thonburi WTP, and Mahasawat WTP. Bangkhen WTP is the largest plant and highest production capacity. Raw water is taken from Chao Phraya River at Sam Lae pumping station, located in Pathum Thani. Raw water is treated by conventional process including coagulation-flocculation followed by sedimentation, filtration, and disinfection by chlorine.

1.3 Objectives

The main objectives of this research work included:

1.3.1 To investigate the efficiency of *M. oleifera* extraction using different solvents including distilled water, sodium chloride (NaCl), and sodium hydroxide (NaOH).

1.3.2 To evaluate the optimum parameters (including slow mixing speed of jar test, sedimentation time, and dosage of coagulants) in terms of turbidity reduction for coagulation processes using the selected *M. oleifera* extraction as well as alum as a coagulant.

1.3.3 To investigate the effectiveness of *M. oleifera* extract, alum and the combination of *M. oleifera* extract and alum used as coagulants for turbidity reduction.

1.3.4 To compare the quality of water treated with *M. oleifera* extract, alum, and the combination of *M. oleifera* and alum, in terms of pH, conductivity, alkalinity, organic matter, heavy metals, Trihalomethane Formation Potential (THMFP), etc.

1.4 Scope of the Study

The scope of this study included:

1.4.1 Preparation of *M. oleifera* seed powder

Good quality *M. oleifera* seeds were selected from the commercially available varieties in the market. The seeds' shells and wings were removed manually to obtain the kernels. The kernels were then ground to a fine powder and screened through the 0.5 mm pore size sieve to enhance solubilization of the active components of the seeds in the solvents.

1.4.2 Preparation of *M. oleifera* extraction and alum stock solution

Alum stock solution was prepared by using 50% w/w alum sulfate dissolved in distilled water.

Three different solvents were used to extract active components from the prepared seed powder: distilled water, 0.5 M NaCl and 0.5 M NaOH.

1.4.3 Collection of raw water samples

The raw water samples were collected from the intake of Bangkhen WTP, MWA during two sampling periods between July and December 2014.

1.4.4 Jar test operation

Jar tests were conducted in the laboratory of Bangkhen WTP, MWA. The clarified samples were then be collected from the supernatant at the top of the beakers and analyzed for the determination of water quality.

1.4.5 Evaluation of the optimum parameters for turbidity removal by using *M. oleifera* as a coagulant or co-coagulant

The effectiveness of *M. oleifera* as a coagulant or co-coagulant was evaluated by jar tests via following investigations:

1.4.5.1 Efficiency of different solvents including distilled water, 0.5 M NaCl and 0.5 M NaOH for extracting *M. oleifera*

1.4.5.2 Efficiency of turbidity removal with *M. oleifera* extraction as well as alum as a coagulant by varying slow mixing speed of jar test, sedimentation time, and dosage of coagulants

1.4.5.3 Comparison of water quality after being treated between *M. oleifera* extraction and alum

1.4.5.4 Efficiency of turbidity removal with *M. oleifera* extraction used with alum as a co-coagulant

1.4.5.5 Comparison of water quality after being treated by *M. oleifera* as well as alum used as coagulants individually and the combination of two used as co-coagulants

CHAPTER II
LITERATURE REVIEW

2.1 Turbidity and its Impact on Water Quality

Turbidity is the cloudiness of a fluid that is usually visible to the naked eye, like smoke in the air. Turbidity in water is occurred by suspended and colloidal substances that obstruct light from passing through the water. It might be caused by an inorganic (e.g. clay, silt, and sand) or organic matter (e.g. algae and microbes) or a combination of the two (APHA et al., 2012; WHO, 2011).

2.1.1 Sources of Turbidity

Turbidity in several groundwater sources is from the presence of inert clay when the water is pumped from the underground whereas, turbidity in some surface water sources can occur as a particulate matter of many types and usually include microbes which are hazardous to health. Turbidity in distribution systems might be resulted from the agitation of sediments and biofilms and also from the ingression of external dirty water when there are leaks in the system (WHO, 2011).

Many impurities in water are colloidal solids, which do not easily settle. Small dispersed and suspended particles that cause turbidity and color of the water cannot be completely removed by the simple sedimentation. Normally, colloidal particles carry a negative electrical charge. Their diameter ranges from 10^{-4} to 10^{-6} mm. These particles are clustered around by a double layer preventing contact between each other (Pritchard et al., 2010b).

2.1.2 Impact of turbidity

Turbidity can negatively affect on consumer acceptability of water. Although turbidity is not actually harmful to health, it is a visible indicator of the possible presence of contaminants that might be related to health concern. Various data show an increasing risk of gastro-intestinal infections that may be associated with high turbidity level.

Turbidity can reduce the efficiency of disinfection since it protects organisms. Several water treatment processes focused on the removal of particulate matter or turbidity before the disinfection process. This will increase the capability of disinfection by chemical disinfectants such as chlorine and ozone, as well as enhance the efficiency of physical disinfection processes such as ultraviolet irradiation, as light transmission through water is deteriorated by particulates. The turbidity removal by coagulation and sedimentation and by filtration is an important obstacle in achieving safe drinking water (WHO, 2011).

2.1.3 Turbidity used as an indicator of microbial contamination in water

Regular monitoring of microbial contamination or disease-causing microorganisms such as helminth eggs and *E. coli* in water is expensive and requires skilled personnel. An important step in simplifying water quality measurements to allow for more regular monitoring is to establish a relationship between concentration of microorganisms and a proxy parameter that is much easier and cheaper to measure,

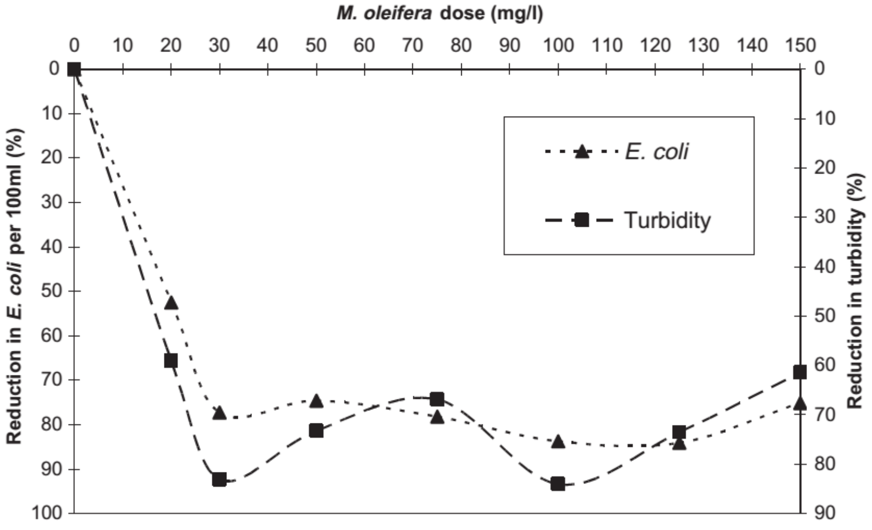


Fig. 2.1 Relationship between turbidity removal (initial turbidity 175 NTU) and *E.coli* reduction in water coagulated with *M. oleifera* (Pritchard et al., 2010b)

i.e. turbidity. A positive relationship was established between reduction of turbidity and the reduction of helminth eggs (Sengupta, et al., 2012). In addition, Pritchard and co-workers (2010b) reported that reduction in numbers of E. coli was directly associated with reduction in turbidity (Fig. 2.1). Therefore, turbidity may be used as an indicator of possible sources of microbial contamination (WHO, 2011).

2.2 Measurement of Turbidity

Turbidity refer to the cloudiness of water It is a measure of the optical property that causes light scattering and absorption rather than transmission with no change in direction or flux level. Light-absorbing materials such as activated carbon result in a negative interference. Dirty glassware and the presence of air bubbles give false results.

Most commercial turbidimeters which can measure low turbidities are called nephelometers. This instrument consists of a light beam for illuminating the sample and one or more photoelectric detectors that measures the intensity of light scattered that perpendicular to the path of incident light (Fig. 2.2). Nephelometers are the standard instrument for measurement of low turbidities.

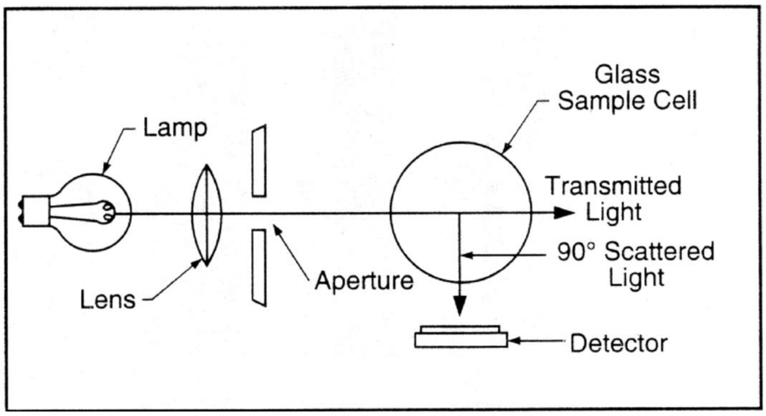


Fig. 2.2 Illustration of basic nephelometers

The principle of nephelometric method is based on a comparison of the intensity of light scattered by the sample with the intensity of light scattered by standard reference suspension. The nephelometric method is preferable to visual methods because of its precision, sensitivity, and applicability over a wide turbidity range. Report nephelometric measurement results as nephelometric turbidity units (NTU) (APHA, 2012).

It should be noted that turbidity is not a measurement of the amount of light scattered or absorb; it does not measure the amount of suspended solids present or the sedimentation rate of an estuary (USEPA (Office of Water), 2006).

2.3 WHO Guidelines for Turbidity in Drinking Water

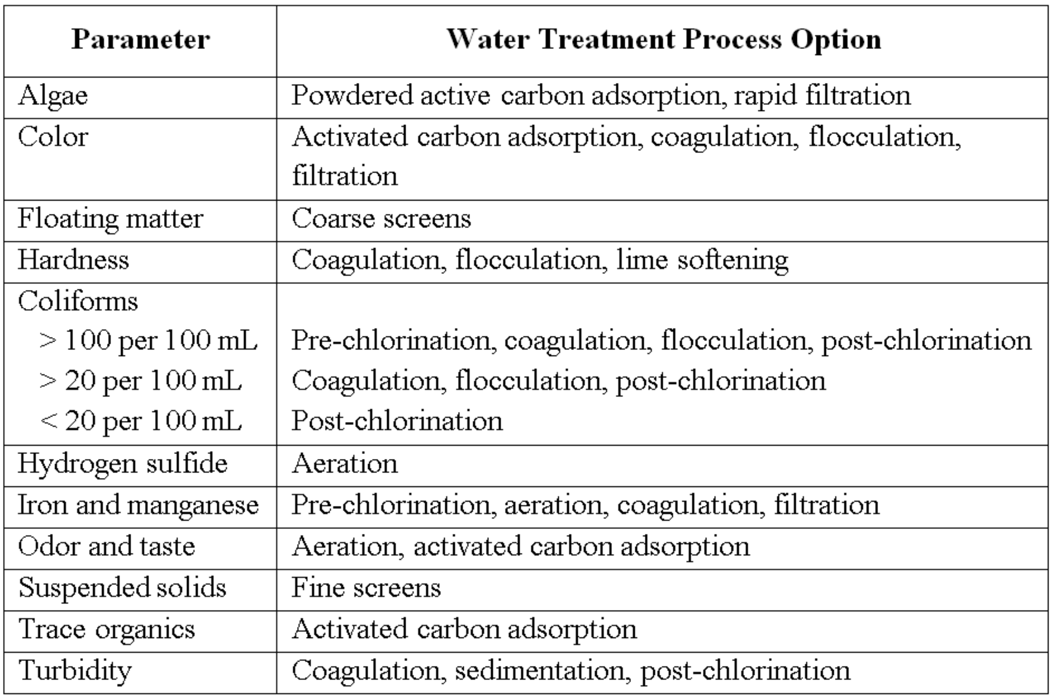
At above approximately 4.0 NTU, turbidity in water can be noticed by the naked eye. Although turbidity slightly above 4.0 NTU in drinking water does not show significant health impacts, it is aesthetically unappealing for human consumption. It is important that drinking water is safe and acceptable in appearance. Water that looks unappealing will lower the confidence in consumption, which may lead to complaints or could even make the consumers turn to water from sources that are less safe (USEPA (Office of Water), 2004).

In addition, to ensure that the disinfection process is effective, turbidity should be not reach 1 NTU and should be much lower if possible. A large and well-run municipal water supply with good resources should be able to achieve less than 0.5 NTU before disinfection. Water treatment systems that achieve below 0.3 NTU before disinfection have showed that they have important barriers against pathogenic organisms which adsorb to particulate matter. Measurement of residual turbidity is important owing to the fact that it would be a good indicator of chlorine-resistant pathogenic organisms e.g. *Cryptosporidium* (WHO, 2011).

2.4 Unit Processes for Water Treatment for the Removal of Specific Parameters

The water treatment process options for the removal of various parameters are shown in Table 2.1. It can be seen that coagulation, sedimentation, and post-chlorination are used to remove turbidity in water. In addition, the coagulation can be also used to reduce color, hardness, coliforms, and iron and manganese in water (Davis, 2010).

Table 2.1 Water treatment process options for the removal of various parameters (Gray, 2005)



Parameter	**Water Treatment Process Option**
Algae	Powdered active carbon adsorption, rapid filtration
Color	Activated carbon adsorption, coagulation, flocculation, filtration
Floating matter	Coarse screens
Hardness	Coagulation, flocculation, lime softening
Coliforms	
> 100 per 100 mL	Pre-chlorination, coagulation, flocculation, post-chlorination
> 20 per 100 mL	Coagulation, flocculation, post-chlorination
< 20 per 100 mL	Post-chlorination
Hydrogen sulfide	Aeration
Iron and manganese	Pre-chlorination, aeration, coagulation, filtration
Odor and taste	Aeration, activated carbon adsorption
Suspended solids	Fine screens
Trace organics	Activated carbon adsorption
Turbidity	Coagulation, sedimentation, post-chlorination

This study was focused on coagulation process to remove turbidity in the raw water.

2.5 Coagulation

Coagulation process is one of the necessary processes for water treatment system especially surface water. The dissolved chemical substances and the turbidity from water could be removed from this process. Coagulation is achieved by addition of coagulants, normally salts of aluminum and iron, to form a solid flocculent mass, usually called flocs. The flocs remove suspended and dissolved solids via sedimentation, charge neutralization, adsorption and entrapment. The flocs are removed from the treated water by subsequent solid–liquid separation processes, including sedimentation, flotation and pressure gravity filtration (Joseph et al., 2012).

The flocs are usually removed by sedimentation which is normally achieved in horizontal flow or flocs blanket clarifiers. After the flocs removal, the treated water is then filtered through rapid gravity filters in order to remove remaining solids, subsequently disinfection and supply.

The efficiency of coagulation system relies on the quality of raw water, the type of coagulant, the dosage of coagulant and pH value, and operational factors such as mixing speed. Coagulation process is proper for the removal of matters and microbe contaminants and some heavy metals (WHO, 2011).

Coagulant is divided into two main types, namely, chemical coagulant and natural coagulant.

2.6 Chemical Coagulants

Chemical coagulation is commonly used for the treatment of surface water. There are several chemical coagulants widely used in drinking water treatment as briefly described below.

2.6.1 Aluminum-based coagulants

The most common aluminum-based coagulant is alum ($Al_2(SO_4)_3$) and other coagulants such as aluminium chloride ($AlCl_3$). Although alum is the most well-known coagulant in water treatment system, the performance of alum could be reduced, especially at low temperatures or at low pH value. In addition, there are relatively high aluminum residuals in the treated water, which may cause harmful to health or other problems in distribution system such as spontaneous flocculation. The control of pH levels can help avoid these problems, but turbidity removal will be affected. The pH has significant impact on the efficiency of coagulation, and it has been observed that the optimum pH for alum coagulation is between 5.0 and 6.5 (with dosage of alum of 5-100 mg/L), giving approximately 97 % of turbidity removal (Alexander et al., 2012).

Recently, there have been the developments and researches on prehydrolyzed aluminum coagulants, e.g. polyaluminium chloride (PACl) and polyaluminium sulfate (PAS). These coagulants are considered as the most effective Al-species because of their larger size and higher positive charges.

2.6.2 Ferric-based coagulants

Ferric salts that are generally used as coagulant are ferric chloride ($FeCl_3$) and ferric sulfate ($Fe_2(SO_4)_3$). It has been observed that the optimum pH value for ferric coagulation is in the range of 4.5 and 6.

2.6.3 Organic polyelectrolytes as coagulants or coagulant aids

A polymer is considered as a polyelectrolyte, when its monomeric unit contains ionizable groups (e.g. carboxyl, amino or sulfonic). Polyelectrolytes can be cationic, anionic or ampholytic, whereas polymers without ionizable groups are considered as non-ionic. Cationic polyelectrolytes include polydiallyldimethyl ammonium chloride, cationic polyacrylamides, and natural cationic polymers (e.g. chitosan, starch), while anionic polyelectrolytes include natural biopolymers. Non-ionic polyelectrolytes include polyacrylamide). However, polyelectrolytes, especially cationic organic polyelectrolytes are regarded as quite toxic to aquatic organisms. Many countries have restricted their use in water purification (Matilainen et al., 2010).

The properties of variety of coagulant are shown in Table 2.2.

Although the effectiveness of these chemicals as coagulants is well-known, they are pH dependent and significantly affect pH of treated water. Moreover, the large sludge volume obtained from treatments using aluminum salts leads to disposal problems such as aluminum accumulation in the environment (Ndabigengesere and Narasiah, 1998). Furthermore, some studies have reported that residual aluminum in drinking water may pose a risk towards Alzheimer disease. Aluminum has also been indicated to be a causative agent in neurological disease like ‘per-senile dementia’ (Bhatia et al., 2007). Whereas the synthetic organic polymers, such as acrylamide, have neurotoxic and carcinogenic effects (Muthuraman and Sasikala, 2013).

Many of the chemical coagulants are associated with human health and environmental impact. One possible method to solve these problems may be natural coagulants which are preferably alternative excellent method for removal of turbidity from drinking water. The main advantages of using natural plant-based coagulants as water treatment material are apparent; they are cost effective, unlikely to produce treated water with extreme pH and highly biodegradable.

Table 2.2 Properties of variety of coagulants (Gray, 2005)

Type of water	Alum	Ferric salts	Polymer
Type 1. High turbidity, high alkalinity (easiest to coagulate)	Effective over pH range 5-7. No need to add alkalinity or use coagulant aid	Effective over pH range 6-7. No need to add alkalinity or use coagulant aid	Cationic polymers usually very effective. Anionic and non-ionic may also work.
Type 2. High turbidity, low alkalinity	Effective over pH range 5-7. May need to add alkalinity to control pH. Coagulant aid not needed	Effective over pH range 6-7. May need to add alkalinity to control pH. Coagulant aid not needed	Cationic polymers usually very effective. Anionic and non-ionic may also work.
Type 3. Low turbidity, high alkalinity	Relatively high dose needed to form sufficient flocs. pH near to 7. Coagulant aid may help	Relatively high dose needed to form sufficient flocs. Coagulant aid may help	Will not work well alone due to low turbidity. Adding a clay to increase turbidity may be effective
Type 4. Low turbidity, low alkalinity (most difficult to coagulate)	Relatively high dose needed to form sufficient flocs. pH near to 7. Alkalinity or clay need to be dosed to produce type 2 or type 3 water	Relatively high dose needed to form sufficient flocs. pH near to 7. Alkalinity or clay need to be dosed to produce type 2 or type 3 water	Will not work well alone due to low turbidity. Adding a clay to increase turbidity may be effective

Note: 1. Low turbidity < 10 NTU; high turbidity > 100 NTU

2. low alkalinity < 50 mg $CaCO_3$; high alkalinity > 250 mg $CaCO_3$

2.7 Natural Coagulants

Natural coagulants are the substances produced from the plants. Over the past few years, many plants have been investigated to be used as coagulants in water treatment process e.g. Nirmali, Tannin, Cactus, *Moringa oleifera*.

Natural coagulants can have cationic, anionic or non-ionic charge, in which the former two are polyelectrolytes. Mostly natural coagulants are mostly either polysaccharides or proteins. However, it is not necessary that non-ionic polymer are absent of charged interactions, since there may be interactions between the polymer and a solvent within a solution environment as the polymer may contain partially charged groups including –OH along its chain (Yin, 2010).

It is essential to understand the basis of coagulation mechanisms related to these natural coagulants. Particulates in a solution can aggregate via four classic coagulation mechanisms, namely double layer compression, sweep flocculation, adsorption and charge neutralization, and adsorption and interparticle bridging.

Although several natural coagulants have been reported, only four types are generally well-known within the scientific community, namely, nirmali seeds (*Strychnos potatorum*), *Moringa oleifera*, tannin and cactus.

2.7.1 Nirmali

S. potatorum (nirmali) is found in southern and central parts of India, Sri Lanka, and Burma. It is a moderate-sized tree and be used prominently as a traditional medical extract. It was reported that its seed extracts have been used in order to treat turbid surface water over 4000 years ago. Nirmali seed extracts are anionic polyelectrolytes which destabilize the matters in water by interparticle bridging (Yin, 2010).

2.7.2 Tannin

Tannin is a common name of large polyphenol compounds obtained from natural materials such as the organic extract from bark and wood of trees. It is a polymer having molecular weights of 100–10,000 and customarily used in the leather industry. There have been conflicting reports on the effect of tannin on human health. Nevertheless, its application as natural coagulant for water purification is still a preferred research area for many researchers. Chemical coagulants could be replaced by Tannin (Graham et al., 2008).

2.7.3 Cactus

Cactus is not only used as medical medicine and food sources, but also used as effective plant-based coagulant. The efficient coagulation capability is from viscous carbohydrate kept in cactus inner and outer pads, called mucilage.

Diaz et al. (1999) study the efficiency of two natural coagulants, namely *Cactus latifaria* and the seeds of *Prosopis juliflora*. The water with turbidity of 100 – 200 NTU, considered as high turbidity and that of 30 – 40 NTU, considered as low turbidity, was synthesized to resemble the water supply in the city of Maracaibo. It was found that both plant materials have the potential that is used as natural coagulants.

Another interesting study on cactus as natural coagulant was conducted by Zhang et al. (2006) via the jar test. The performance of cactus coagulation achieved rather high turbidity removal efficiency. The turbidity of treated water below 5 NTU can be reached with initial turbidities ranging from 20-200 NTU.

2.7.4 *Moringa oleifera*

Moringa oleifera (*M. oleifera*), belonging to the family *Moringacae,* is a multipurpose tree native to Northern India but is now widely found throughout the tropics. It is gemerally known as ‘drumstick tree’, ‘horse-radish tree’, ‘ben oil tree’, and ‘benzoil tree’. It is full of nutrients and is suitable to be human food as well as animals. Moreover, it can be used as traditional medicines and helps to purify drinking water. The *M. oleifera*’s tree, pods, seeds, shelled seeds, and powder were shown in Fig. 2.3 (Bhatia et al., 2007).

The *M. oleifera* seeds contain up to 40% by weight of quality edible oil (greater than 80% unsaturated fatty acid content). The seed cake which is obtained after extracting the active ingredients contains high levels of protein resulting in produce a valid fertilizer for agriculture (Bhuptawat et al., 2007).

The capable of *M. oleifera* seeds as an effective coagulant in water treatment process is owing to its water soluble cationic proteins in the seeds. These proteins are densely charged cationic dimmers (protein complex made up of two subunits with a positive charge) with relatively low molecular weight (6-16 kDa). The isolelectric pH value is between 10 and 11. The principal mechanism of *M.*

oleifera coagulation is adsorption and neutralization of charges. In addition, it is feasible to extract an edible vegetable oil from the *M. oleifera* seeds before using as the coagulant (Ndabigengesere et al., 1995).

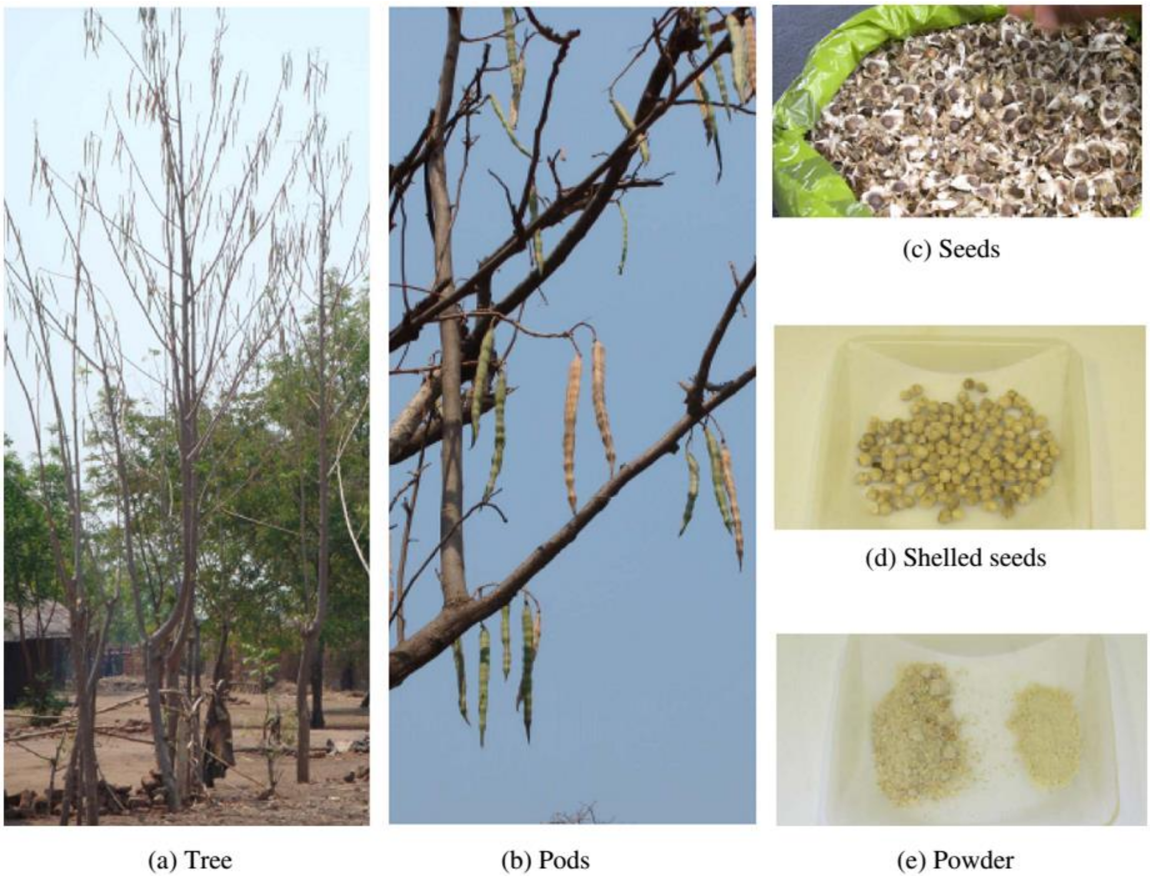

(a) Tree (b) Pods (c) Seeds (d) Shelled seeds (e) Powder

Fig. 2.3 *M. oleifera* various parts (Bhatia et al., 2007)

Since the impurity particles are normally negatively charged, the most effective coagulants should be cationic polyelectrolytes, such as *M. oleifera*. One mechanism of action is that positive charged *M. oleifera* proteins bind to the negative charged suspended particles by coulomb forces neutralizing the surface charge, i.e. colloidal charge neutralization and reduced electrostatic repulsion cause flocculation of matters, i.e. bridging of destabilized particles. Another mechanism of action is that positive charged *M. oleifera* proteins bind to parts of the surface of the negatively charged particles (by adsorption), and owing to matter collision and interparticulate saturation of the differently charged particle surface areas flocs are formed (Sengupta et al., 2012).

The optimum pH of *M. oleifera* is slightly basic since impurity particles are predominantly negatively charged at pH higher than 7. The impurity particles are slight negatively charged at pH below 7 resulting in enhanced repulsion effect between the polyelectrolytes and particles (Yin, 2010).

M. oleifera hardly affects the pH, conductivity and alkalinity to treated water. Therefore, the usage of *M. Oleifera* extract in water treatment process could reduce the cost of chemicals used for pH adjustment. Moreover, the volume of sludge is substantially lower than that of alum and do not offer any disposal problem. Therefore, *M. oleifera* seed after oil extraction is recommended as a suitable resource material for water purification since its excellent properties as an environmental friendly coagulant (Ndabigengesere and Narasiah, 1998).

2.8 Plant-based Coagulants Used in Water Treatment

The common processing steps for preparation of plant-based coagulants could be divided into three principal stages, namely primary, secondary and tertiary as shown in Fig. 2.4. The primary processing step is highly straight and does not require sophisticated processing equipment. Most studies use only this processing step to simulate the conventional approach of drying and subsequent grinding of plant into fine powder. However, an obvious drawback occurs because the seed powder contains not only active agents, but also plant tissues. The latter is full with organic substances resulting in increasing organic matters in the finished water that might severe the situation further, upwards enhancing the performance of treatment. It could be solved by processing the powder through secondary and tertiary processing stages which is extraction and purification, respectively (Fatombi et al., 2013). This is done by the extraction of active agents and subsequently purification of them to remove unrequired organic matters.

In the secondary processing stage, the extraction of active coagulating agents could be done by using different solvents such as water and salt solution. Mostly, different solvents are together utilized to extract useful oil and active coagulating agents in separate sub-steps. Extraction of active coagulating agents by using water is apparently the most recognized alternative since its abundance and cost-effectiveness. For example, the active component of *M. oleifera* is water-soluble protein. However, extraction of the active component of *M. oleifera* by using the solution of sodium chloride has been reported to be superior to water (Muthuraman and Sasikala, 2013).

Tertiary processing stage is infrequently performed for plant-based coagulants and is nowadays limited to academic research on purification of *M. oleifera* extracts due to the ineffective cost. Preliminary studies suggest that lyophilization, ion-exchange and dialysis are possible purification methods for *M. oleifera* extracts which could be incorporated into a scaled-up setup for treatment of higher throughput of turbid water. Such methods have not been extensively applied to other plant-based coagulants and this presents opportunities for other research (Yin, 2010).

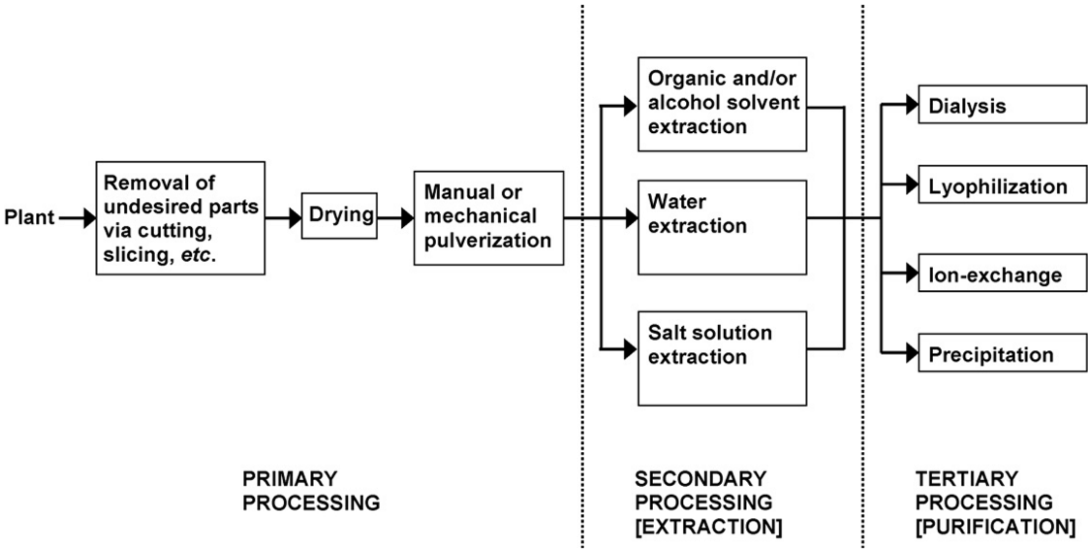


Fig. 2.4 General processing steps in preparation of plant-based coagulants (Yin, 2010)

Due to the limitation of the cost as well as the equipment, the secondary processing (extraction) step was performed in this study.

2.9 Study Site- Bangkhen Water Treatment Plant (WTP)

Metropolitan Waterworks Authority (MWA) is responsible for clean disinfected water production, transmission and distribution to people living in three provinces, which are Bangkok, Nonthaburi and Samut Prakan. There are four water treatment plants, namely, Bangkhen WTP, Samsen WTP, Thonburi WTP, and Mahasawat WTP. Bangkhen WTP is the largest plant and highest production capacity.

The Bangkhen WTP can be divided into 6 main sections, namely, raw water section, clarification, filtration, water storage, transmission and distribution, and sludge lagoon.

2.9.1 Raw water source

Raw water used in Bangkhen WTP is obtained from Chao Phraya River at Sam Lae Pumping Station, located about 18 km north of the Bangkhen WTP in Pathum Thani Province. The raw water from the canal, namely Klong Prapa, is pumped to Bangkhen raw water pumping stations through coarse and fine screen before conveyed to the clarification section.

2.9.2 Clarification (coagulation, flocculation and sedimentation)

The conical tanks of clarifiers are solid contact units of slurry recirculation type. The tank is divided into 2 zones that is reaction and sedimentation zones. The reaction zone is in the center area of the tank where water is agitated and mixed with coagulants. The latter area is the zone where raw water mixed with coagulants form flocs and sedimentation occurs.

As a result, the water and sludge are then separated since the clarified water flow to the surface whereas the accumulated sludge settles down at the bottom of the tank for sludge removal process. The clarified water is radial collected in launders and then delivered to the filtration section.

2.9.3 Filtration

The clarified water is conveyed through the clarifier effluent channels to rapid sand/anthracite coal filters. The dual media comprise of anthracite coal on the top layer and graded sand at the bottom layer. Air/water backwash system is operated every 48 h to remove clogging of the filter media. The filtrate water is then transmitted to the water storage section.

2.9.4 Water storage

Filtrate water is conveyed and collected in the water storage, called Reservoir. The post-lime and disinfectants, such as chlorine are dosed in this section in order to improve water quality and maintain drinking water quality.

2.9.5 Transmission and distribution

The treated water is delivered and distributed to the customers by transmission and distribution pumping stations through water tunnels and conduits.

2.9.6 Sludge lagoon

Sludge is drained from the bottom of the tanks of clarifiers and backwash water from the filters is pumped to sludge lagoon. Dried accumulated sludge is periodically removed.

2.10 Main Water Quality Parameters Monitored in Present Study

Several parameters were investigated in this study including:

2.10.1 Conductivity

Conductivity is a measurement of the capability of water to carry an electrical current. The capability relies on the presence of ions as well as the concentration of ions in the water, and the temperature of measurement. In practical, conductivity is used to determine the mineral in the water that is normally called total dissolved solids, to estimate the volume of water sample for other analysis, and to determine the amounts of chemical reagents to be added to water sample (APHA, 2012).

2.10.2 pH

pH is the intensity factor of acidity, defined as $-\log[H^+]$. It is one of the most significant water quality parameters and regularly used for testing of water. Practically every step of water treatment process, including coagulation, precipitation, disinfection and corrosion, is pH-dependent. pH control is essential for water treatment process in order to assure desirable water clarification and disinfection. For example, pH should be below 8 to capable disinfection with chlorine; whereas, pH of 7 or less is probably to be corrosive in mains and pipes. The pH of water must be handled to minimize the corrosion in distribution systems as well as household water systems.

The desired pH in the distribution system is usually between 6.5 and 8.5. However, there is no health-based guideline value proposed for pH value (WHO, 2011).

2.10.3 Alkalinity

Alkalinity is defined as the acid-neutralizing ability of water. The alkalinity of abundant surface waters is principally a function of carbonate, bicarbonate, and hydroxide content. Alkalinity is the measurement of aggregate property of water and could be interpreted in terms of specific substances only when chemical composition of the sample is known, usually expressed in term of equivalent calcium carbonate ($CaCO_3$). The determined value might vary importantly with the end point of pH used (APHA, 2012).

2.10.4 Organic matter

Organic matter is the matter containing organic substances that originates from the remains of organisms, including plants and animals and their waste products in the environment. Basic structures are produced from cellulose, tannin, cutin and lignin, along with other various proteins, lipids, and carbohydrates. Organic matters normally found in the water are lignin, tannin, and humic substances.

Total organic carbon (TOC) is usually used to determine the total organic content in the water. TOC in the drinking water is often in the range of < 0.1 – 25 mg/L.

Because several organic substances found in the water (such as lignin, tannin and humic substances) strongly absorb ultraviolet (UV) radiation, UV absorption is also useful surrogate measure of such compounds. There is the strong correlation between UV absorption and organic carbon content and precursors of trihalomethanes (THMs). UV absorption, often measured at 254 nm, could be used to determine the organic matter and help control disinfection byproducts.

2.10.5 Trihalomethanes (THMs)

Trihalomethanes (THMs) are produced during chlorination of organic substances in the water. Such organic substances are called as THMs precursors. The most common THMs and the major disinfection by-product in chlorinated water are chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$ or BDCM), dibromochloromethane ($CHBr_2Cl$ or DBCM), and bromoform ($CHBr_3$). These by-products are considered as significance adverse health impact in drinking-water.

Chloroform is considered as toxic and harm to the centrilobular region of the liver. Exposure to BDCM is likely to increase in reproductive effects, increase in risk for spontaneous abortion or stillbirth. Further, both chloroform and BDCM is classified as carcinogenic and classified in group 2B (possibly carcinogenic to humans) by International Agency for Research on Cancer (IARC).

DBCM induced hepatic tumours in female mice and possibly in male mice but not in rats. Bromoform induced a small increase in relatively rare tumours of the large intestine in rats but did not induce tumours in mice. However, IARC has classified both DBCM and bromoform in group 3 (not classifiable as to its carcinogenicity to humans).

Guideline values proposed for chloroform, BDCM, DBCM, and bromoform are 300, 60, 100, and 100 μg/L, respectively. THMs are calculated from the fraction of four by-products and could be taken as following fractionation approach.

$$\text{THMs} = \frac{C_{\text{chloroform}}}{GV_{\text{chloroform}}} + \frac{C_{\text{BDCM}}}{GV_{\text{BDCM}}} + \frac{C_{\text{DBCM}}}{GV_{\text{DBCM}}} + \frac{C_{\text{bromoform}}}{GV_{\text{bromoform}}}$$

Where: C = Concentration

GV = Guideline value

Guideline value for proposed THMs must to be equal to or less than 1

2.10.6 Hardness

Hardness in water is caused by various multivalent cations dissolved in the water, prominently calcium and magnesium. This is generally indicated by the ability of water that precipitate the soap and the necessary for excess usage of soap to get cleaning, easy to be noticed the change in hardness by consumers. No health-based guideline value is proposed for hardness in drinking water (WHO, 2011).

Carbonate hardness, also called temporary hardness, is resulted from the presence of dissolved bicarbonate minerals in the water such as carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) anions. It could be eliminated by boiling the water which promotes the formation of carbonate from the bicarbonate and thus precipitates calcium carbonate out of solution, leaving water that is softer upon cooling. Moreover, it is also reduced by the addition of lime (calcium hydroxide).

Non-carbonate hardness, also called permanent hardness, is resulted from the presence of sulfate and chloride compounds in the water, which do not precipitate out as boiling.

Total hardness is defined as the sum of calcium and magnesium concentrations, expressed as calcium carbonate ($CaCO_3$), in unit of mg/L. When total hardness numerically is higher than total alkalinity, carbonate hardness is equivalent to total alkalinity; the amount of hardness in excess of this is called non-carbonate hardness. When total hardness numerically is equal to or lower than total alkalinity, carbonate hardness is total hardness; non-carbonate hardness is zero (APHA, 2012).

2.10.7 Calcium

Calcium is essential in plant and animal nutrition and is significant component of bones, shells, and plant structure. The most common forms of calcium are calcium carbonate (calcite) and calcium-magnesium carbonate (dolomite). The presence of calcium in water is caused by the deposit of limestone, dolomite, and gypsum. The solubility of calcium carbonate is controlled by pH and dissolved carbondioxide (CO_2) (APHA, 2012).

2.10.8 Magnesium

Magnesium only occurs naturally in combination with other elements, having +2 oxidation states. Magnesium is used in fertilizers, pharmaceuticals, and foods. It is a significant element in chlorophyll and in red blood cells (APHA, 2012).

2.10.9 Chloride

Chloride is one of the principal inorganic anions in the water. The major source of human exposure to chloride is the addition of salt to food and the intake of excessive chloride in drinking water. High concentrations of chloride give a salty taste to water and probable to enhance rates of corrosion of metals in the distribution system, resulting in increasing concentrations of metals in the distribution system. Concentrations in excess of 250 mg/L are likely to be noticed by consumer. However, there is no health-based guideline value proposed for chloride in drinking water (WHO, 2011).

2.10.10 Sulfate

High concentrations of sulfate in drinking water could cause noticeable taste and might cause a laxative effect in unaccustomed consumers. However, existing data do not identify that sulfate in drinking water cause adverse human health effect. The concentration of sulfate in drinking water in excess of 250 mg/L could be detected by consumer which can impact acceptability of drinking water.

2.10.11 Aluminum

Aluminum salts are well-known applied in water treatment process as coagulants to remove turbidity, color, and microbes, leading to enhanced concentrations of aluminum in treated water. There is little indication that orally ingested aluminum is acutely toxic to humans although the widespread occurrence of the element in foods, drinking water and several antacid preparations. It has been assumed that exposure to aluminum is a risk factor for the development or acceleration of onset of Alzheimer disease in humans. A health-based value derived from The Joint FAO/WHO Expert Committee on Food Additives (JECFA) provisional tolerable weekly intake (PTWI) would be 0.9 mg/l (rounded value), based on an allocation of

20% of the PTWI to drinking-water and assuming a 60 kg adult drinking 2 L of water per day.

2.10.12 Heavy metals

Several heavy metals are worth to investigate due to their impact on human health and aesthetic concern as well as corrosion problems in the distribution systems. These heavy metals, including lead, copper, zinc, chromium, cadmium, silver, arsenic, barium, manganese, nickel, antimony and selenium are included in the WHO guidelines for drinking water quality.

2.11 Use of *M. oleifera* as a natural Coagulant for turbidity reduction - Past Studies

These past studies are divided into two parts. The first one is the effectiveness of *M. oleifera* as coagulant and the latter one is the comparison of the effectiveness of *M. oleifera* as a natural coagulant with chemical coagulant**.**

2.11.1 The effectiveness of *M. oleifera* as coagulant

In recent years, there have been several studies on the use of *M. oleifera* as a natural coagulant for turbidity reduction in water treatment process. A review of the published literature was carried out to investigate the effectiveness of *M. oleifera* as natural coagulants as presented below.

A study to determine the active components of *M. oleifera* as coagulant and the process mechanism (Ndabigengesere et al., 1995) reported that it can be used as effective natural coagulant in water treatment in two principal crude forms, namely, shelled and non-shelled dry seeds. Coagulation activity of extracts from *M. oleifera* seeds with various solvents such as petroleum ether, hexane, chloroform, acetone, water, and methanol was also investigated in this study. The results showed that only water extract own coagulation activity. It was also concluded that the performance of *M. oleifera* as coagulant was in the form of water soluble cationic proteins in the seeds. These proteins was cationic peptides of molecular weight ranging from 6 to 16 kDa, having a dimer with molecular weight of about 13 kDa, and having isoelectric point in the range of 10-11. In addition, adsorption and neutralization of charges are the main mechanisms of coagulation. (Ndabigengesere et al., 1995).

Based on the results of a study on the usage of *M. oleifera* seed suspension for the softening of hard water, *M. oleifera* could be used for treatment of hard water. It was reported that the removal of hardness increased with increasing *M. oleifera* dosage. Moreover, it was found that the efficiency of hardness removal with *M. oleifera* seeds was independent of pH and alkalinity but dependent on the permanent hardness (non-carbonate hardness) of water (Muyibi and Evison, 1995a).

Another interesting study was also conducted by Muyibi and Evison (1995b) to investigate the physical parameters that influence on the *M. oleifera* coagulation. It was concluded that the initial turbidity of the raw water and dosage of *M. oleifera* were significant factors. At optimum dosage, the improvement of turbidity reduction occurred with increasing initial turbidity. With increase in *M. olefera* dose, the final turbidity was reduced up to the optimum dosage after that the residual turbidity increases since floc re-stabilization.

An experimental study (Gassenschmidt et al., 1995) was carried out to study flocculating protein from *M. oleifera* seeds. The results showed that the molecular mass of the protein was approximate 6.5 kDa and the isoelectric point was above pH 10. Moreover, the amino acid analysis and sequencing showed high contents of glutamine, arginine and proline, and a total of 60 residues. The amino terminus is blocked by pyroglutamate.

According to another study, Mcconnachie et al. (1999) undertook field trials of appropriate hydraulic flocculation processes at the Thyolo Water Treatment Works in Malawi. The results showed that the effectiveness of crushed seed kernels from *M. oleifera* was possible to treat river water for communities up to small town size. It was found that with the raw water ranging from 15 to 5600 NTU, the final turbidity was less than the WHO's guideline value of 5 NTU (in 1993) for drinking water.

The improvement approach for the extraction of the active component from *M. oleifera* seeds was carried out by Okuda et al. (1999). 1 M of sodium chloride (NaCl) was used to extract the active component, compared to distilled water as an ordinary method. With initial turbidity of 50 NTU, 1 M NaCl outperformed and required a lower dosage than the distilled water about 7.4 times for turbidity reduction. This indicates that extraction of *M. oleifera* seeds by using sodium chloride can improve the efficiency of coagulation. Further, there was no difference in the efficiency of extraction of the active component from *M. oleifera* seeds by using other salts, namely, potassium nitrate (KNO_3), potassium chloride (KCl), and sodium nitrate ($NaNO_3$).

Afterwards, Okuda et al. (2001a) purified an active component from *M. oleifera* seeds extracted by NaCl. The active component was isolated and purified from the crude extract through salting-out by dialysis, removal of lipids and carbohydrates by homogenization with acetone, and anion exchange. The results showed that the specific coagulation activity of the active component enhanced up to 34 times more than the crude extract after the ion exchange. It was also found that the optimum pH of the purified active component for coagulation of turbidity was 8 or higher.

A subsequent research focused on the coagulation mechanism of the purified active component. The coagulation mechanism was supposed to form a net-like structure. It removes suspended solids in water by a sweep coagulation mechanism, that is, enmeshment of insoluble matters. The formation of suspended solids was affected by bivalent cations such as Ca^{2+} which might connect each molecule of active component and form a net-like structure (Okuda et al., 2001b).

Recently, Ghebremichael et al. (2005) investigated purification of coagulant active component from *M. oleifera* seeds extracted with water and salt (0.5 M NaCl). The purification technique was performed by using high-trap cation exchanger column. It was found that the coagulant from both water and salt extracts was cationic protein with isoelectric point above 9.6 and molecular mass below 6.5 kDa. It comprised at least four homologous proteins. These proteins were thermal resistant and remained active after heat treatment at 95 °C for 5 hours. The major benefit of this purification is the reduction of the organic matters as well as microbial populations in the water treatment systems, providing its attractiveness as flocculant. Moreover, the coagulation activity of *M. oleifera* extract was almost the same to alum for samples of high turbidity.

A study was done (Katayon et al., 2006) to examine the coagulation performance of *M. oleifera* kept in different storage conditions. The performance of *M. oleifera* was evaluated based on the turbidity removal. It was found that no remarkable difference between the effectiveness of *M. oleifera* stored in refrigerator and room temperature was observed. Moreover, the difference between open and closed container was also not significantly. However, *M. oleifera* kept for one month outperformed those kept for 3 and 5 months. It was concluded that the performance of *M. oleifera* was independent of storage temperature and container but dependent on storage duration. In addition, *M. oleifera* was found to be a potential coagulant particularly for high turbidity water.

According to a study (Kwaambwa and Maikokera, 2007), ionic strength had minimum effect on the conformation of the coagulant protein; however, it was influenced when pH value was more than 9. They suggested that tryptophan environment change remarkably with pH of solution above 9, proposing the protein is denatured.

Recently, *M. oleifera* seed as a natural coagulant was investigated in wastewater treatment using the actual wastewater. The effectiveness of *M. oleifera* as a primary coagulant and the co-coagulant of *M. oleifera* with alum were evaluated in term of chemical oxygen demand (COD). The results showed that overall COD removals of 50% were obtained at both 50 and 100 mg/L *M. Oleifera* doses. When 50 and 100 mg/L seed doses were applied in combination with 10 mg/L of alum, COD removal increased to 58 and 64%, respectively (Bhuptawat et al., 2007).

In an experimental study, three plant extracts, namely *M. oleifera*, *Jatropha curcas* and Guar gum, were investigated in Malawi for the treatment of shallow well water having turbidity of 49 NTU. It was found that all three extracts removed the turbidity above 90% and reduced coliforms about 80%. Moreover, the effectiveness of *M. oleifera* as coagulant was the highest among three plant extracts, followed by Guar gum and *J. curcas* (Pritchard et al., 2009).

According to another study, the cross flow filtration with microfiltration (oil extraction, followed by salt extraction, and filtration with size of 0.45 μm) was found to be enough technique to provide the effective coagulation activity from *M. oleifera* seeds. With initial low turbidity of water (34 – 36 NTU), the turbidity was removed up to 96.23% using very low dosage level, 0.4 mg/L. It was also observed that the molecular weight of bio-active constituents was in the range of low molecular weight, 1000 – 6500 Dalton (Ali et al., 2010).

In one experimental study, Sánchez-Martín et al. (2010) evaluated the performance of one-step and two-step process purified coagulants obtained from *M. oleifera* as compared with the crude extract in terms of turbidity reduction. The one-step purified coagulant was eluted by only 0.6 M NaCl; whereas two-steps purification was done by 0.3 M NaCl followed by 0.6 M NaCl. The results showed that the effectiveness of two-step purified coagulant is significantly higher than the single-step purified coagulant and the crude extract, respectively. They suggested that the second elution provided more purified coagulant since it contains only the active coagulant proteins.

Another recent study was conducted to determine the parameters affecting the performance of *M. oleifera*, as coagulant in water treatment based on the greatest reduction in turbidity. The coagulant performance was insignificantly affected by pH with the optimum pH of 6.5. The alkaline conditions were found to be more effective than acidic conditions. Moreover, colder waters (<15°C) reduced the coagulation performance. The efficiency of coagulation was increased with increasing temperature. In addition, the shelf life of the *M. oleifera* seeds ranging from 18 to 24 months was observed (Pritchard et al., 2010a).

To study the reduction in turbidity of water by using available natural coagulants, *M. oleifera*, *Cicer arietinum*, and *Dolichos lablab* were used. These natural coagulants performed better with high turbidity of water compared to medium and low turbidity of water. About 84 to 96% removal of turbidity was found with natural coagulant treatment of high turbidity water. Among these three coagulants, *C. arietinum* is the most effective in turbidity removal (Asrafuzzaman, et al., 2011).

In another similar study, Sengupta et al. (2012) studied the effect of *M. oleifera* extracts as coagulant for irrigation water, turbid water, wastewater, and tap water. For medium (50-150 NTU) to high turbid water (>150 NTU), *M. oleifera* extracts were effective in reducing turbidity to 7-11 NTU which is 85-96% reduction. In contrast, the treatment of water with low turbidity (<50 NTU) did not result in any significant reduction in turbidity. The reason for this may be that low turbid waters contain low concentrations of suspended particles and that *M. oleifera* proteins have a low molecular weight, resulting in smaller and lighter flocs.

A recent study was carried out to investigate factors, such as stirring period and agitation speed, affecting the performance of coagulation in water treatment process. It was found that the reduction of turbidity was increased up to 95% with increasing the stirring time in the slow stage (30 rpm) of jar test. The agitation rate in the slow stage was varied ranging from 10 to 120 rpm. It was found that the optimum agitation rate was about 80 rpm (Sánchez-Martín et al., 2012).

An experiment study was carried out to investigate the effectiveness of *M. oleifera* seeds as a primary coagulant in water purification. The three forms of the *M. oleifera* coagulants including shelled blended powder (representative of carbohydrates, oil, and protein), de-oiled powder (representative of oil and protein), and protein powder (representative of only protein) were studied. It was found that the turbidity reduction increased with increasing initial turbidity for all three coagulants. Moreover, the effectiveness of protein powder provided superior followed by deoiled and shelled blended powder, respectively (Gidde et al., 2012).

According to a review study (Muthuraman and Sasikala, 2013), the performance of three seeds such as *M. oleifera*, *Strychnos potatorum* (*S. potatorum*), and *Phaseolus vulgaris* (*P. vulgaris*), as natural coagulants was investigated. The active coagulant agent from these seeds was extracted by using different solvents such as sodium NaCl and sodium hydroxide (NaOH), and distilled water. The results showed that NaCl was higher turbidity reduction, above 99%, than distilled water and NaOH, respectively. It was also concluded that the extraction of active component by addition of ultrasound was not significantly different. Moreover, among these three coagulant, *M. oleifera* seed extracts is the highest effectiveness in turbidity removal.

2.11.2 Comparison of the effectiveness of *M. oleifera* as a natural coagulant with chemical coagulant

Some investigations on the effectiveness of *M. oleifera* as a natural coagulants compared with aluminum salts or iron salts which are the most typical chemical coagulants used in water and wastewater treatment have been reported. The effectiveness of shelled and non-shelled dry *M. oleifera* seeds as coagulant was compared with alum in term of turbidity removal. With initial turbidity of 105 NTU, the optimum dosage of shelled *M. oleifera* seeds and alum were not significant different. Both shelled and non-shelled *M. oleifera* seeds could be used as a coagulant but shelled seeds are more effective based on less than the optimal dosage. The coagulation with *M. oleifera* seeds did not remarkably influence the quality of the treated water such as pH, conductivity, and alkalinity. Compared to alum, *M. oleifera* seeds do not require the addition of alkalinity (such as lime) to adjust pH and do not result in corrosion in distribution system. Moreover, it was found that the volume of sludge produced from *M. oleifera* was substantially less than that of alum about 4 to 5 times. Besides being voluminous, the sludges of alum are gelatinous, acidic, and difficult to dissolve in water and to dispose of in the environment. In contrast, *M. oleifera* by-products are biodegradable organics and no heavy metals; therefore, the sludge can be used as a fertilizer. Further, alum does not remarkably decrease the organic matter, whereas *M. oleifera* seeds were likely to enhance it substantially in the finish water (Ndabigengesere and Narasiah, 1998).

A recent study focused on the comparison between the performance of *M. oleifera* and synthetic coagulants, namely alum and ferric sulfate, in the water treatment. The performance of both alum and ferric outperformed than that of *M. oleifera* in the various conditions. The optimum dosage of alum and ferric sulfate were lower than that of *M. oleifera* to achieve optimum turbidity reduction conditions. Although *M. oleifera* was not as effective as alum and ferric, the use of *M. oleifera* together with sand filtration proposes important improvements to drinking water by using locally available products (Pritchard et al., 2010b).

The comparative review of some of the past studies on the effectiveness of *M. oleifera* as coagulant is summarized in Table 2.3. Also the comparative review of some of the past studies on the comparison of the effectiveness of *M. oleifera* as natural coagulant with chemical coagulant is summarized in Table 2.4.

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as a natural coagulant

Year	Authors	Title	Summary of the work
1995	Ndabigengesere, A., Narasiah, K. S., Talbot, B. G.	Active agents and mechanism of coagulation of turbid waters using *Moringa oleifera*	- *M. oleifera* can be used as effective natural coagulant in two principal crude forms, namely, shelled and non-shelled dry seeds. - The performance of *M. oleifera* as coagulant was in the form of water soluble cationic proteins in the seeds. - The protein extracted from *M. oleifera* seeds was cationic peptides of molecular weight ranging from 6 to 16 kDa, having a dimeric of 13 kDa with subunits of about 6.5 kDa. - Adsorption and neutralization of charges are the main mechanisms of coagulation.
1995a	Muyibi, S. A., Evison, L. M.	*Moringa oleifera* seeds for softening hardwater	- *M. oleifera* could be used for treatment of hard water. - The removal of hardness increase with increasing *M. oleifera* dosage. - The efficiency of hardness removal with *M. oleifera* seeds was independent of pH and alkalinity but dependent on hardness of water

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
1995b	Muyibi, S. A., Evison, L. M.	Optimizing physical parameters affecting coagulant of turbid water with *Moringa oleifera* seeds	- Physical parameters that influence on the *M. oleifera* coagulation were the initial turbidity of the raw water and dosage of *M. oleifera*. - At optimum dosage, the improvement of turbidity reduction occurred with increasing initial turbidity. - With increase in *M. olefera* dose, the final turbidity was reduced up to the optimum dosage.
1995	Gassensch-midt, U., Jany, K. D., Tauscher, B., Niebergall, H.	Isolation and characterization of a flocculating protein from *Moringa oleifera* Lam	- The molecular mass of the protein was approximate 6.5 kDa and the isoelectric point was above pH 10. - Amino acid analysis and sequencing showed high contents of glutamine, arginine and proline, and a total of 60 residues. - The amino terminus is blocked by pyroglutamate.

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
1999	Mcconnachie, G. L., Folkard, G. K., Mtawali, M. A., Sutherland, J. P.	Field trials of appropriate hydraulic flocculation processes	- The effectiveness of crushed seed kernels from *M. oleifera* was possible to treat river water for communities up to small town size. - With the raw water ranging from 15 to 5600 NTU, the final turbidity was less than the WHO's guideline value of 5 NTU (in 1993) for drinking water.
1999	Okuda, T., Baes, A. U., Nishijima, W., Okada, M.	Improvement of extraction method of coagulation active components from *Moringa oleifera* seed	- 1 M of sodium chloride (NaCl) was used to extract the active component, compared to distilled water as an ordinary method. - With initial turbidity of 50 NTU, 1 M NaCl outperformed and required a lower dosage than the distilled water about 7.4 times for turbidity reduction. - The extraction of *M. oleifera* seeds by using sodium chloride can improve the efficiency of coagulation - There was no difference in the efficiency of extraction of the active component from *M. oleifera* seeds by using other salts, namely, potassium nitrate (KNO_3), potassium chloride (KCl), and sodium nitrate ($NaNO_3$).

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
2001a	Okuda, T., Baes, A. U., Nishijima, W., Okada, M.	Isolation and characterization of coagulant extracted from *Moringa oleifera* seed by salt solution	- The active component was isolated and purified from the crude extract through salting-out by dialysis, removal of lipids and carbohydrates by homogenization with acetone, and anion exchange. - the specific coagulation activity of the active component enhanced up to 34 times more than the crude extract after the ion exchange. - The optimum pH of the purified active component for coagulation of turbidity was 8 or higher.
2001b	Okuda, T., Baes, A. U., Nishijima, W., Okada, M.	Coagulation mechanism of salt solution extracted active component in *Moringa oleifera* seed	- The coagulation mechanism of the purified active component was supposed to form a net-like structure. - It removes suspended solids in water by a sweep coagulation mechanism, that is, enmeshment of insoluble matters. - The formation of suspended solids was affected by bivalent cations such as Ca^{2+} which might connect each molecule of active component and form a net-like structure

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
2005	Ghebremichael, K. A., Gunaratna, K.R., Henriksson, H., Brumer, H., Dalhammar, G.	A simple purification and activity assay of the coagulant protein from *Moringa oleifera* seed	- Proteins from *M. oleifera* seed was extracted by water and salt and purified by using high-trap cation exchanger column. - These proteins were thermal resistant and remained active after heat treatment at 95 °C for 5 hours reduced microbial populations. - The major benefit of this purification is the reduction of the organic matters as well as microbial populations in the water treatment systems, providing its attractiveness as flocculant. - The coagulation activity of *M. oleifera* extract was almost the same to alum for samples of high turbidity
2006	Katayon, Noor, M.J. M. M., Asma, M., Ghani, L.A. A., Thamer, A.M., Azni, I., Ahmad, J., Khor, B.C., Suleyman, A.M.	Effects of storage conditions of *Moringa oleifera* seeds on its performance in coagulation	- The performance of *M. oleifera* was independent of storage temperature and container but dependent on storage duration - *M. oleifera* was found to be a potential coagulant particularly for high turbidity water.

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
2007	Kwaambwa, H. M., Maikokera, R.	A fluorescence spectroscopic study of a coagulating protein extracted from *Moringa oleifera* seeds	- The ionic strength had minimum effect on the conformation of the coagulant protein; however, it was influenced when pH value was more than 9. - The tryptophan environment change remarkably with pH of solution above 9, proposing the protein is denatured.
2007	Bhuptawat, H., Folkard, G.K., Chaudhari, S.	Innovative physico-chemical treatment of wastewater incorporating *Moringa oleifera* seed coagulant	- Based on using actual wastewater, the overall COD removals of 50% were obtained at both 50 and 100 mg/L *M. Oleifera* doses. - With the combination of 50 and 100 mg/L and 10 mg/L of alum, COD removal increased to 58 and 64%, respectively.
2009	Pritchard, M., Mkandawire, T., Edmondson, A., O'Neill, J. G., Kululanga, G.	Potential of using plant extracts for purification of shallow well water in Malawi	- For the treatment of shallow well water, having turbidity of 49 NTU, in Malawi, all three plant extracts, *namely M. oleifera, Jatropha curcas* and Guar gum, removed the turbidity above 90% and reduced coliforms about 80%. - The effectiveness of *M. oleifera* as coagulant was the highest among three plant extracts, followed by Guar gum and *J. curcas*.

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
2010	Ali, E. N., Muyibi S. A., Salleh, H. M., Alam, Md. Z., Salleh, M. R. M.	Production of natural coagulant from *Moringa Oleifera* seed for application in treatment of low turbidity water	- The cross flow filtration with microfiltration (oil extraction, followed by salt extraction, and filtration with size of 0.45 μm) was enough technique to provide the effective coagulation activity from *M. oleifera* seeds.
2010	Sánchez-Martín, J., Ghebremichael, K., Beltrán-Heredia, J.	Comparison of single-step and two-step purified coagulants from *Moringa oleifera* seed for turbidity and DOC removal	- The performance of one-step and two-step purification of the coagulant from *M. oleifera* was compared with the crude extract. - One-step purification was performed directly with 0.6M NaCl; whereas two-steps procedure was done first with 0.3M NaCl followed by 0.6M NaCl elution. - The effectiveness of two-step purified coagulant is significantly higher than the single-step purified coagulant and crude extract.
2010a	Pritchard, M., Craven, T., Mkandawire, T., Edmondson, A. S., O’neill, J. G.	A study of the parameters affecting the effectiveness of *Moringa oleifera* in drinking water purification	- *M. oleifera* Coagulation was insignificantly affected by pH, which was found to be at pH 6.5 and the shelf life of the seeds was 18 - 24 months. - The higher the temperature, the more superior the coagulation.

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
2011	Asrafuzza-man, Md., Fakhruddin, A. N. M., Hossain, Md. A.	Reduction of turbidity of water using locally available natural coagulants	- *M. oleifera*, *C. arietinum*, and *D. lablab* performed better with high turbidity of water (about 84 to 96% removal of turbidity) compared to medium and low turbidity of water. - *C. arietinum* is the most effective in turbidity removal.
2012	Sengupta, M. E., Keraita, B., Olsen, A., Boateng, O. K., Thamsborg, S. M., Palsdottir, G. R., Dalsgaard, A.	Use of *Moringa oleifera* seed extracts to reduce helminth egg numbers and turbidity in irrigation water	- For medium (50-150 NTU) to high turbid water (>150 NTU), *M. oleifera* extracts were effective in reducing turbidity to 7-11 NTU which is 85-96% reduction. - The treatment of water with low turbidity (<50 NTU) did not result in any significant reduction in turbidity.
2012	Sánchez-Martín, J., Beltrán-Heredia, J., Peres, J. A.	Improvement of the flocculation process in water treatment by using *Moringa oleifera* seeds extract	- the reduction of turbidity was increased up to 95% with increasing the stirring time in the slow stage (30 rpm) of jar test - The agitation rate in the slow stage was varied ranging from 10 to 120 rpm. - The optimum agitation rate was about 80 rpm.

Table 2.3 The comparative review of some of the past studies on the effectiveness of *M. oleifera* as natural coagulant (cont.)

Year	Authors	Title	Summary of the work
2012	Gidde, M. R., Bhalerao, A. R., Malusare, C. N.	Comparative study of different forms of *Moringa oleifera* extracts for turbidity removal	- Among three forms of the *M. oleifera* coagulants, including shelled blended powder (representative of carbohydrates, oil, and protein), de-oiled powder (representative of oil and protein), and protein powder (representative of only protein), the turbidity reduction increased with increasing initial turbidity for all three coagulants. - The effectiveness of protein powder provided superior followed by de-oiled and shelled blended powder, respectively.
2013	Muthuraman, G., Sasikala, S.	Removal of turbidity from drinking water using natural coagulants	- The seed of *M. oleifera, P. vulgaris,* and *S. potatorum* provided significant improvement in removing turbidity from synthetic raw water - *M. oleifera* seed extracts outperformed among these three coagulant - 0.5M NaCl extract gives high removal of turbidity greater than 99% compared to 0.5M NaOH and distilled water extract. - The removal of turbidity by using ultrasound-assisted extraction was not significantly different.

Table 2.4 The comparative review of some of the past studies on the comparison of the effectiveness of *M. oleifera* as a natural coagulant and chemical coagulant

Year	Authors	Title	Summary of the work
1998	Ndabigengesere, A., Narasiah, K. S.	Quality of water treated by coagulation using *Moringa oleifera* seeds	- Both shelled and non-shelled *M. oleifera* seeds can be used as a coagulant - Compared to alum, *M. oleifera* seeds do not need pH and alkalinity adjustments. - The volume of sludge produced from *M. oleifera* was substantially less than that of alum.
2010b	Pritchard, M., Craven, T., Mkandawire, T., Edmondson, A. S., and O'neill, J. G.	A comparison between *Moringa oleifera* and chemical coagulants in the purification of drinking water – An alternative sustainable solution for developing countries	- The performance of both alum and ferric outperformed than that of *M. oleifera* in the various conditions. - Alum and ferric required a lower dose level than *M. oleifera* to achieve optimum conditions. - Although *M. oleifera* was not found to be as effective as alum and ferric, the use of *M. oleifera* together with sand filtration offers significant improvements to drinking water for developing countries using locally available products.

CHAPTER III
METODOLOGY

3.1 Sampling Site

Bangkhen Water Treatment Plant (WTP), which is the largest plant of Metropolitan Waterworks Authority (MWA) with the highest capacity for the production of treated water, was selected for this study to obtain the water samples from its intake. Bangkhen WTP provides most of the tap water used in Bangkok, Nonthaburi, and Samut Prakan provinces.

Raw water used in Bangkhen WTP is taken from Chao Phraya River at Sam Lae Pumping Station through a water canal - Klong Prapa. The intake point in Klong Prapa is located at coordinates 13°53'02.9"N, 100°33'13.7"E (13.88413, 100.55381), as shown in Fig. 3.1. The water from the intake is also directed via piping system to the laboratory for raw water quality analysis. The raw water samples for this study were collected from the end of this piping system (inflow to the lab) as shown in Fig. 3.2.

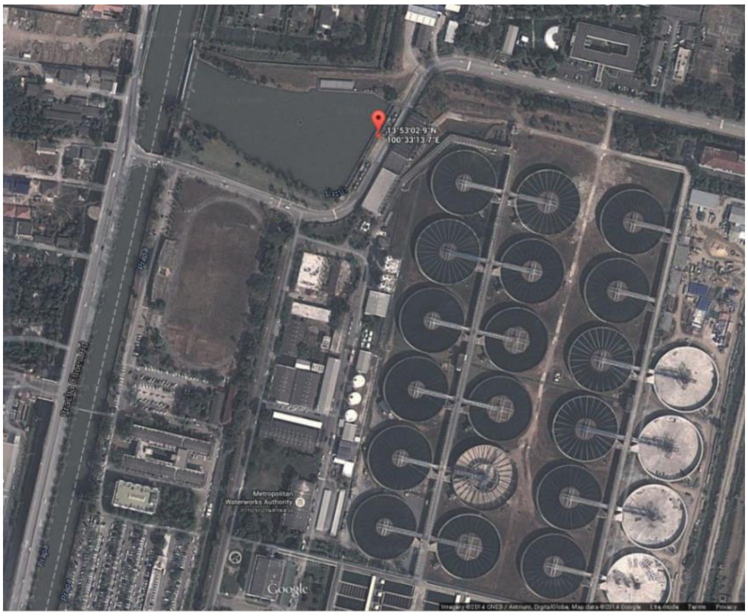


Fig. 3.1 Location and sampling site of intake of Bangkhen WTP

Fig. 3.2 Faucets for collection of raw water samples

3.2 Experimental Site

All experiments were conducted in the laboratory of Bangkhen WTP, MWA, as shown in Fig. 3.3.

Fig. 3.3 Laboratory of Bangkhen WTP

3.3 Materials

3.3.1 *Moringa oleifera* (*M. oleifera*) seeds

Naturally matured and dried *M. oleifera* seeds were purchased from Suan Petch Shop in Prachuapkhirikhan, Thailand. Matured seeds (Fig. 3.4) showing no signs of discoloration, softening, or extreme desiccation were used in this study.

Fig. 3.4 *M. oleifera* seeds

3.3.2 Reagents

Sodium chloride (NaCl) in dry powder form was purchased from Merck Co., Ltd.

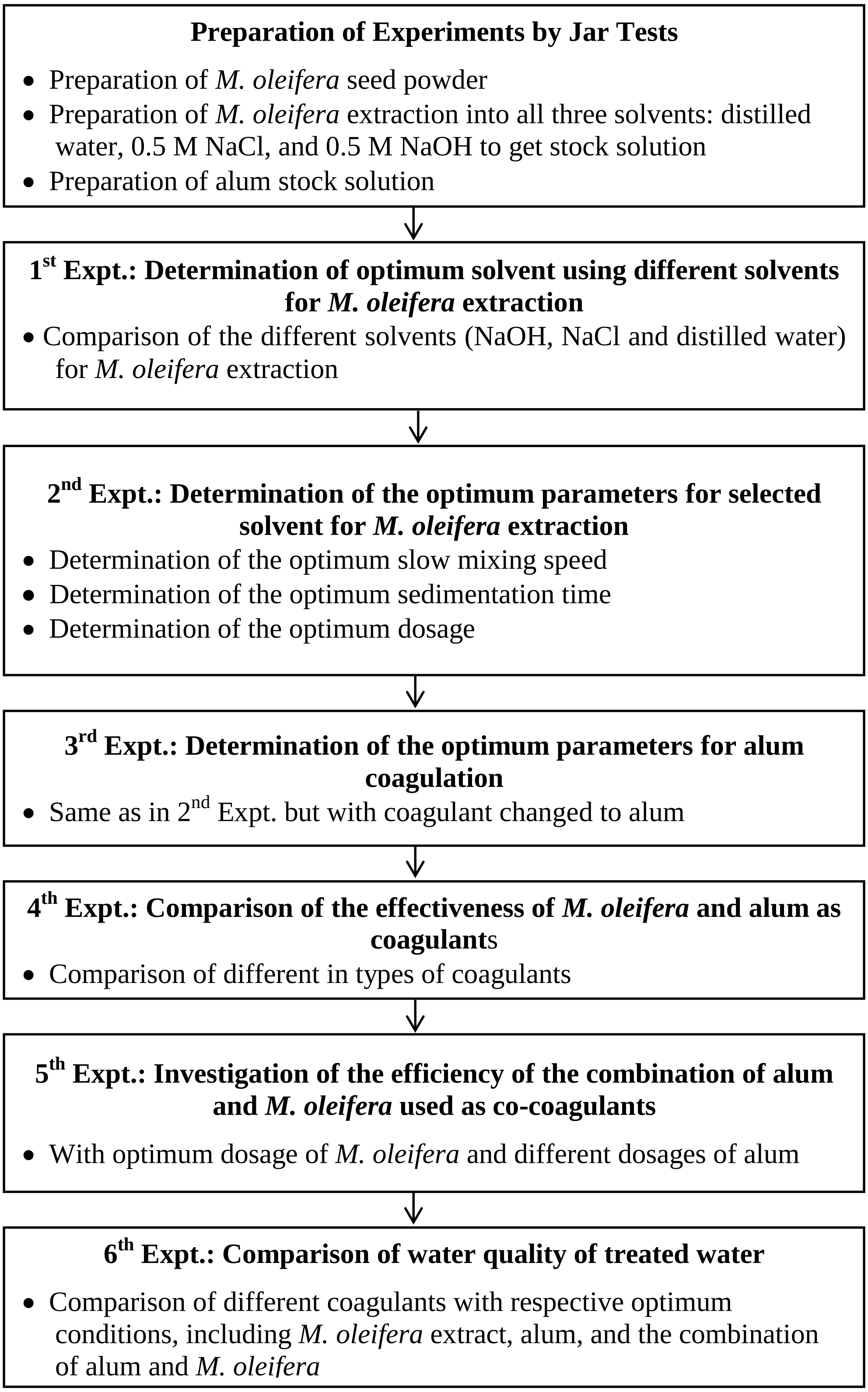
Sodium hydroxide (NaOH) in dry form was purchased from Carlo Erba Reagents.

50% aqueous aluminium sulfate (alum) ($Al_2(SO_4)_3$) was supplied by Bangkhen Water WTP, MWA

10% aqueous sodium hypochlorite (NaOCl) solution was supplied by Department of Water Quality, MWA

3.4 Experimental Procedure

Overall experimental procedure included the steps as shown in Fig. 3.5



Preparation of Experiments by Jar Tests

- Preparation of *M. oleifera* seed powder
- Preparation of *M. oleifera* extraction into all three solvents: distilled water, 0.5 M NaCl, and 0.5 M NaOH to get stock solution
- Preparation of alum stock solution

1st Expt.: Determination of optimum solvent using different solvents for *M. oleifera* extraction

- Comparison of the different solvents (NaOH, NaCl and distilled water) for *M. oleifera* extraction

2nd Expt.: Determination of the optimum parameters for selected solvent for *M. oleifera* extraction

- Determination of the optimum slow mixing speed
- Determination of the optimum sedimentation time
- Determination of the optimum dosage

3rd Expt.: Determination of the optimum parameters for alum coagulation

- Same as in 2nd Expt. but with coagulant changed to alum

4th Expt.: Comparison of the effectiveness of *M. oleifera* and alum as coagulants

- Comparison of different in types of coagulants

5th Expt.: Investigation of the efficiency of the combination of alum and *M. oleifera* used as co-coagulants

- With optimum dosage of *M. oleifera* and different dosages of alum

6th Expt.: Comparison of water quality of treated water

- Comparison of different coagulants with respective optimum conditions, including *M. oleifera* extract, alum, and the combination of alum and *M. oleifera*

Fig. 3.5 Flow chart of overall experimental procedure

3.5 Preparation of Experiments by Jar Tests

3.5.1 Preparation of *M. oleifera* seed powder

Good quality *M. oleifera* seeds were selected and kept for drying in sun for 2-3 days. The seeds' shells and wings were removed manually to obtain the kernels. The kernels were ground to a fine powder by using domestic food blender (Phillips, HR 2061) for 3 minutes. The powder was then screened through the 0.5 mm pore size sieve to enhance solubilization of the active components of the seeds in the solvents.

3.5.2 *M. oleifera* extraction for stock solutions

3.5.2.1 <u>Extraction with distilled water</u>

5 g of *M. oleifera* seed powder was placed in 100 mL volumetric flask followed by adding distilled water up to the mark. To extract the active coagulation component from the seeds, the suspension was vigorously mixed for 30 min using a magnetic stirrer. The suspension was then filtered twice: starting with a muslin cloth followed by a filter paper (ADVANTEC No.5C with less than 5 μm of pore size) in a vacuum suction apparatus. Thus, a stock solution of 5% w/v was obtained.

3.5.2.2 <u>Extraction with 0.5 M NaCl</u>

29.25 g of NaCl was mixed with distilled water to a volume of 1000 mL to obtain 0.5 M NaCl. The procedure of extraction with 0.5 M NaCl was similar to that of distilled water.

3.5.2.3 <u>Extraction with 0.5 M NaOH</u>

20 g of NaOH was mixed with distilled water to a volume of 1000 mL to obtain 0.5 M NaOH. The procedure of extraction with 0.5 M NaOH was similar to that of distilled water and 0.5 M NaCl.

3.5.3 Preparation of alum stock solution

10 g of 50% w/w alum sulfate was placed in the 500 mL volumetric flask followed by adding of distilled water up to the mark and thoroughly mixed. Thus, a stock solution of 1% w/v was obtained.

3.6 Experiments by Jar Tests

The raw water samples were collected from the intake of Bangkhen WTP during two study periods between July and December 2014. The turbidity was found to be 40 – 50 NTU in July 2014, considered as the medium range while in December 2014. It was in the range of 20 – 30 NTU, considered to be the low range.

The raw water samples were stored in a 60 L bucket for a day's operation of jar test. The sample water was mixed homogenously before conducting the jar test. A series of jar tests were conducted in batches of simultaneous runs in 6 beakers filled with 1000 mL of water sample along with six spindle steel. The coagulant dosage and the speed of mixing were varied in the six beakers in each batch. The supernatant was then collected from the coagulating mixtures with varying sedimentation time period followed by the water quality analyses to determine optimum parameters of jar test.

All the measurements were repeated at least three times for consistency and results were averaged. All the experiments were performed at ambient temperature in the range of 25-32 °C. Efficiency of *M. oleifera* coagulant was investigated as follows.

3.6.1 Determination of optimum solvent using different solvents for *M. oleifera* extraction

The effect of using three different solvents as the extracting agent of the active coagulant components from *M. oleifera* seed powder was investigated, using distilled water, 0.5 M NaCl and 0.5 M NaOH. The prepared 5%w/v stock solutions of the extracted *M. oleifera* in three solvents were added to the raw water samples at 4 different dosages of 30, 60, 80, and 100 mg/L. The raw water samples with medium turbidity (40 – 50 NTU) were used for this test.

Different batches of jar tests were carried out. Each batch of 6 jar tests consisted 2 jars each for *M. oleifera* extractions in the three solvents with two different dosages of coagulants (30, 60 mg/L). A set of three replications was carried out. Similar set of three replications was also conducted with 2 more dosages of the coagulants (80, 100 mg/L).

The jar tests in each batch were conducted with the same speed of rapid mixing (100 rpm) and duration (1 minute) followed by two different speeds of slow mixing starting with 50 rpm for 5 minutes to allow coagulation to occur, and then to reduce it to 20 rpm for 5 minutes. A sedimentation time of 55 minutes was used to allow the flocs to settle.

The optimum solvent for extraction of the active coagulating agent was determined based on the water quality, e.g. turbidity, conductivity, pH, and alkalinity. The summary of the experiments to evaluate the effect of using different solvents is presented in Table 3.1.

Table 3.1 Summary of the experiments to evaluate the optimum solvent

Turbidity of Raw Water	Medium turbidity
Type of Solvent	1) Distilled water 2) 0.5 M NaCl solution 3) 0.5 M NaOH solution
Dosage of *M. oleifera*	30, 60, 80, and 100 mg/L
Jar Test Operation	100 rpm (rapid mixing) for 1 min 50 rpm (slow mixing) for 5 min 20 rpm (slow mixing) for 5 min sedimentation time for 55 min
Water Quality Parameter	Turbidity, conductivity, pH and alkalinity

3.6.2 Determination of the optimum parameters for selected solvent for *M. oleifera* extraction

The efficiency of turbidity removal for selected solvent for *M. oleifera* extraction was investigated by varying slow mixing speed of jar test, sedimentation time and *M. oleifera* dosage. The optimum parameters were determined based on the reduction in turbidity. These experiments were conducted using raw water samples with medium and low turbidity.

The first part of 2nd experiment was conducted using raw water with medium turbidity. Different batches of jar tests were carried out. Each batch of 6 jar tests consisted of 6 different dosages of *M. oleifera* extraction (0, 50, 60, 70, 80 and 90 mg/L). Each batch was conducted with the same speed of rapid mixing (100 rpm) and duration (1 minute). Each of these dosages was repeated with 3 different slow mixing speeds (20, 50 and 80 rpm) for 10 minutes in 3 different batches (one each for 3 different slow mixing speeds). Consequently, coagulated water samples from each jar were collected at 6 different sedimentation times (5, 15, 25, 35, 45 and 55 minutes) in every batch. Three replications were carried out for each batch.

The second experiment was conducted using raw water with low turbidity in different batches of jar tests following the steps of first experiment. Each batch of 6 jar tests consisted of 6 different dosages of *M. oleifera* extraction (0, 20, 40, 60, 80 and 100 mg/L).

The summary of the experiments to determine the optimum slow mixing speed, sedimentation time and dosage of *M. oleifera* is shown in Table 3.2.

Table 3.2 Summary of the experiments to obtain the optimum parameters for *M. oleifera* extract

Turbidity of Raw Water	1) Medium turbidity 2) Low turbidity
Dosage of *M. oleifera*	1) 0, 50, 60, 70, 80, and 90 mg/L (medium turbid.) 2) 0, 20, 40, 60, 80, and 100 mg/L (low turbid.)
Jar Test Operation	1) 100 rpm (rapid mixing) for 1 min 20 rpm (slow mixing) for 10 min sedimentation time for 5, 15, 25, 35, 45 and 55 min 2) 100 rpm (rapid mixing) for 1 min 50 rpm (slow mixing) for 10 min sedimentation time for 5, 15, 25, 35, 45 and 55 min 3) 100 rpm (rapid mixing) for 1 min 80 rpm (slow mixing) for 10 min sedimentation time for 5, 15, 25, 35, 45 and 55 min
Water Quality Parameter	Turbidity

3.6.3 Determination of the optimum parameters for alum coagulation

The efficiency of turbidity removal for alum coagulant was also investigated by varying slow mixing speed of jar test, sedimentation time and alum dosage. The optimum parameters were determined based on the turbidity removal. These experiments were conducted using low turbidity raw water samples.

Different batches of jar tests were carried out. Each batch of 6 jar tests consisted of 6 different dosages of *alum* (0, 10, 20, 30, 40 and 50 mg/L). Each batch was conducted with the same speed of rapid mixing (100 rpm) and duration (1 minute). Each of these dosages was repeated with 3 different slow mixing speeds (20, 50 and 80 rpm) for 10 minutes in 3 different batches (one each for 3 different slow mixing speeds). Consequently, coagulated water samples from each jar were collected at 6 different sedimentation times (5, 15, 25, 35, 45 and 55 minutes) in every batch. Three replications were carried out for each batch.

The summary of the experiments to determine the optimum slow mixing speed of jar test, the optimum sedimentation time and the optimum dosage of alum is presented in Table 3.3.

Table 3.3 Summary of the experiments to obtain the optimum parameters for alum

Turbidity of Raw Water	Low turbidity
Dosage of alum	0, 10, 20, 30, 40 and 50 mg/L
Jar Test Operation	1) 100 rpm (rapid mixing) for 1 min 20 rpm (slow mixing) for 10 min sedimentation time for 5, 15, 25, 35, 45, and 55 min 2) 100 rpm (rapid mixing) for 1 min 50 rpm (slow mixing) for 10 min sedimentation time for 5, 15, 25, 35, 45, and 55 min 3) 100 rpm (rapid mixing) for 1 min 80 rpm (slow mixing) for 10 min sedimentation time for 5, 15, 25, 35, 45, and 55 min
Water Quality Parameter	Turbidity

3.6.4 Comparison of the effectiveness of *M. oleifera* and alum as coagulants

The water quality after being treated by the *M. oleifera* extract as well as by alum was investigated. The optimum slow mixing speed and the optimum sedimentation time for both *M. oleifera* and alum were used in these experiments with low turbidity raw water samples. The quality of the water after coagulation process was determined based on the water quality, e.g. turbidity, conductivity, pH, alkalinity, and UV absorbance at 254 nm.

Different batches of jar tests were carried out. The first batch of 6 jar tests consisted of 6 different dosages of *M. oleifera* extraction (0, 20, 40, 60, 80 and 100 mg/L). The second batch of 6 jar tests consisted of 6 different dosages of alum (0, 10, 20, 30, 40 and 50 mg/L). Each batch was conducted with the same speed of rapid mixing (100 rpm) and duration (1 minute) followed by optimum slow mixing speed for 10 minutes and optimum sedimentation time (optimum parameters were obtained from the results of experiments of sections 3.6.2 and 3.6.3 for *M. oleifera* and alum, respectively). Three replications were carried out for each batch.

The summary of the experiments to compare the effectiveness of *M. oleifera* extract and alum as coagulants is shown in Table 3.4.

Table 3.4 Summary of the experiments to compare the effectiveness of *M. oleifera* extract and alum as coagulants

Turbidity of Raw Water	Low turbidity
Dosage of Coagulant	1) 0, 20, 40, 60, 80 and 100 mg/L (*M. oleifera*) 2) 0, 10, 20, 30, 40, and 50 mg/L (alum)
Jar Test Operation	100 rpm (rapid mixing) for 1 min followed by optimum slow mixing speed and optimum sedimentation time for both *M. oleifera* and alum
Water Quality Parameter	Turbidity, conductivity, pH, alkalinity, and UV absorbance at 254 nm

3.6.5 Investigation of the efficiency of the combination of alum and *M. oleifera* used as co-coagulants

The efficiency of the combination of *M. oleifera* and alum as co-coagulants were investigated by setting the optimum slow mixing speed and the optimum dosage of the *M. oleifera* with various dosages of alum in the range of 0 – 25 mg/L. The low turbidity raw water was used in this experiment.

A batch of 6 jar tests was carried out consisting of *M. oleifera* extraction at optimum dosage (obtained from the results of section 3.6.2) along with 6 different dosages of alum (0, 5, 10, 15, 20 and 25 mg/L). Each jar test conducted with the same speed of rapid mixing (100 rpm) and duration (1 minute) followed by optimum slow mixing speed for 10 minutes and optimum sedimentation time (optimum parameters were obtained from the results of section 3.6.2). Three replications were carried out.

The summary of the experiments to investigate the efficiency of *M. oleifera* and alum as co-coagulants is shown in Table 3.5.

Table 3.5 Summary of the experiments to investigate the efficiency of *M. oleifera* and alum as co-coagulants

Turbidity of Raw Water	Low turbidity
Dosage of *M. oleifera*	Optimum dosage of *M. oleifera* (Fixed concentration)
Dosage of Alum	0, 5, 10, 15, 20 and 25 mg/L
Jar Test Operation	100 rpm (rapid mixing) for 1 min followed by optimum slow mixing speed for *M. oleifera* with different sedimentation times of 5, 15, 25, 35, 45 and 55 min
Water Quality Parameter	Turbidity

3.6.6 Comparison of water quality of treated water

The quality of water after being treated by three different types of coagulations, including *M. oleifera*, alum, and the combination of *M. oleifera* and alum, was investigated. The optimum values of slow mixing speed, sedimentation time and the dosage for each coagulation process (obtained from the results of sections

3.6.2, 3.6.3 and 3.6.5) were used in these experiments with low turbidity raw water samples. After coagulation process, the water samples were divided into two parts to investigate the physical-chemical properties and to study the formation potential of trihalomethanes (THMs).

The Summary of the experiments to compare the quality of water is presented in Table 3.6.

Table 3.6 Summary of the experiments to compare the quality of treated water

Turbidity of Raw Water	Low turbidity
Dosage of Coagulant	1) Optimum dosage of *M. oleifera* 2) Optimum dosage of alum 3) Optimum dosage of the combination of *M. oleifera* and alum
Jar Test Operation	100 rpm (rapid mixing) for 1 min followed by each coagulant's optimum slow mixing speed and sedimentation time
Water Quality Parameter	1) Physical and chemical properties e.g. turbidity, conductivity, pH, alkalinity, UV absorbance at 254 nm, chloride, sulfate, aluminum, chromium, cadmium, silver, arsenic, etc. 2) Trihalomethane formation potential (THMFP)

3.7 Determination of Water Quality (Analytical Methods)

The following parameters were used to determine the quality of raw and treated water.

3.7.1 Turbidity

The turbidity of water samples was determined by using turbidity meter; model 2100 N, HACH Company. It is expressed in NTU.

3.7.2 Conductivity

Conductivity meter (MultiLab 540, WTW) was used to determine conductivity of water samples, having unit of microsiemens per centimeter (μS/cm). Conductivity measured at any temperature was converted to the value at 25° C.

3.7.3 pH

pH meter (model pMX 3000, WTW) was used to determine pH of water samples.

3.7.4 Total alkalinity

Total alkalinity was determined by using titration method, usually reported in terms of equivalent calcium carbonate ($CaCO_3$). 50 mL of the water sample was pipetted to an Erlenmeyer flask over a white surface. A few drops of mixed bromocresol green-methyl red as indicator was then added and titrated with 0.02 N sulfuric acid (H_2SO_4) by mixing gentle until the color change from green to pink (APHA, 2012).

Total alkalinity was calculated by the following equation.

$$\text{Total alkalinity (mg as } CaCO_3\text{/L)} = \frac{\text{mL of } H_2SO_4 \text{ x Normality of } H_2SO_4 \text{ x 50000}}{\text{mL of sample}}$$

3.7.5 UV absorbance at 254 nm

UV absorbance at 254 nm was measured in order to determine the organic matter as well as precursors of trihalomethanes (THMs) by using UV/Vis spectrophotometer, model lambda 20, Perkin Elmer Co., Ltd, with quartz cell, allowing a light path of 1 cm.

Spectrophotometer was set wavelength to 254 nm and adjusted to read zero absorbance with distilled water. About 50 mL of water sample was filtered through a filter paper with pore size of 0.45 μm in a vacuum suction apparatus. The subsequent filtrate was then measured absorbance of at least three filtered portions of sample at room temperature (APHA, 2012).

3.7.6 Total organic carbon (TOC)

TOC was analyzed to determine total organic contents by using TOC analyzer, model 1010, OI analytical, with heated-persulfate oxidation method. Usually are reported in term of equivalent carbon (mg C/L).

3.7.7 Trihalomethanes Formation Potential (THMFP)

The formation potentials of trihalomethanes (THMs) was determined by adding excess of chlorine to the water sample and stored at room temperature for 24 h to allow the complete reaction. At the end of the reaction, the residual chlorine should be 3 to 5 mg Cl_2/L. These test conditions did not be desired to simulate water treatment systems but be universally useful to estimate the concentration of THMs precursors, along with to determine the performance of water treatment processes for removing THMs precursors in the raw water. The concentration of THMs was determined by using gas chromatograph with electron capture detector (GC-ECD), model 263-50, Hitachi, by means of head-space technique.

The procedure of THMs formation potential is shown as follow.

1. Preparation of stock sodium hypochlorite solution (NaOCl): 5 mL of 10%w/w sodium hypochlorite was placed in the 500 mL volumetric flask followed by adding of distilled water up to the mark and thoroughly mixed.

2. Standardization of stock sodium hypochlorite solution: according to Thai Industrial Standard (TIS) for hypochlorite 225-1999, 50 mL of stock sodium hypochlorite solution was pipetted to an erlenmeyer flask over a white surface. 5 mL of conc. acetic acid (glacial) was then added to adjust pH to between 3 and 4. After that about 1 g of potassium iodide (KI) estimated on a spatula was added and titrated with 0.12 N sodium thiosulfate ($Na_2S_2O_3$) by mixing gentle until the yellow color of the liberated iodine almost was discharged. Then, 1 mL of starch solution was added and titrated until blue color was discharged.

Chlorine concentration of the sodium hypochlorite solution stock was calculated by the following equation (TIS 225, 1999).

$$\text{Stock hypochlorite (mg as } Cl_2\text{/L)} = \frac{\text{mL of } Na_2S_2O_3 \text{ x Normality of } Na_2S_2O_3 \text{ x } 35450}{\text{mL of sample}}$$

3. Chlorination of water sample: 300 mL of water sample was placed in BOD bottle. The prepared stock solution of sodium hypochlorite was added to the water samples at 4 different concentrations of 10, 20, 30, 70 mg/L. Subsequently, BOD bottle was covered with glass stopper and snap-lid stopper, and stored in the dark at room temperature for 24 h to allow the complete reaction.

In this study, a range of chlorine concentrations was added to several sample portions to investigate the likelihood of achieving THMs formation potential at the end of reaction period.

4. After 24-hour reaction period, the residual chlorine was determined as following TIS 225-1999. Further, 40 mL of water sample was placed in 60 mL of vial bottle. 0.2 mL of 0.5%w/v sodium sulfite (Na_2SO_3) and 0.2 mL of (1+10) phosphoric acid (H_3PO_4) were then added to stop the reaction between chlorine and THMs precursors as well as to prevent the decomposition of THMs. After that, it was sealed with septum and teflon sheet. Until ready for THMs analysis (preferably no longer than 7 days), it was kept at low temperature (about 4°C) to prevent the evaporation of target compounds from the sample.

5. THMs Analysis: GC-ECD by means of head-space method was used to analyze THMs compounds. For head space method, water sample was kept at 30°C for 1 h in water bath to reach equilibrium between gas and liquid phase (water sample). 0.1 mL of head space (gas phase) into gas tight syringe was injected into GC to measure THMs.

3.7.8 Total hardness

Total hardness was determined by using titration technique. 50 mL of the water sample was pipetted to an erlenmeyer flask over a white surface. 2 mL of buffer solution (pH 10) was then added to adjust pH to 10.0 to 10.1. After that an appropriate amount of dry powder indicator (the mixture of Eriochrome Black T and NaCl) was added and titrated with 0.01 N Ethylenediaminetetraacetic acid or its sodium salts (EDTA) by mixing gentle until the color changed from wine red to blue. To minimize the tendency toward $CaCO_3$ precipitation, the the duration of the titration was set at 5 min (APHA, 2012).

Total hardness was calculated by the following equation.

$$\text{Total hardness (mg as CaCO}_3\text{/L)} = \frac{\text{mL of EDTA x Normality of EDTA}}{\text{mL of sample}} \text{ x } 50000$$

3.7.9 Calcium

Calcium was determined by using EDTA titrimetric technique. 50 mL of the water sample was pipetted to an erlenmeyer flask over a white surface. 2 mL of 1 N NaOH was then added to adjust pH about 12. After that an appropriate amount of calcium hardness indicator (dry powder mixture of Murexide and NaCl) was added and titrated with 0.01 N EDTA by mixing gentle until the color changed from red pink to bright purple (APHA, 2012).

Calcium was calculated by the following equation.

$$\text{Calcium (mg Ca/L)} = \frac{\text{mL of EDTA x Normality of EDTA}}{\text{mL of sample}} \text{ x } 40000$$

3.7.10 Magnesium

Magnesium was determined as the difference between total hardness (as $CaCO_3$) and calcium (as $CaCO_3$). It was calculated by the following equation (APHA, 2012).

$$\text{Magnesium (mg as Mg/L)} = [\text{Total hardness (mg as CaCO}_3\text{/L)} - \text{Calcium hardness (mg as CaCO}_3\text{/L)}] \text{ x } 0.24$$

3.7.11 Chloride

Chloride was determined by using titration technique, argentometric method. 50 mL of the water sample was pipetted to an erlenmeyer flask over a white surface. A few drops of potassium chromate (K_2CrO_4) as indicator was then added and titrated with 0.0141 N silver nitrate ($AgNo_3$) by mixing gentle until the color change from yellow to red-brown (APHA, 2012).

To establish reagent blank value, the water sample was changed to distilled water. Usually, a blank is 0.3 – 0.5 mL

Chloride was calculated by the following equation.

$$\text{Chloride (mg Cl}^{-}\text{/L)} = \frac{\underline{(A - B) \text{ x Normality of AgNo}_3} \text{ x } 35450}{\text{mL of sample}}$$

where: A = mL of $AgNo_3$ for water sample

B = mL of $AgNo_3$ for blank

3.7.12 Sulfate

Sulfate was determined by using turbidimetric method. 50 mL of the water sample was filtrate through a filter paper with pore size of 0.45 μm in a vacuum suction apparatus and placed to an erlenmeyer flask. Then, 2.5 mL of buffer solution A followed by 1 mL of 4% barium chloride ($BaCl_2$) was added and stirred for 1 min using a magnetic stirrer. After that, immediately measure the turbidity of sample using turbidity meter.

Sulfate was calculated by the following equation.

$$\text{Sulfate (mg SO}_4^{2-}\text{/L)} = \text{Turbidity reading x Factor (from standard curve)}$$

Note: The buffer solution A was prepared by adding 30 g of magnesium chloride in the 1000 mL volumetric flask followed by 5 g of sodium acetate, 1 g of potassium nitrate, 20 mL of conc. acetic acid, and distilled water up to the mark and thoroughly mixed

3.7.13 Metals and heavy metals

Metals and heavy metals were analyzed by using flame atomic absorption spectrophotometer (Flame-AAS), Graphite furnace atomic absorption spectrophotometer (GF-AAS), also known as electrothermal AAS, and inductively coupled plasma optical emission spectrometer (ICP-OES).

In this work, flame-AAS, model AA-240, Agilent Technologies (Thailand) Co., Ltd., was used to analyze copper (Cu) and zinc (Zn) in the water. GF-AAS, model AA-240Z, Agilent Technologies (Thailand) Co., Ltd., was used to determine chromium (Cr), cadmium (Cd) and lead (Pb) in the water. ICP-OES, model optima 8000, Perkin Elmer Co., Ltd., was used to measure silver (Ag), aluminum (Al), arsenic (As), barium (Ba), manganese (Mn), nickel (Ni) and selenium (Se) in the water.

3.8 Study Plan

The overall study plan is shown in Table 3.7.

Table 3.7 Study Plan

Activity	2014												2015			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Literature Review & Proposal Writing	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
Proposal Defence										▨						
Experimental Work					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Data Analyses								▨	▨	▨	▨	▨	▨	▨		
Thesis Writing												▨	▨	▨	▨	
Presentation											▨	▨				
Thesis Defense																▨

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Raw Water Characteristics

The characteristics of raw water at the intake of Bangkhen Water Treatment Plant (WTP) in July 2014 and December 2014, as documented in the routine water quality monitoring, are presented in Table 4.1 and Table 4.2, respectively.

For the present study, the raw water samples were collected from the intake of Bangkhen WTP during two study periods between July and December 2014. The turbidity was found to be 40 – 50 NTU in July 2014, considered as the medium range while in December 2014 it was in the range of 20 – 30 NTU, considered to be the low range.

Table 4.1 Characteristics of raw water at the intake of Bangkhen WTP in July 2014

Parameter	Value	Unit
True color	8	Platinum-Cobalt
Turbidity	44	NTU
pH	7.58	µS/cm
Conductivity	351	mg/L
Total alkalinity (as calcium carbonate)	98	mg/L
Phenolphthalein alkalinity (as calcium carbonate)	0	mg/L
Total solids	289	mg/L
Total dissolved solids	211	mg/L
Total suspended solids	78	mg/L
Total hardness (as calcium carbonate)	108	mg/L
Carbonate hardness (as calcium carbonate)	98	mg/L
Non-carbonate hardness (as calcium carbonate)	10	mg/L
Chloride	22	mg/L
Sulfate	30	mg/L

Table 4.1 Characteristics of raw water at the intake of Bangkhen WTP in July 2014 (cont.)

Parameter	Value	Unit
Nitrate (as nitrogen)	0.573	mg/L
Nitrite (as nitrogen)	ND	mg/L
Total nitrogen	1.123	mg/L
Total phosphorus	0.029	mg/L
Calcium	33.6	mg/L
Iron	0.64	mg/L
Fluoride	0.28	mg/L
Manganese	0.10	mg/L
Magnesium	5.76	mg/L
Total organic carbon (TOC)	3.1	mg/L
Dissolved oxygen (DO)	5.3	mg/L
Biochemical oxygen demand (BOD)	2.1	mg/L
Coliform bacteria	2,300	MPN/100 mL
Fecal coliform bacteria	2,300	MPN/100 mL
Total algae	116,600	Unit/100 mL

Source: Department of Water Quality, MWA

Table 4.2 Characteristics of raw water at the intake of Bangkhen WTP in December 2014

Parameter	Value	Unit
True color	37	Platinum-Cobalt
Turbidity	25	NTU
pH	7.56	µS/cm
Conductivity	353	mg/L
Total alkalinity (as calcium carbonate)	103	mg/L
Phenolphthalein alkalinity (as calcium carbonate)	0	mg/L
Total solids	214	mg/L
Total dissolved solids	188	mg/L
Total suspended solids	26	mg/L
Total hardness (as calcium carbonate)	100	mg/L
Carbonate hardness (as calcium carbonate)	100	mg/L
Non-carbonate hardness (as calcium carbonate)	0	mg/L
Chloride	20	mg/L

Table 4.2 Characteristics of raw water at the intake of Bangkhen WTP in December 2014 (cont.)

Parameter	Value	Unit
Sulfate	3	mg/L
Nitrate (as nitrogen)	0.778	mg/L
Nitrite (as nitrogen)	ND	mg/L
Total nitrogen	1.194	mg/L
Total phosphorus	0.034	mg/L
Calcium	28.8	mg/L
Iron	0.56	mg/L
Fluoride	0.19	mg/L
Manganese	0.02	mg/L
Magnesium	6.72	mg/L
Total organic carbon (TOC)	5.0	mg/L
Dissolved oxygen (DO)	4.4	mg/L
Biochemical oxygen demand (BOD)	1.9	mg/L
Coliform bacteria	1,700	MPN/100 mL
Fecal coliform bacteria	450	MPN/100 mL
Total algae	5,400	Unit/100 mL

Source: Department of Water Quality, MWA

4.2 Determination of Optimum Solvent for *M. oleifera* Extraction

The efficiency of different solvents including distilled water, 0.5 M NaCl, 0.5 M NaOH for extracting *M. oleifera* were investigated in jar tests. The prepared 5% w/v stock solutions of the extracted *M. oleifera* in three solvents were added to the raw water samples at 4 different dosages of 30, 60, 80, and 100 mg/L. The optimum solvent for extraction of the active coagulant agent was determined based on the coagulated water quality, e.g. turbidity, conductivity, pH and alkalinity (Figs. 4.1 – 4.4). The raw water samples with medium turbidity (40 – 50 NTU) were used for this test.

After treating raw water with *M. oleifera* extractions, the residual turbidity was found to decrease with increasing *M. oleifera* dosage as shown in Fig 4.1. It can be seen that, the stock solution of extracted *M. oleifera* with 0.5 M NaCl required dosage of only 30 mg/L to achieve high turbidity removal (from 46.5 NTU to 4.2

NTU). While higher dosages of distilled water and 0.5 M NaOH were required to achieve the desired turbidity removal.

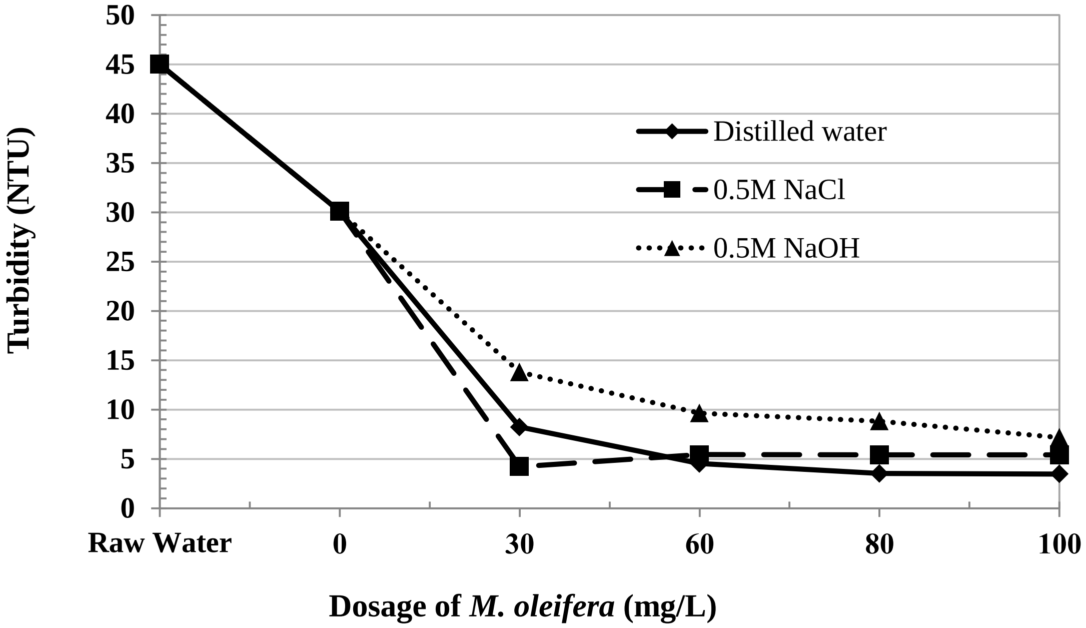


Fig. 4.1 Turbidity profile of raw water treated with *M. oleifera* extractions in three solvents

Fig. 4.2 shows that conductivity of the raw water treated with extracted *M. oleifera* in NaOH increased from 403 μS/cm to 445 μS/cm with increasing dosage, while it increased from 403 μS/cm to 506 μS/cm in case of NaCl. It was only the *M. oleifera* extraction with distilled water that did not remarkably change the conductivity of treated water for all dosages.

It can be seen in Figs. 4.3 and 4.4 show that pH and alkalinity of treated water were significantly affected as their values increased (from 7.63 to 9.14 and 101 to 135 for pH and alkalinity, respectively) by increasing dosage with 0.5 M NaOH extracts. Whereas, in case of the other two solvents, these remained constant with increasing dosages.

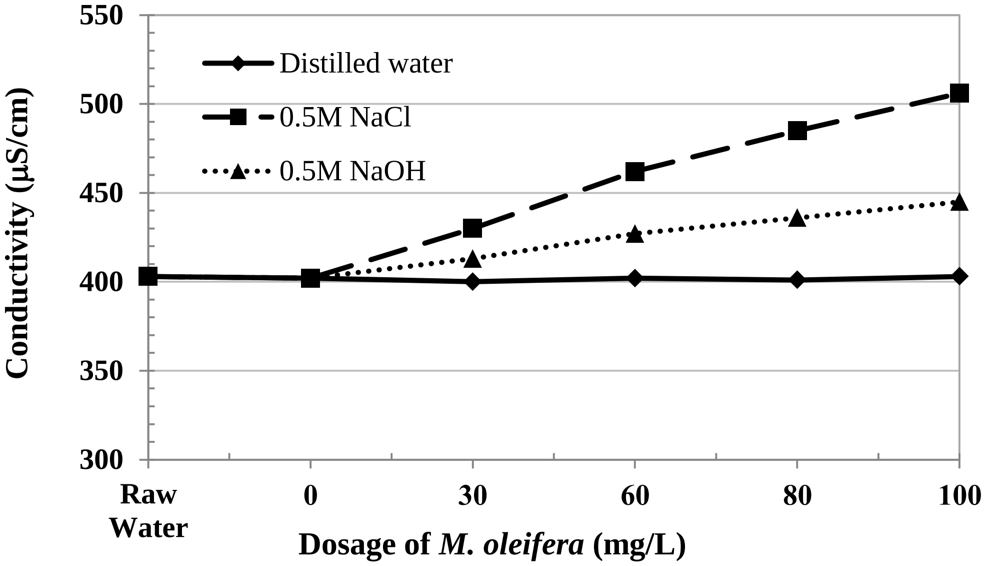


Fig. 4.2 Conductivity profile of raw water treated with *M. oleifera* extractions in three solvents

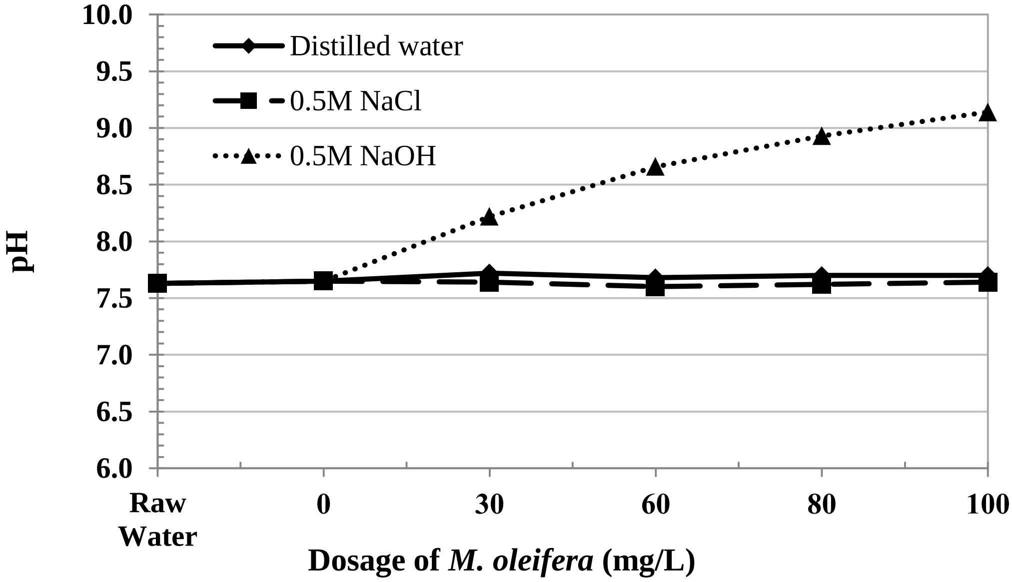


Fig. 4.3 pH profile of raw water treated with *M. oleifera* extractions in three solvents

Based on the results of the evaluation of optimum solvent for *M. oleifera* extraction, it could be seen that 0.5 M NaCl required a lowest dosage among three solvents to achieve high turbidity removal. However, it did not appear to be a good solvent for *M. oleifera* extraction because of significant increase in conductivity of treated water with increasing dosages (Fig. 4.2). Moreover, NaOH also did not appear to be a good solvent for *M. oleifera* extraction as there was significant increase in both pH and alkalinity of the treated water with increasing dosages (Figs. 4.3 – 4.4). Therefore, it can be said that distilled water is the most suitable solvent for *M. oleifera* extraction.

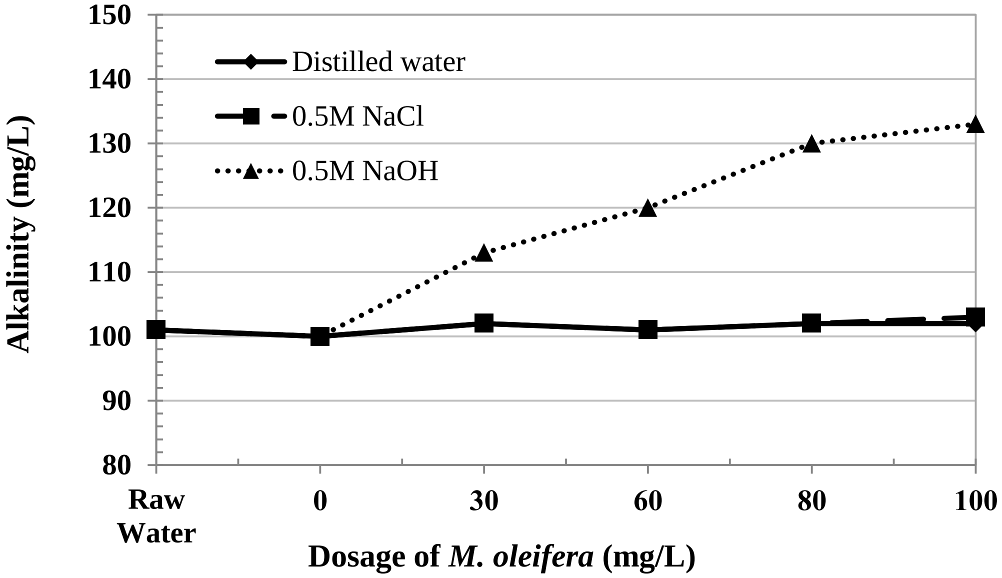


Fig. 4.4 Alkalinity profile of raw water treated with *M. oleifera* extractions in three solvents

The quality of the water after being treated with *M. oleifera* extractions in distilled water was investigated through further experiments.

4.3 Determination of Optimum Parameters for Coagulation Process using *M. oleifera* as Coagulant

Efficiency of turbidity removal with *M. oleifera* extraction in distilled water was investigated by varying slow mixing speed of jar test, sedimentation time, and *M. oleifera* dosage. The duration of the rapid mixing speed was kept at 1 minute while for slow mixing speed it was 10 minutes. It was based on the results of a recently reported study in which it was found that although the duration of slow mixing speed affected the turbidity removal, it did not show significant influence on the effectiveness of *M. oleifera* coagulation with longer durations. Moreover, the relevance of the slow agitation stage was higher than the rapid one (Sánchez-Martín et al., 2012).

The optimum parameters were determined based on the sufficient turbidity removal to achieve the final turbidity of less than 4 NTU. These experimental runs were conducted using raw water samples with medium and low turbidity at two different periods of time.

4.3.1 Optimum slow mixing speed

The slow mixing speed of jar tests was varied at 20, 50, and 80 rpm while the mixing duration was kept constant at 10 minutes.

4.3.1.1 Medium turbidity

Figs. 4.5 – 4.9 show the effect of the slow mixing speed on turbidity removal with five different dosages of *M. oleifera* (50, 60, 70, 80 and 90 mg/L, respectively). It can be seen that with all dosages of *M. oleifera,* the slow mixing speed of 50 rpm showed the highest turbidity removal among the three mixing speeds.

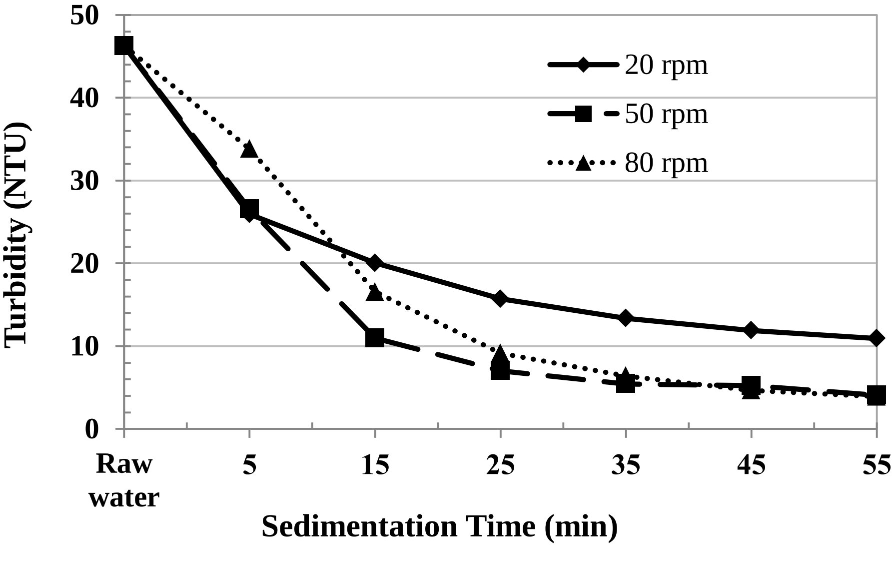


Fig. 4.5 Effect of slow mixing speed on turbidity reduction in medium turbidity raw water treated with 50 mg/L of *M. oleifera* extract

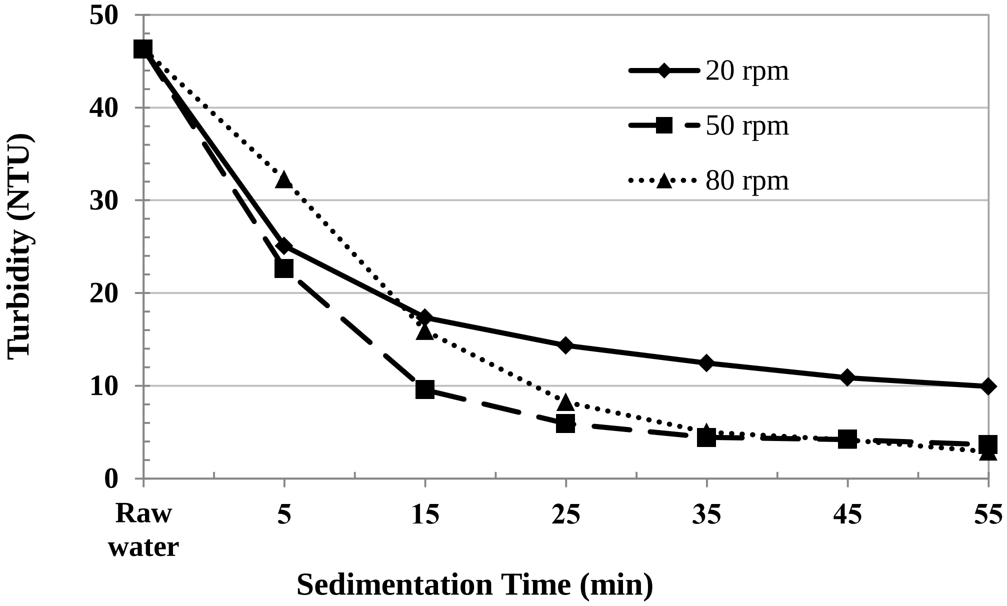


Fig. 4.6 Effect of slow mixing speed on turbidity reduction in medium turbidity raw water treated with 60 mg/L of *M. oleifera* extract

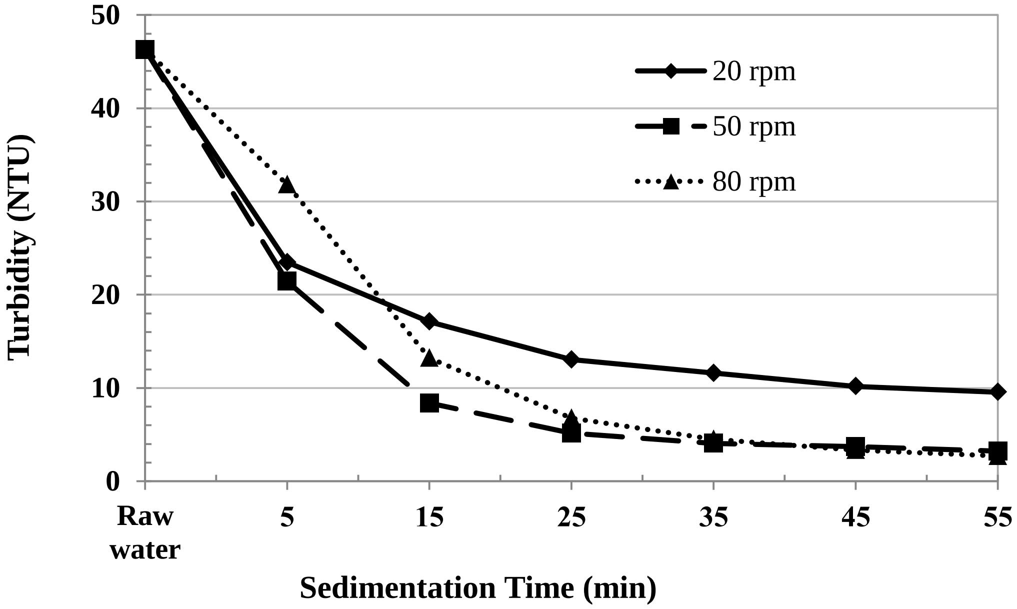


Fig. 4.7 Effect of slow mixing speed on turbidity reduction in medium turbidity raw water treated with 70 mg/L of *M. oleifera* extract

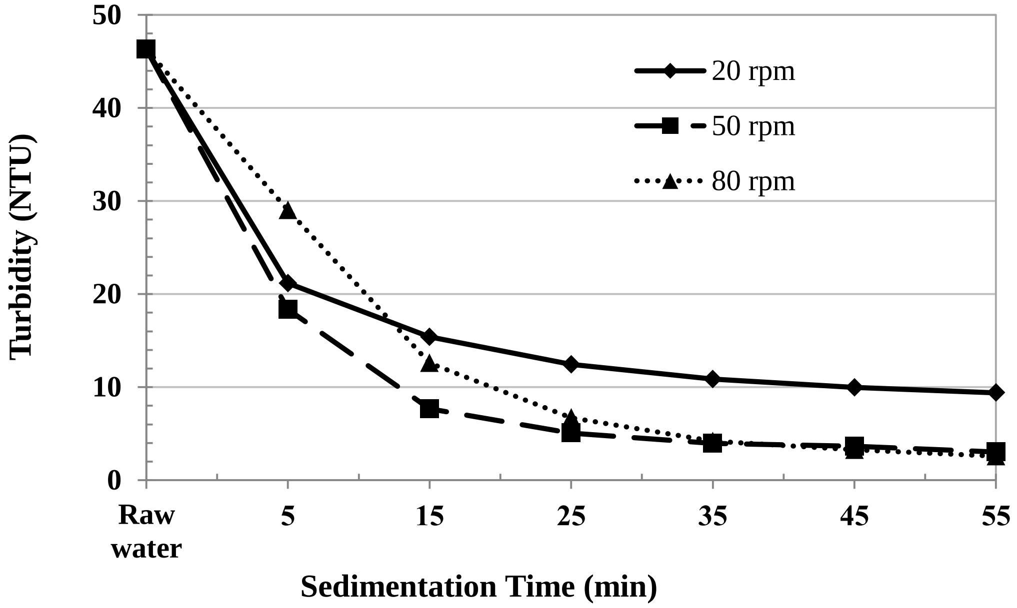


Fig. 4.8 Effect of slow mixing speed on turbidity reduction in medium turbidity raw water treated with 80 mg/L of *M. oleifera* extract

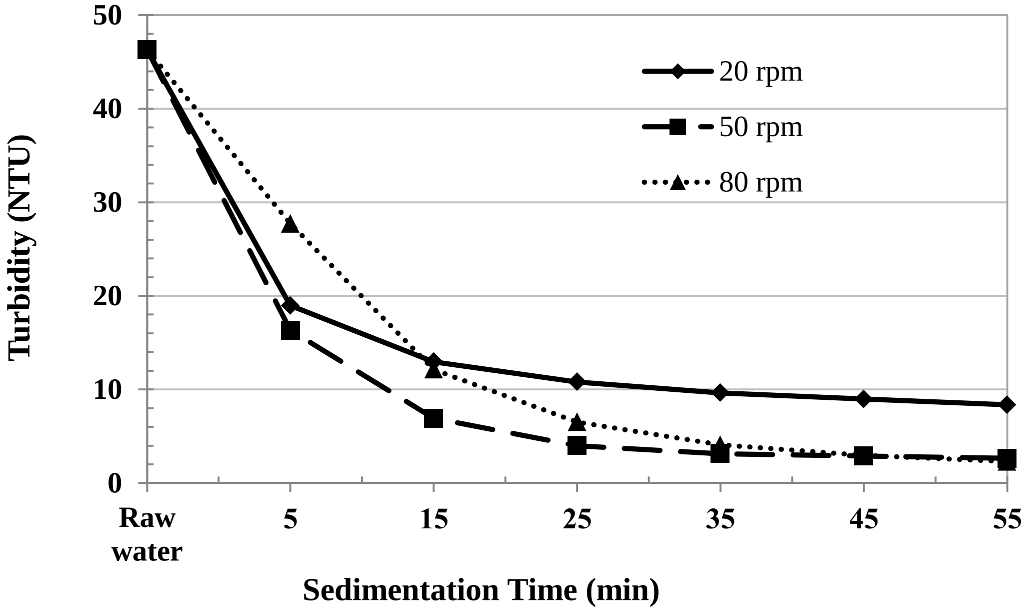


Fig. 4.9 Effect of slow mixing speed on turbidity reduction in medium turbidity raw water treated with 90 mg/L of *M. oleifera* extract

Moreover, it was found that for all the five dosages of *M. oleifera* extracts, the slow mixing speed of 80 rpm showed the worst efficiency of reduction in turbidity at 5 minutes sedimentation time. It could be understood that the mixing speed of 80 rpm was too fast, causing flocs fragility and diffusion all over the jar; so the longer time was required for flocs to settle down. However, for sedimentation time of longer than 35 minutes, efficiency of turbidity removal at the slow mixing speeds of 50 and 80 rpm were not significantly different.

4.3.1.2 Low turbidity

It can be seen in Fig. 4.10 that at the lowest *M. oleifera* dosage (20 mg/L), the highest turbidity reduction in low turbidity raw water was achieved with the fastest mixing speed i.e. the speed of 80 rpm. It could be explained by the assumption that the amount of coagulant was not enough to build up sufficient mass of flocs of the suspended solids in the raw water. The faster speeds allowed more contact among suspended solids and thus provided more opportunity of flocs formation resulting in high reduction in turbidity due to flocs settling. However, the *M. oleifera* dosage of 20 mg/L was not sufficient to achieve the target turbidity in treated water in order to meet WHO guidelines for turbidity in drinking water which is less than 4 NTU. Therefore, the higher dosage of *M. oleifera* was required.

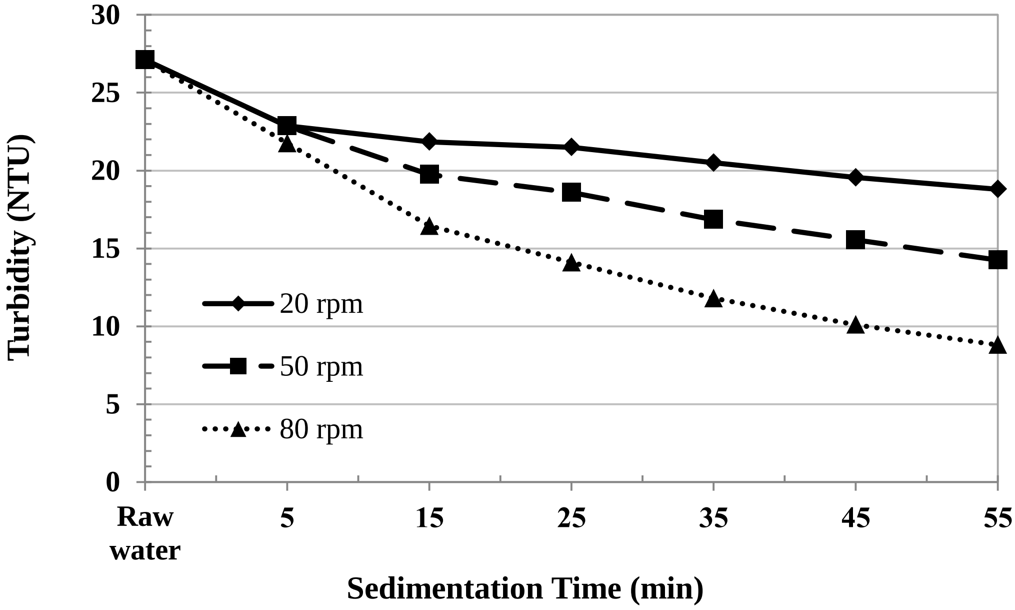


Fig. 4.10 Effect of slow mixing speed on turbidity reduction in low turbidity raw water treated with 20 mg/L of *M. oleifera* extract

As shown in Figs. 4.11 and 4.12, at the *M. oleifera* dosages of 40 and 60 mg/L, respectively the efficiency of turbidity removal with the mixing speeds of 50 and 80 rpm was almost the same and higher than that at 20 rpm. However, the target turbidity in treated water (< 4 NTU) was still not achieved.

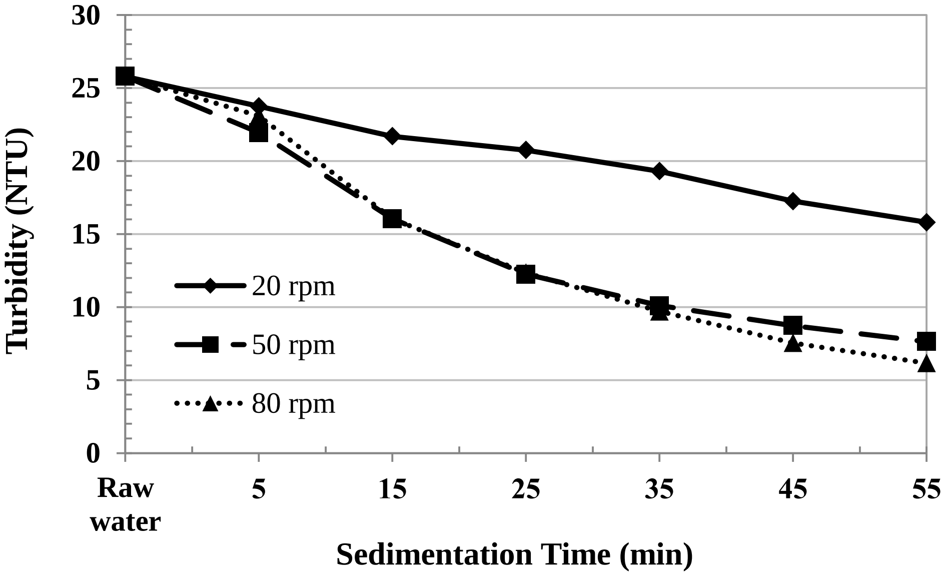


Fig. 4.11 Effect of slow mixing speed on turbidity reduction in low turbidity raw water treated with 40 mg/L of *M. oleifera* extract

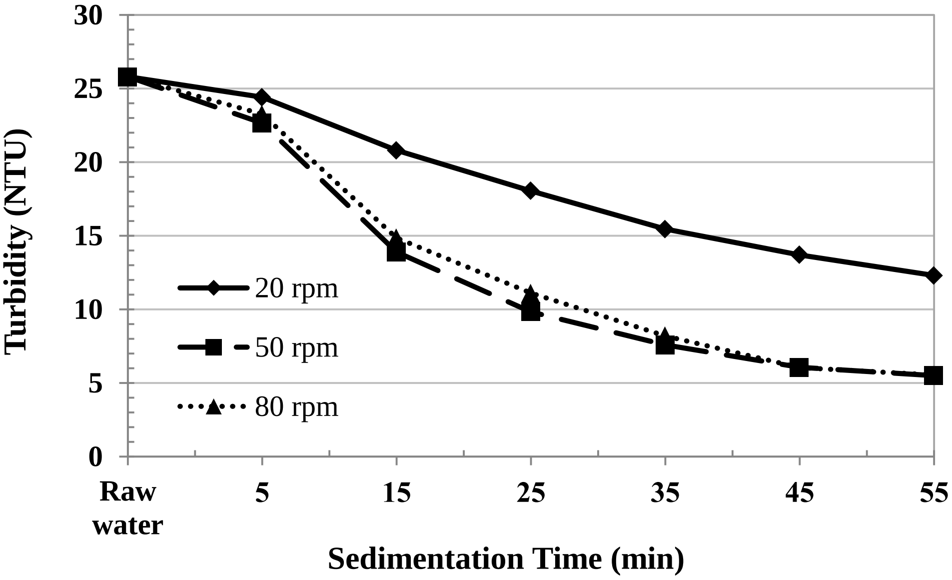


Fig. 4.12 Effect of slow mixing speed on turbidity reduction in low turbidity raw water treated with 60 mg/L of *M. oleifera* extract

It can be seen in Figs. 4.13 and 4.14 that at the *M. oleifera* dosages of 80 and 100 mg/L, respectively the highest turbidity removal was reached with the medium mixing speed (50 rpm) which also allowed to achieve the target turbidity of less than 4 NTU in the treated water.

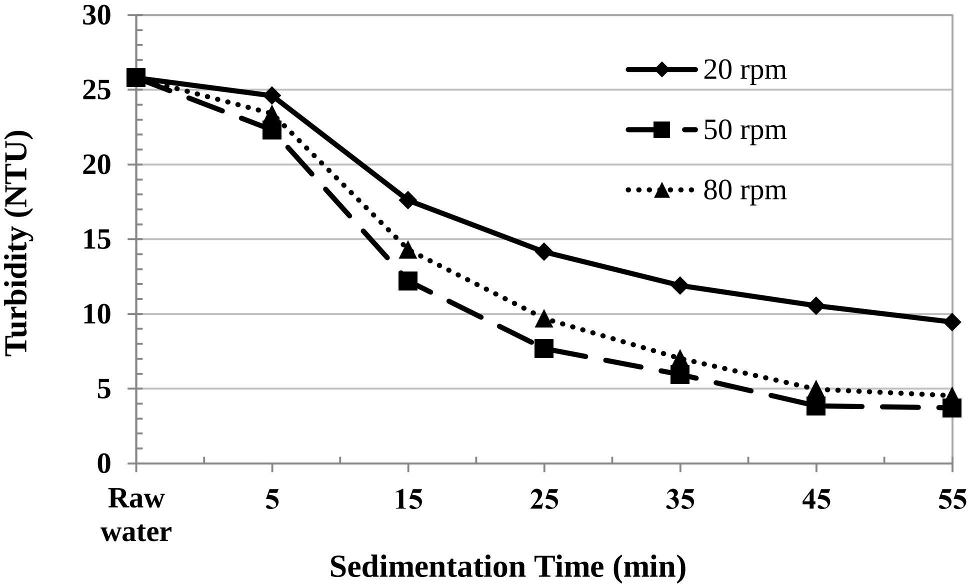


Fig. 4.13 Effect of slow mixing speed on turbidity reduction in low turbidity raw water treated with 80 mg/L of *M. oleifera* extract

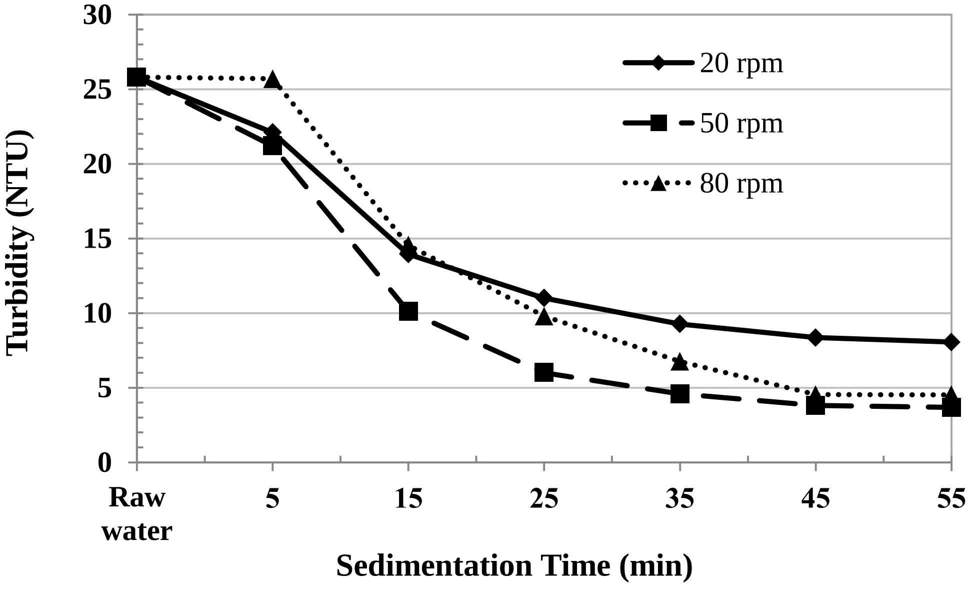


Fig. 4.14 Effect of slow mixing speed on turbidity reduction in low turbidity raw water treated with 100 mg/L of *M. oleifera* extract

This could also be explained by the assumption that the amount of coagulant at these dosages was enough to form sufficient flocs. On the other hand, the mixing speed of 80 rpm was probably too fast causing flocs fragility and thus breaking of already formed flocs. Therefore, the turbidity reduction at 80 rpm slow mixing speed was lower than at 50 rpm but still higher than at 20 rpm.

It could be concluded that the optimum slow mixing speed in jar test for *M. oleifera* extraction in distilled water was 50 rpm for treating both medium and low turbidity raw water.

4.3.2 Optimum sedimentation time

Effect of sedimentation time on the efficiency of turbidity removal at selected slow mixing speed of 50 rpm was also studied by varying it in the range of 5 – 55 minutes.

4.3.2.1 Medium turbidity

Fig. 4.15 shows the effect of sedimentation time on turbidity reduction in medium turbidity raw water being treated with 5 different *M. oleifera* dosages.

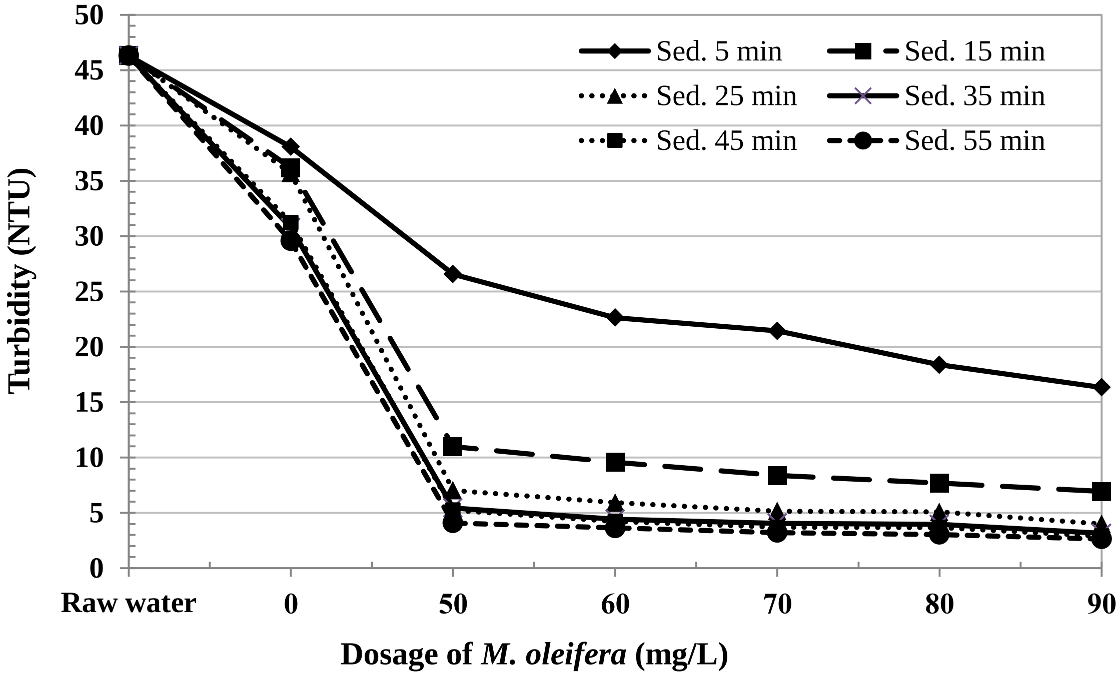


Fig. 4.15 Effect of sedimentation time on turbidity reduction in medium turbidity raw water

It can be noticed that, the efficiency of turbidity removal with all the *M. oleifera* dosages was quite low at sedimentation time of 5 minutes. It could possibly be explained by the fact that even if the flocs were already formed in the water they need some time for sedimentation; and if the flocs formed by coagulation were quite small they would require longer time to settle. It was also found that the efficiency of turbidity removal was enhanced with increasing sedimentation time. However, there was no significant improvement in turbidity removal beyond 35 – 45 minutes sedimentation time.

4.3.2.2 Low turbidity

Effect of the sedimentation time on turbidity reduction in low turbidity raw water is shown in Fig. 4.16. It can be seen that the efficiency of turbidity removal at all the dosages of *M. oleifera* was in general lower than in case of medium turbidity raw water. Moreover, turbidity removal did not increase with increased *M. oleifera* dosage at sedimentation time of 5 minutes. The reason for this was similar to that of medium turbidity raw water, that is, 5 minutes sedimentation time was not sufficient for flocs to settle down even with high *M. oleifera* dosage.

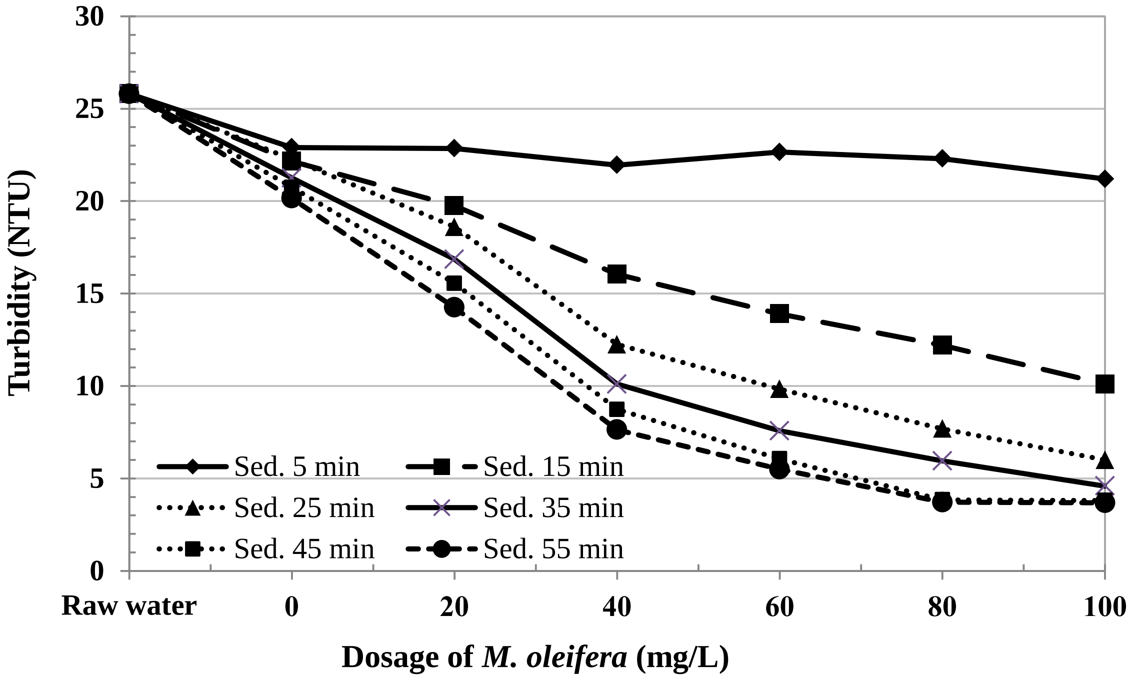


Fig. 4.16 Effect of sedimentation time on turbidity reduction in low turbidity raw water

It can also be seen that in general the turbidity removal increased with increasing sedimentation time up to 45 minutes. However, there was no significant improvement in turbidity reduction beyond 45 minutes sedimentation time as almost all flocs would have settled down by then. So, 45 minutes seems to be the optimum sedimentation time in this study.

Hence, based on the results of these experiments, it can be concluded that the 45 minutes was the optimum sedimentation time while using *M. oleifera* as a coagulant to treat low to medium turbidity raw water.

4.3.3 Optimum dosage of *M. oleifera*

Effect of *M. oleifera* dosage on turbidity removal from low and medium turbidity raw water was also investigated for selected slow mixing speed (50 rpm) and sedimentation time (45 minutes). The optimum dosage is considered to be the lowest possible dosage that gives the final turbidity of less than 4 NTU which is the WHO guidelines for drinking water quality.

4.3.3.1 Medium turbidity

Fig. 4.17 presents the effect of *M. oleifera* dosage on the turbidity reduction in medium turbidity raw water. As can be seen in Fig. 4.17, the *M. oleifera* dosage of 70 mg/L or more provided high removal of turbidity and was enough to achieve the final turbidity to be below 4 NTU.

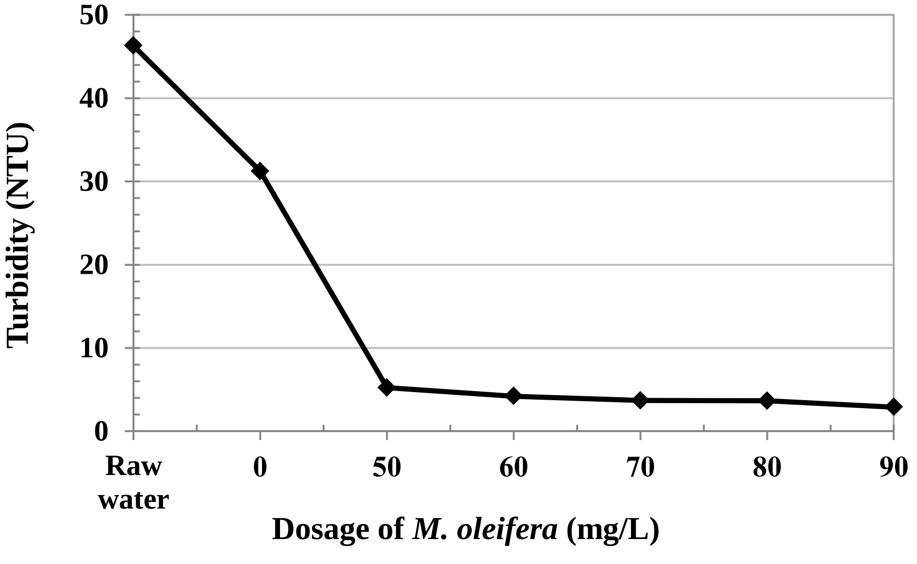


Fig. 4.17 Effect of *M. oleifera* dosage on turbidity reduction in medium turbidity raw water

Hence, the optimum dosage of *M. oleifera* appeared to be 70 mg/L which could remove more than 90% of turbidity.

4.3.3.2 Low turbidity

The effect of the *M. oleifera* dosage on the turbidity reduction in low turbidity raw water is presented in Fig. 4.18. The optimum dosage of *M. oleifera*, allowing the final turbidity to below 4 NTU, was found to be 80 mg/L. The turbidity removal of more than 80% was achieved at this dosage.

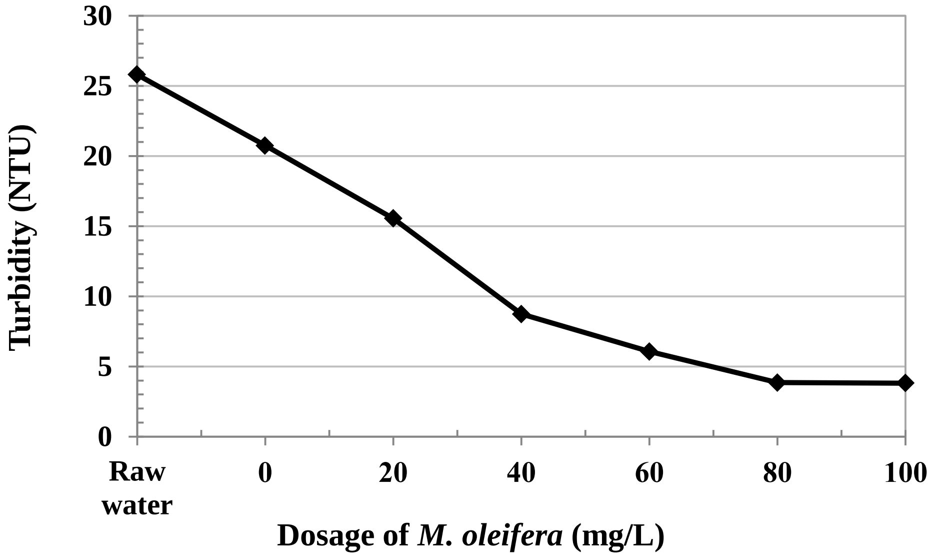


Fig. 4.18 Effect of *M. oleifera* dosage on turbidity reduction in low turbidity raw water

Therefore, based on these experimental results, it could be concluded that the optimum dosage of *M. oleifera* was 70 mg/L for treating medium turbidity raw water; whereas, the *M. oleifera* dosage of 80 mg/L was found to be the optimum dosage to treat low turbidity raw water.

4.4 Determination of Optimum Parameters for Coagulation Process using Alum as Coagulant

Efficiency of turbidity removal with alum was investigated by varying slow mixing speed of jar test, sedimentation time, and alum dosage. The duration of the rapid mixing speed was kept at 1 minute while for slow mixing speed it was 10 minutes. The optimum parameters were determined based on the sufficient turbidity removal to achieve the final turbidity of less than 4 NTU. These experimental runs were conducted using low turbidity raw water samples.

4.4.1 Optimum slow mixing speed

The slow mixing speed of jar tests was varied at 20, 50, and 80 rpm while the mixing duration was kept constant at 10 minutes. Figs. 4.19 – 4.23 present the effect of the slow mixing speed on turbidity removal with five different dosages of alum (10, 20, 30, 40 and 50 mg/L, respectively).

As shown in Fig. 4.19, at the lowest alum dosage (10 mg/L), the highest turbidity reduction in low turbidity raw water was achieved with the fastest mixing speed i.e. the speed of 80 rpm. The results were similar to that with the lowest dosage of *M. oleifera* (20 mg/L). The faster mixing speed can help the low dosage of coagulant to achieve better performance of turbidity removal by allowing more contact among suspended solids and thus providing more opportunity of flocs formation resulting in high reduction in turbidity due to flocs settling. However, the alum dosage of 10 mg/L was not enough to achieve the target turbidity in treated water in order to meet WHO guidelines for turbidity in drinking water which is less than 4 NTU. Therefore, the higher dosage of alum was required.

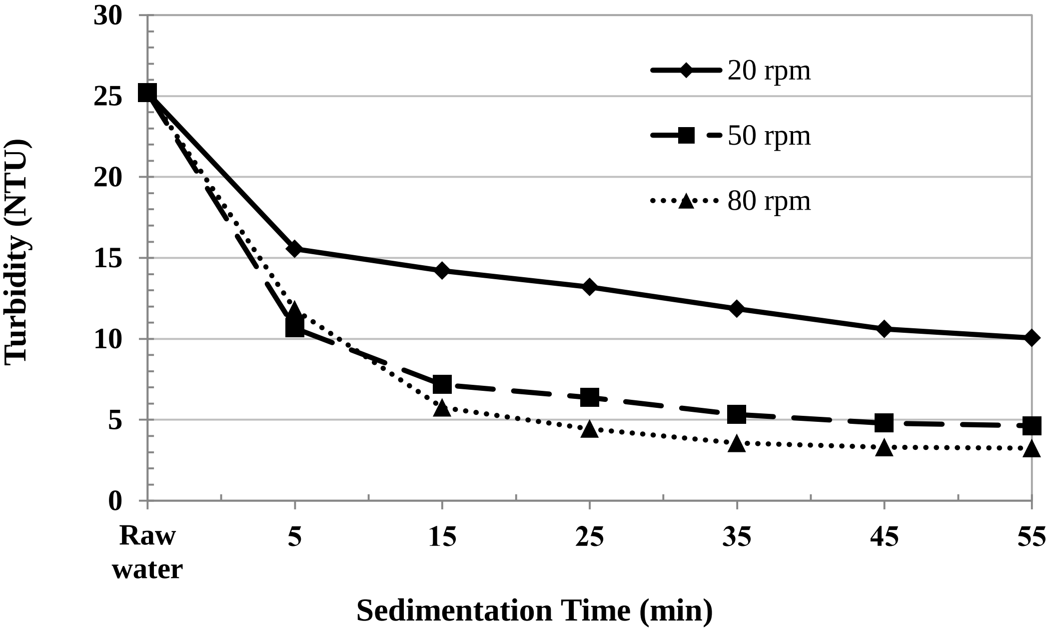


Fig. 4.19 Effect of slow mixing speed on turbidity reduction in raw water treated with 10 mg/L of alum

It can be seen in Fig. 4.20 that at the alum dosage of 20 mg/L, the efficiency of turbidity removal with the mixing speeds of 50 and 80 rpm were almost the same and higher than that at 20 rpm. It was also found that the alum dosage of 20 mg/L was sufficient to achieve the target turbidity of less than 4 NTU in the treated water.

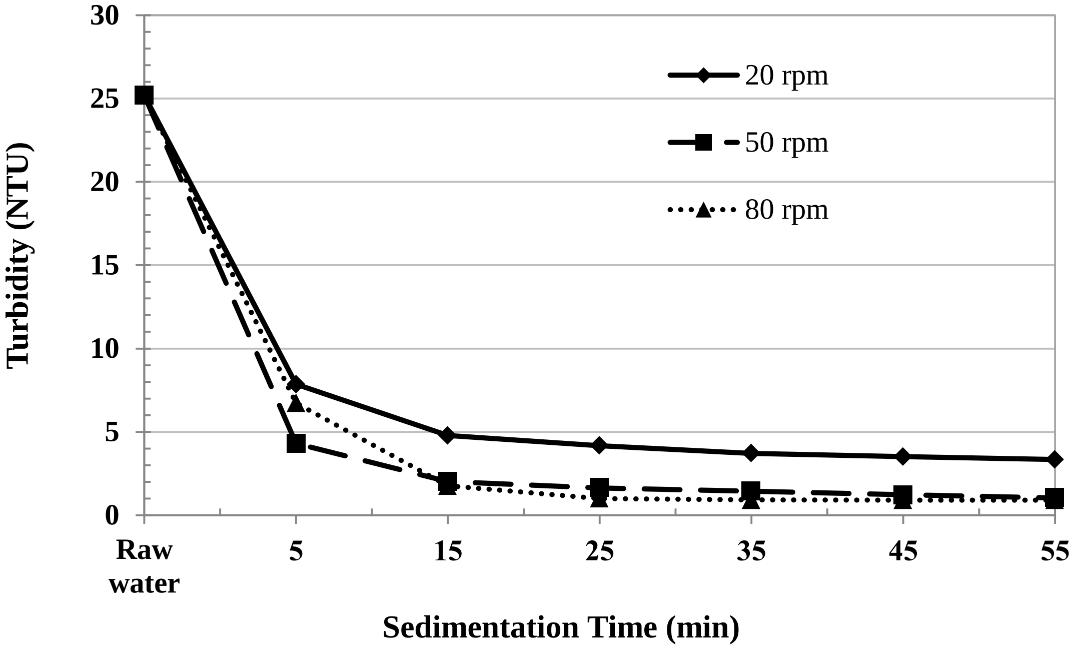


Fig. 4.20 Effect of slow mixing speed on turbidity reduction in raw water treated with 20 mg/L of alum

As can be seen in Figs 4.21 – 4.23, at the alum dosages of 30, 40 and 50 mg/L, respectively the highest turbidity removal was achieved with the medium mixing speed (50 rpm). This could also be explained by the assumption that the mixing speed of 80 rpm was probably too fast causing flocs fragility and thus breaking of already formed flocs. Therefore, the turbidity reduction at 80 rpm slow mixing speed was lower than at 50 rpm but still higher than at 20 rpm.

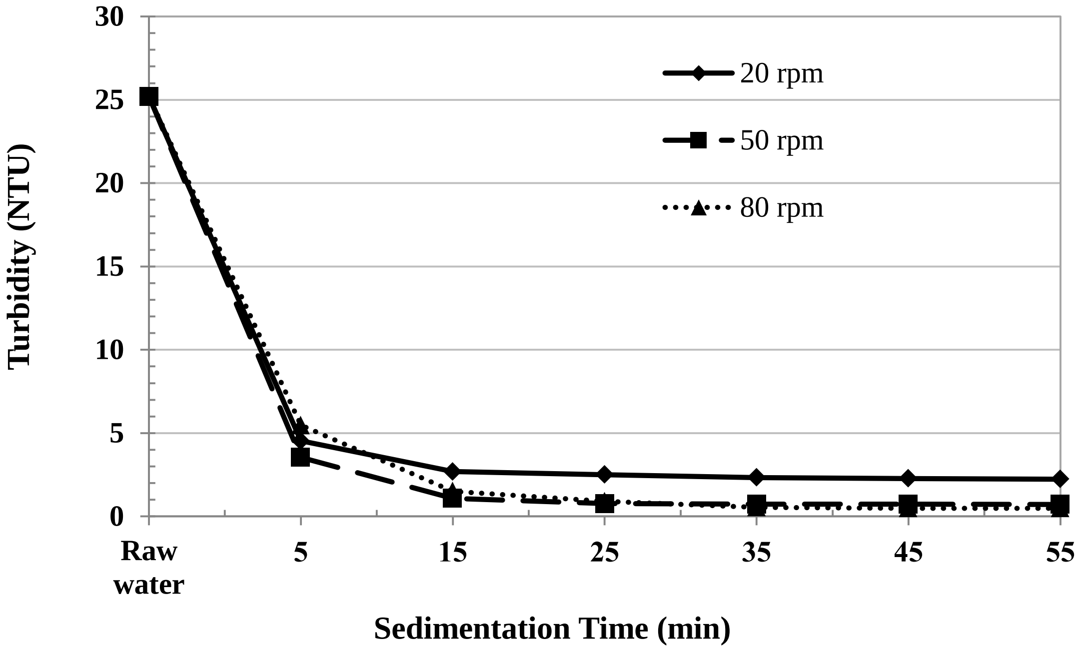


Fig. 4.21 Effect of slow mixing speed on turbidity reduction in raw water treated with 30 mg/L of alum

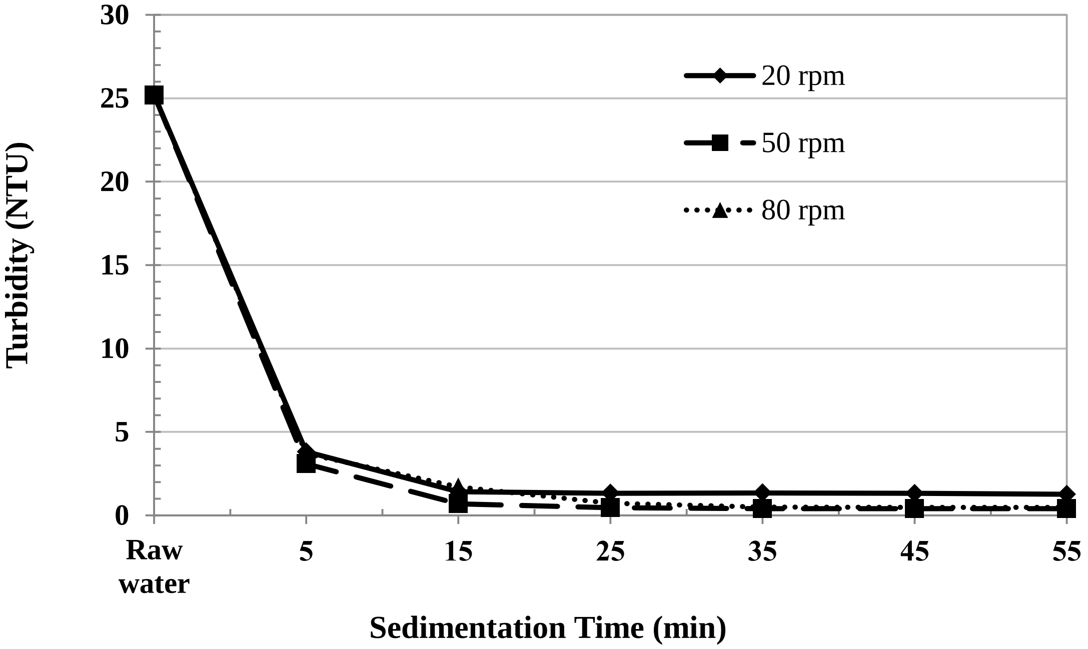


Fig. 4.22 Effect of slow mixing speed on turbidity reduction in raw water treated with 40 mg/L of alum

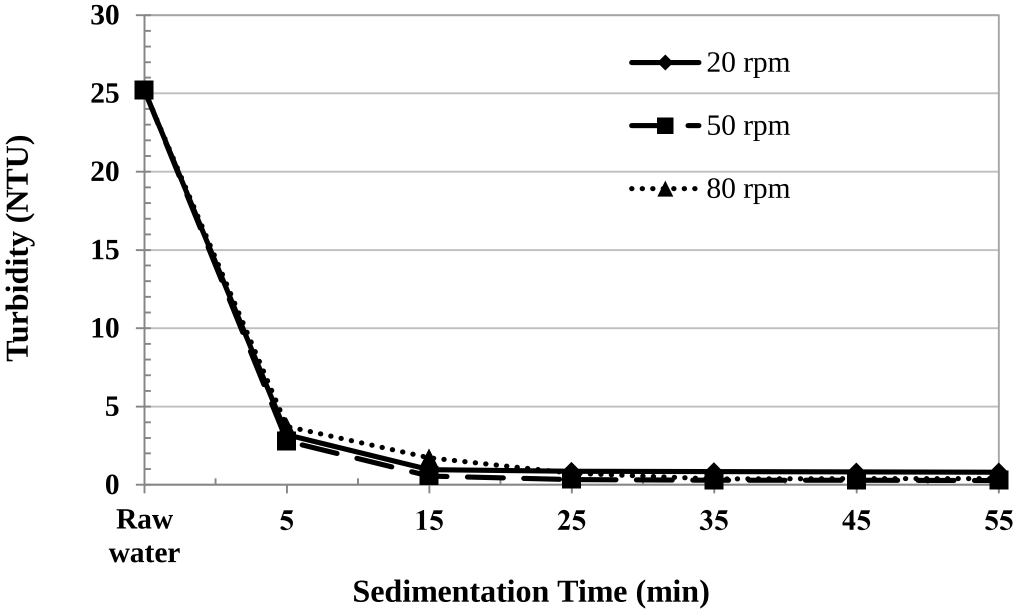


Fig. 4.23 Effect of slow mixing speed on turbidity reduction in raw water treated with 50 mg/L of alum

Hence, based on the results of these experiments, it could be concluded that similar to *M. oleifera*, the 50 rpm was the optimum slow mixing speed while using alum as a coagulant to treat low turbidity raw water.

4.4.2 Optimum sedimentation time

Effect of sedimentation time on the efficiency of turbidity removal at selected slow mixing speed of 50 rpm was also studied by varying it in the range of 5 – 55 minutes. As shown in Fig. 4.24, efficiency of turbidity removal with all the alum dosages was quite low at sedimentation time of 5 minutes. It could possibly be explained by that 5 minutes sedimentation time was not sufficient for flocs to settle down. It can also be seen that the efficiency of turbidity removal at sedimentation time of 15 – 55 minutes was almost the same as almost all flocs would have settled down by 15 minutes sedimentation time.

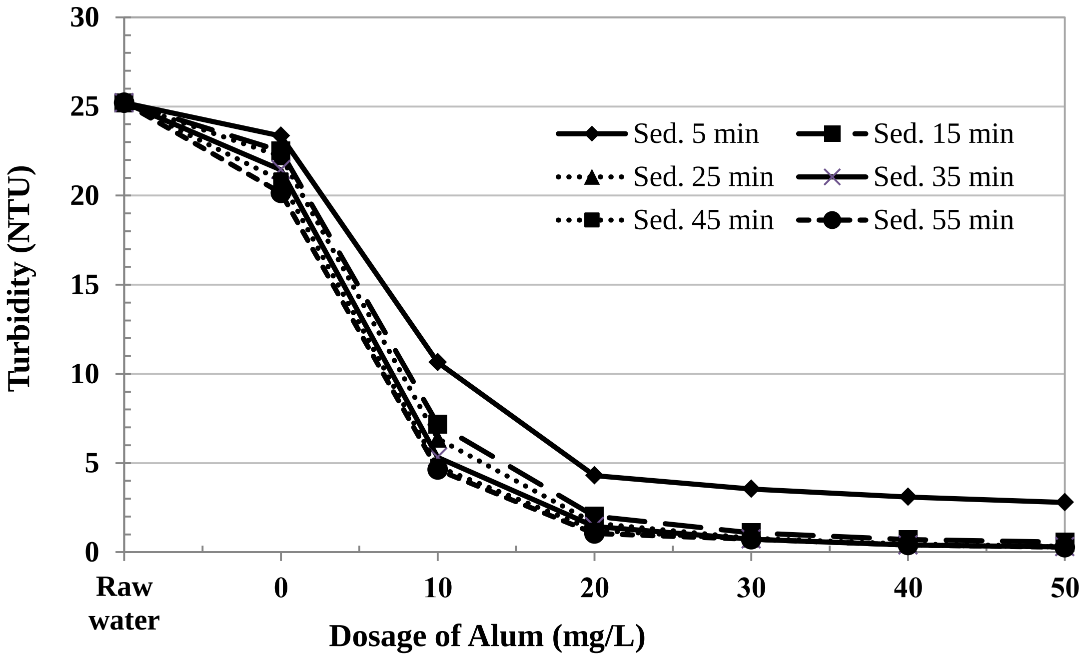


Fig. 4.24 Effect of sedimentation time on turbidity reduction in raw water treated with alum

Hence, based on these experimental results, it can be concluded that the 15 minutes was the optimum sedimentation time to treat low turbidity raw water with alum.

4.4.3 Optimum alum dosage

Effect of alum dosage on turbidity removal from low and medium turbidity raw water was also investigated for selected slow mixing speed (50 rpm) and sedimentation time (15 minutes). The optimum dosage is considered to be the lowest possible dosage that gives the final turbidity of less than 4 NTU which is the WHO guidelines for drinking water quality.

4.4.3.1 Medium turbidity

The effect of alum dosage on the turbidity reduction in medium turbidity raw water is shown in Fig. 4.25. It can be seen that the alum dosage of 20 mg/L or more provided high removal of turbidity and was enough to achieve the final turbidity to be below 4 NTU. Hence, the optimum dosage of alum appeared to be 20 mg/L which could remove more than 90% of turbidity.

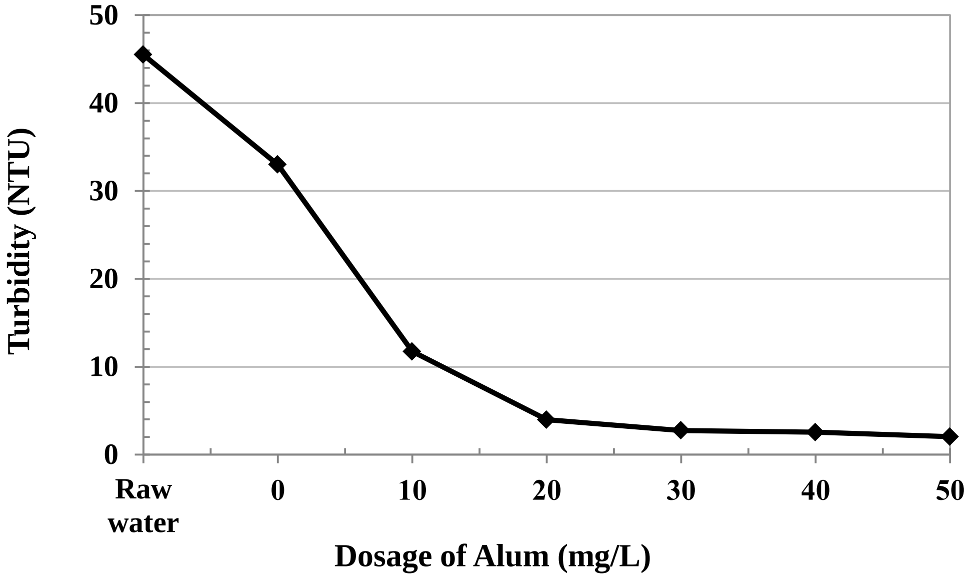


Fig. 4.25 Effect of alum dosage on turbidity reduction in medium turbidity raw water

4.4.3.2 Low turbidity

It can be seen from Fig. 4.26 that the optimum dosage of alum, allowing the final turbidity to be less than 4 NTU, was 20 mg/L. The turbidity removal of more than 90% was achieved at this dosage.

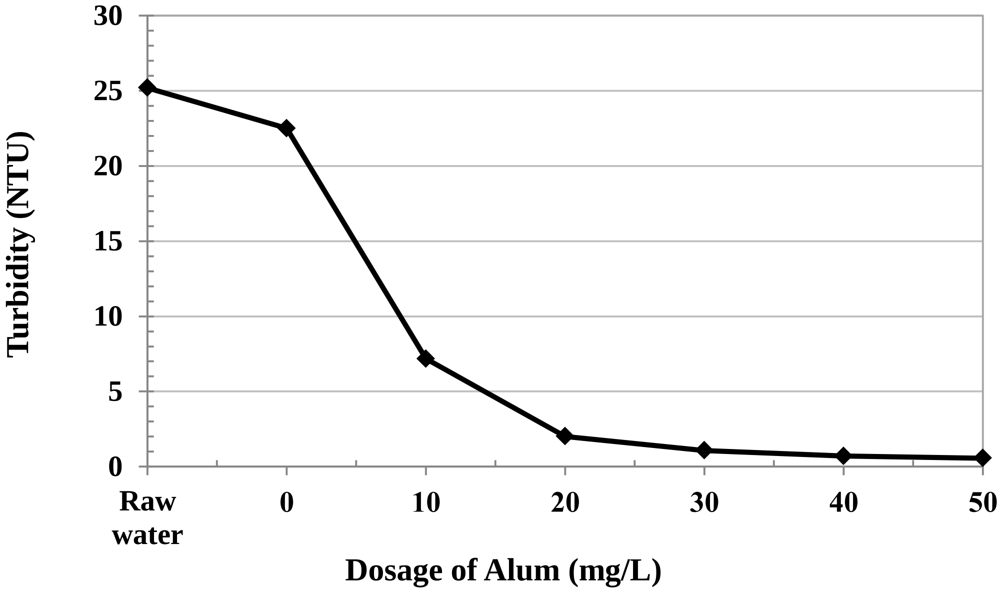


Fig. 4.26 Effect of alum dosage on turbidity reduction in low turbidity raw water

4.5 Comparison of *M. oleifera* and Alum as Coagulants

The experimental results on the quality of the water after being treated by the *M. oleifera* extracted with distilled water as well as by alum are presented in Figs. 4.26 – 4.30. The optimum slow mixing speed and the sedimentation time for both *M. oleifera* (50 rpm, 45 minutes) and alum (50 rpm, 15 minutes) were used in these experiments with low turbidity raw water samples.

It can be seen in Fig. 4.27 that the optimum dosage of *M. oleifera* was 80 mg/L which removed more than 80% of turbidity (from 27.1 NTU to 3.9 NTU); whereas in case of alum it was only 20 mg/L which gave a turbidity removal of more than 90% (from 26.7 NTU to 2.0 NTU). Thus, alum required a lower dosage than *M. oleifera* to achieve the final turbidity to be less than 4 NTU which is WHO guidelines for drinking water quality. Moreover, alum outperformed *M. oleifera* in case of turbidity reduction. However, although *M. oleifera* seemed to be less efficient as compared with alum, it could remove turbidity in raw water to meet WHO guidelines. Therefore, *M. oleifera* could be used as an effective coagulant in water treatment process.

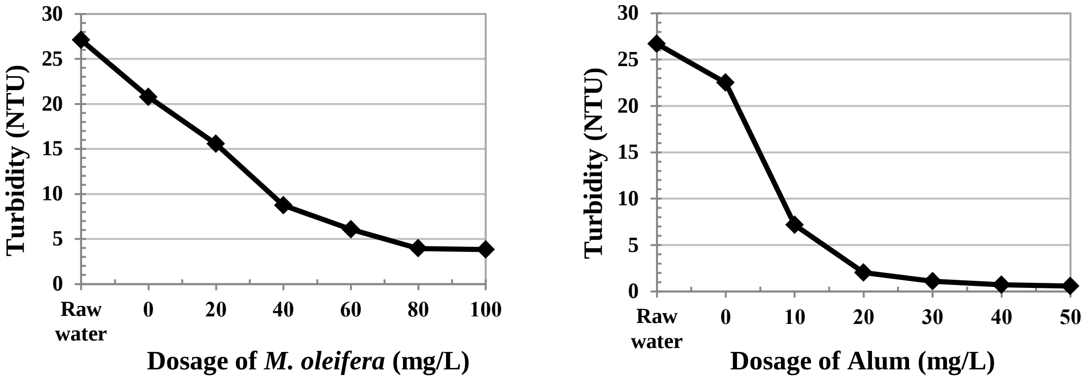


Fig. 4.27 Comparison between efficiency of *M. oleifera* and alum for turbidity removal in raw water

Fig. 4.28 shows that the conductivity of treated water did not significantly change with increasing coagulant dosage. In other words, both *M. oleifera* and alum did not have any effect on the conductivity of treated water.

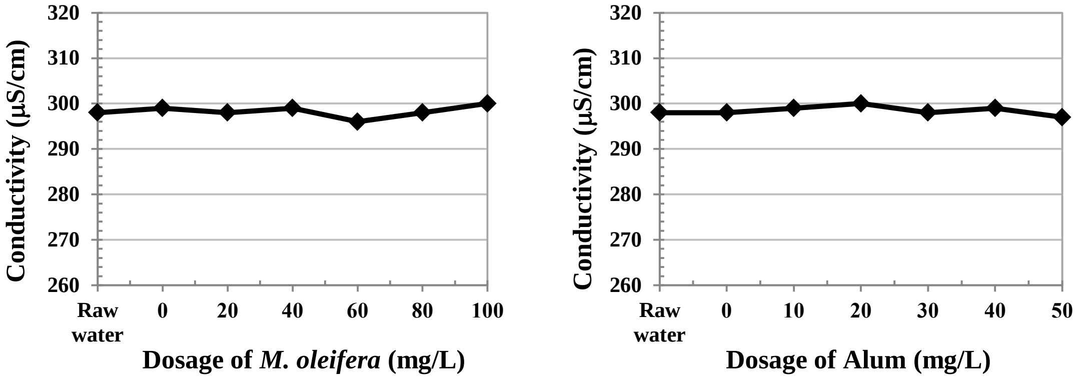


Fig. 4.28 Comparison between conductivity of raw water treated with *M. oleifera* extracted in distilled water and alum

As shown in Figs. 4.29 – 4.30, pH and alkalinity of treated water were significantly affected by increasing dosage of alum (from 0 mg/L to 50 mg/L) as their values decreased (from 7.60 to 7.02 and 101 mg/L to 79 mg/L for pH and alkalinity, respectively). Whereas, in case of *M. oleifera*, these remained constant with increasing dosages.

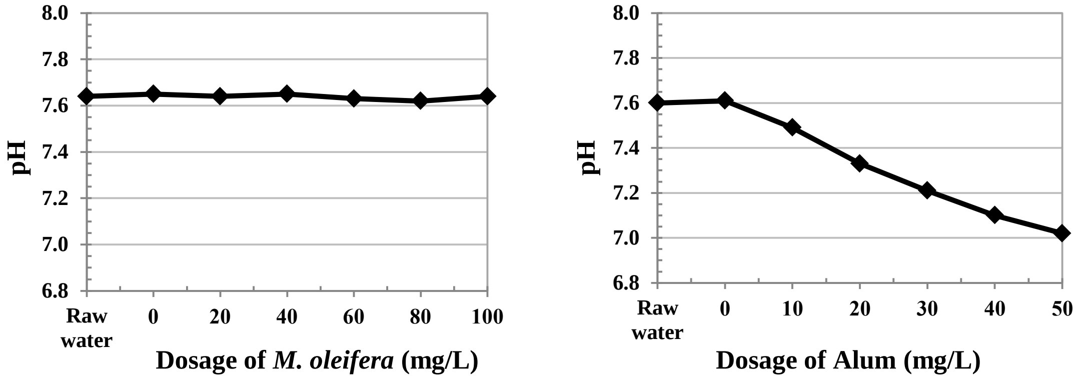


Fig. 4.29 Comparison between pH of raw water treated with *M. oleifera* extracted in distilled water and alum

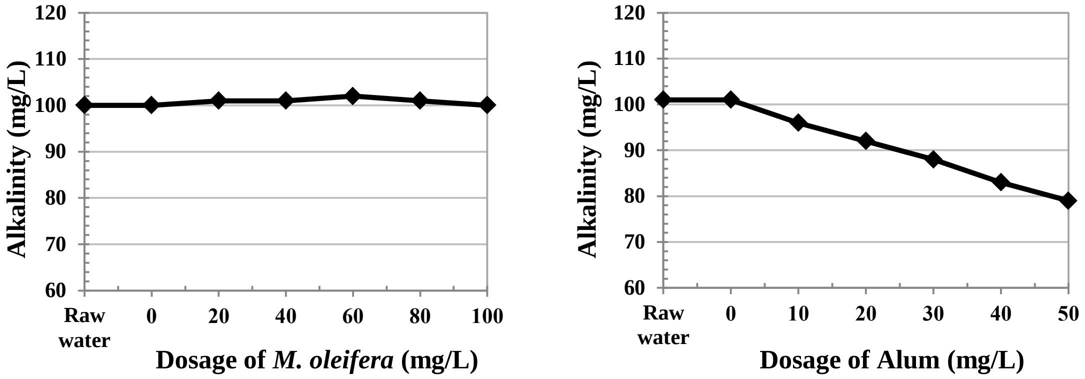


Fig. 4.30 Comparison between alkalinity of raw water treated with *M. oleifera* extracted in distilled water and alum

Fig. 4.31 shows the amount of organic matter in treated water expressed as the UV absorbance at 254 nm. It can be seen that organic matter increased (UV absorbance increased from 0.1010 to 0.1095) as the *M. oleifera* dosage increased (from 0 to 100 mg/L); whereas increasing dosage of alum (from 0 to 50 mg/L) reduced the organic matter (UV absorbance decreased from 0.1010 to 0.0468). It could possibly be explained by that *M. oleifera* extraction contains protein which is the organic matter. After coagulation with *M. oleifera* extraction, some organic matter remains in water resulting in increased UV absorbance at 254 nm.

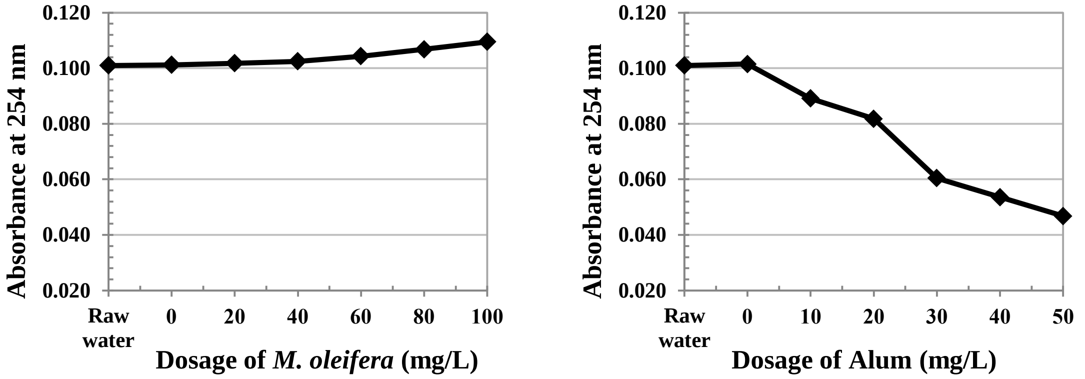


Fig. 4.31 Comparison between UV absorbance at 254 nm of raw water treated with *M. oleifera* extracted in distilled water and alum

Based on the results of these experiments, it could be concluded that although alum outperformed *M. oleifera* with respect to turbidity reduction, the latter did not affect treated water quality e.g. pH and alkalinity. The use of *M. oleifera* as coagulant raises some concern about increased organic matter in treated water. An in-depth investigation about this matter is presented in section 4.7.

Process performance of the *M. oleifera* along with alum used as a co-coagulant was investigated through further experiments.

4.6 Performance Evaluation of *M. oleifera* used with Alum as a Co-coagulant

The efficiency of the combination of *M. oleifera* and alum used as co-coagulants was investigated for the optimum dosage of *M. oleifera* (80 mg/L) by varying the dosage of alum in the range of 0 – 25 mg/L (Fig. 4.32). The slow mixing speed was kept at 50 rpm (optimum speed of slow mixing for both *M. oleifera* and alum). Low turbidity raw water was used in this experiment.

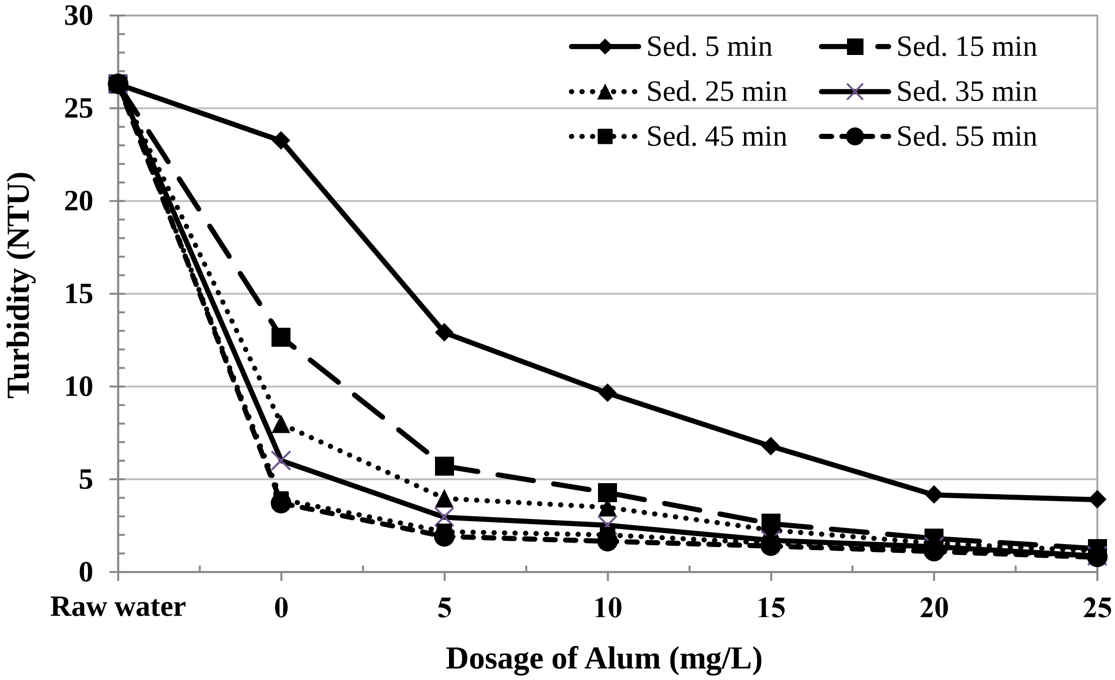


Fig. 4.32 Turbidity profile of raw water treated with the combination of *M. oleifera* (at fixed dosage of 80 mg/L) and varying dosages of alum

It can be seen in Fig. 4.32 that the turbidity of treated water was reduced with increasing alum dosage. This means that alum could further reduce the turbidity of treated water as compared with *M. oleifera* used alone. It was also observed that even though *M. oleifera* alone could achieve the target turbidity (<4 NTU), it took longer sedimentation time of up to 45 minutes. With the combination of *M. oleifera* and only a low dosage of alum at 5 mg/L, the required turbidity could be achieved within 25 minutes. Furthermore, the increased dosage of alum (15 mg/L) as a co-coagulant provided the desired turbidity within 15 minutes. This means that alum could improve the flocculation leading to decrease in the time for flocs to settle down.

Based on these experimental results, it could be concluded that a combination of 80 mg/L of *M. oleifera* along with 5 mg/L of alum was enough to improve the efficiency of turbidity removal. This means that alum used as a co-coagulant could improve the performance of *M. oleifera* extract. In addition, the combination of alum and *M. oleifera* extract can reduce the usage of alum and thus minimizing the negative effects of alum in the treated water.

In this study, the *M. oleifera* extract was selected at the optimum dosage of 80 mg/L, which is with its full potential for turbidity reduction and varied the dosage of alum to investigate the efficiency of the combination of both coagulants. However, if another study was aimed at investigating the final turbidity to just below 4 NTU, the dosage of alum could be selected at 5 mg/L with varying the dosage of *M. oleifera* extract.

4.7 Comparison of Quality of Water Treated with *M. oleifera*, Alum and the Combination of two used as Co-coagulants

The quality of the raw water after being treated by three different types of coagulating agents was investigated while keeping the optimum parameters for each coagulation process, including:

(i) For *M. oleifera* coagulation, the optimum parameters were used by keeping the speed of slow mixing at 50 rpm, the sedimentation time at 45 minutes, and the coagulant dosage at 80 mg/L.

(ii) For alum coagulation, the optimum parameters were used by keeping the speed of slow mixing at 50 rpm, the sedimentation time at 15 minutes, and the coagulant dosage at 20 mg/L.

(iii) For the combination of *M. oleifera* and alum coagulation, the optimum parameters were used by keeping the speed of slow mixing at 50 rpm, the sedimentation time at 25 minutes, and the *M. oleifera* dosage of 80 mg/L and the alum dosage of 5 mg/L.

The raw water samples as well as the water samples after being treated by three types of coagulating agents were divided into two portions to analyze the physical and chemical properties (Table 4.3) and to investigate the potential of trihalomethanes (THMs) formation (Table 4.4).

4.7.1 Physical and Chemical Properties

Table 4.3 shows the various physic-chemical parameters analyzed in the raw water as well as the water after being treated by *M. oleifera*, alum, and the combination of *M. oleifera* and alum as co-coagulants with the optimum parameters for respective coagulating agents.

As already explained in the sections 4.5 and 4.6, the alum outperformed *M. oleifera* as well as the combination of the two in terms of turbidity reduction. The conductivity of water treated with three different coagulating agents did not change significantly. The pH and alkalinity of treated water decreased with the use of alum and the combination of *M. oleifera* and alum as coagulating agents. Moreover, the organic matter in the treated water, expressed as UV absorbance at 254 nm, and total organic carbon (TOC) increased when *M. oleifera* was used alone or with alum in the combination of two co-coagulants. In contrast, alum used alone as a coagulant did not increase the organic matter in treated water.

The total hardness of water remained constant after treated with three types of coagulating agents. The carbonate hardness (or temporary hardness) and the alkalinity values were similar due to the fact that carbonate hardness is a measure of the minerals contents dissolved in the water caused by the presence of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) anions. On the other hand, the non-carbonate hardness (or permanent hardness) of water after treated by alum increased almost to the double as compared with raw water, and was highest among the three types of coagulating agents.

Table 4.3 Comparison of quality of raw water and after treated with three coagulating agents

Parameter	**Unit**	**Raw Water**	***M. oleifera***	**Alum**	***M. oleifera* + Alum**	**WHO Guideline Value**
Turbidity	NTU	26.5	3.87	2.08	2.14	4
Conductivity	µS/cm	300	299	302	301	-
pH	-	7.62	7.60	7.38	7.56	6.5 - 8.5
Total alkalinity (as calcium carbonate)	mg/L	100	101	90	97	-
Total hardness (as calcium carbonate)	mg/L	112	112	112	112	-
Carbonate hardness (as calcium carbonate)	mg/L	100	101	90	97	-
Non-carbonate hardness (as calcium carbonate)	mg/L	12	11	24	19	-
Calcium	mg/L	32.0	32.0	32.0	32.0	-
Magnesium	mg/L	8.16	8.16	8.16	8.16	-
Chloride	mg/L	29	29	29	29	250
Sulfate	mg/L	22	22	28	24	250
Copper	mg/L	0.01	0.01	0.01	0.01	2
Zinc	mg/L	ND	ND	ND	ND	3
Lead	mg/L	0.00040	ND	ND	ND	0.01
Chromium	mg/L	ND	ND	ND	ND	0.05
Cadmium	mg/L	ND	ND	ND	ND	0.003
Silver	mg/L	ND	ND	ND	ND	0.1
Aluminum	mg/L	0.1510	0.0710	0.4749	0.2115	0.9
Arsenic	mg/L	ND	ND	ND	ND	0.01
Barium	mg/L	0.0609	0.0584	0.0575	0.0578	0.7
Manganese	mg/L	0.0347	0.0040	0.0035	0.0040	0.1
Nickel	mg/L	ND	ND	ND	ND	0.07
Antimony	mg/L	ND	ND	ND	ND	0.02
Selenium	mg/L	ND	ND	ND	ND	0.04
UV Absorbance at 254 nm	-	0.1012	0.1068	0.0818	0.1052	-
Total organic carbon (TOC)	mg/L	4.73	11.21	4.69	11.12	-

The concentrations of calcium and magnesium in water treated with all the three coagulating agents were similar to that of raw water. This was also reflected by no significant change in the total hardness in treated water that is caused by both calcium and magnesium.

After being treated by three types of coagulating agents, the concentration of chloride remained constant and was below the WHO guideline value for drinking water quality. The presence of chloride in drinking water is associated with taste and corrosion problem and is limited to 250 mg/L. Excessive concentrations of chloride give a salty taste to water and may contribute to corrosion in the distribution systems.

The concentration of sulfate after treated by alum was higher than that of the combination of *M. oleifera* and alum and that of *M. oleifera* extraction alone, respectively. It is obviously due to the fact that alum, having the chemical formula of $Al_2(SO_4)_3$, affected sulfate concentration in treated water. However, the concentration of sulfate in the water after treated by three types of coagulating agents was well below the WHO guidelines value for drinking water quality. The concentration of sulfate in drinking water, which is associated with noticeable taste, is limited to 250 mg/L. Moreover, the excessive levels of sulfate may cause laxative effect.

The non-carbonate hardness is caused by chloride and sulfate. It has been reported by Ndabigengesere and Narasiah (1998) that high concentration of sulfate results in an increase in non-carbonate hardness in the treated water. The present study supports their results.

The concentration of heavy metals including zinc, chromium, cadmium, silver, arsenic, nickel, antimony, and selenium in the raw water as well as the treated water were non-detectable (ND). The limits of detection (LOD) of these heavy metals were 0.003, 0.00001, 0.000003, 0.0003, 0.0019, 0.0004, 0.0012, and 0.0016 mg/L, respectively. This means that these heavy metals were less than LOD and also below the WHO guideline value for drinking water quality. The concentration of copper in the raw water and the treated water were similar (0.01 mg/L). This might indicate that the coagulation did not remove copper in the water. The concentrations of lead (LOD of lead was 0.00005 mg/L), barium, and manganese were in general reduced by three types of coagulating agents.

In case of aluminum concentration, *M. oleifera* extraction could reduce aluminum in the treated water; whereas aluminum increased when alum was used as coagulant. This is due to the fact that aluminum is the part of alum ($Al_2(SO_4)_3$), similar to that of sulfate.

Levels of all of these parameters, analyzed to determine both physical and chemical properties of treated water, were considerably less than the WHO guidelines for drinking water quality.

4.7.2 Trihalomethane Formation Potential (THMFP)

Trihalomethanes (THMs) are produced during chlorination of organic matter in the water. The most common THMs and the major disinfection by-products in chlorinated water are chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$ or BDCM), dibromochloromethane ($CHBr_2Cl$ or DBCM), and bromoform ($CHBr_3$). Presence of these by-products in drinking-water is considered to cause significant health impact. Chloroform and BDCM were considered to be carcinogenic and classified in group 2B (possibly carcinogenic to humans) by International Agency for Research on Cancer (IARC) (WHO, 2011).

Due to the observed increase in organic matter in the water after being treated by *M. oleifera* extraction, it was worth investigating the formation potential of these by-products. These by-products could be formed during organic reactions between chlorine and THMs precursors. Rate of THMs formation is enhanced by increasing temperature, pH, reaction time, level of THMs precursors, and chlorine concentration.

To achieve experimental results with minimum errors, some parameters were controlled by keeping them at considerably constant levels (the coagulated water dosed with chlorine was kept at room temperature and 24 hours reaction time). According to standard methods for the examination of water and wastewater, the residual chlorine should be at least 3 – 5 mg/L at the end of reaction period. In this study, the concentration of chlorine added to the treated water was varied in the range of 10 – 70 mg/L to determine THMFP. Table 4.4 shows the Trihalomethane Formation Potential (THMFP) with various concentration of chlorine.

As shown in Table 4.4, it was found that the amount of DBCM and bromoform was non-detectable, so the two major by-products that cause formation of THMs in the water treatment processes were chloroform and BDCM. The experimental results of the formation potential of chloroform, BDCM and THMs with different dosages of chlorine are presented in the Figs. 4.33 – 4.35, respectively.

Table 4.4 Trihalomethane Formation Potential (THMFP) caused by three coagulating agents with various concentrations of chlorine

Water Sample	**Res. Chlorine (mg/L)**	**Chloro form (µg/L)**	**BDCM (µg/L)**	**DBCM (µg/L)**	**Bromo form (µg/L)**	**THMFP (Sum of Ratio)**
With chlorine dosage of 10 mg/L						
Raw Water	3.2	100.83	11.15	ND	ND	0.52
M. oleifera	0.0	55.34	4.06	ND	ND	0.25
Alum	3.9	76.08	10.55	ND	ND	0.43
Combination of *M. oleifera* + Alum	0.0	46.48	3.89	ND	ND	0.22
With chlorine dosage of 20 mg/L						
Raw Water	12.9	101.51	11.51	ND	ND	0.53
M. oleifera	3.6	93.12	7.41	ND	ND	0.43
Alum	13.6	80.24	11.48	ND	ND	0.46
Combination of *M. oleifera* + Alum	4.2	82.47	6.51	ND	ND	0.38
With chlorine dosage of 30 mg/L						
Raw Water	22.7	106.43	11.85	ND	ND	0.55
M. oleifera	11.7	113.39	9.57	ND	ND	0.54
Alum	23.4	82.15	11.83	ND	ND	0.47
Combination of *M. oleifera* + Alum	13.2	94.95	8.51	ND	ND	0.46
With chlorine dosage of 70 mg/L						
Raw Water	61.5	111.14	12.13	ND	ND	0.57
M. oleifera	46.6	167.67	14.27	ND	ND	0.80
Alum	62.1	84.40	14.05	ND	ND	0.52
Combination of *M. oleifera* + Alum	48.5	154.05	12.80	ND	ND	0.73

As can be seen in Fig. 4.33, the amount of chloroform increased with increasing dosage of chlorine. In case of *M. oleifera* extraction and the combination of *M. oleifera* and alum, the chloroform concentration increased considerably with increasing chlorine dosage; whereas there was only slight influence of chlorine dosage on chloroform levels in raw water as well as the water treated with alum. This could be due to the fact that organic matter in the water treated with either *M. oleifera* extraction alone or with the combination of *M. oleifera* and alum was higher than in the water treated with alum, resulting in higher rate of THMs formation in the first two cases.

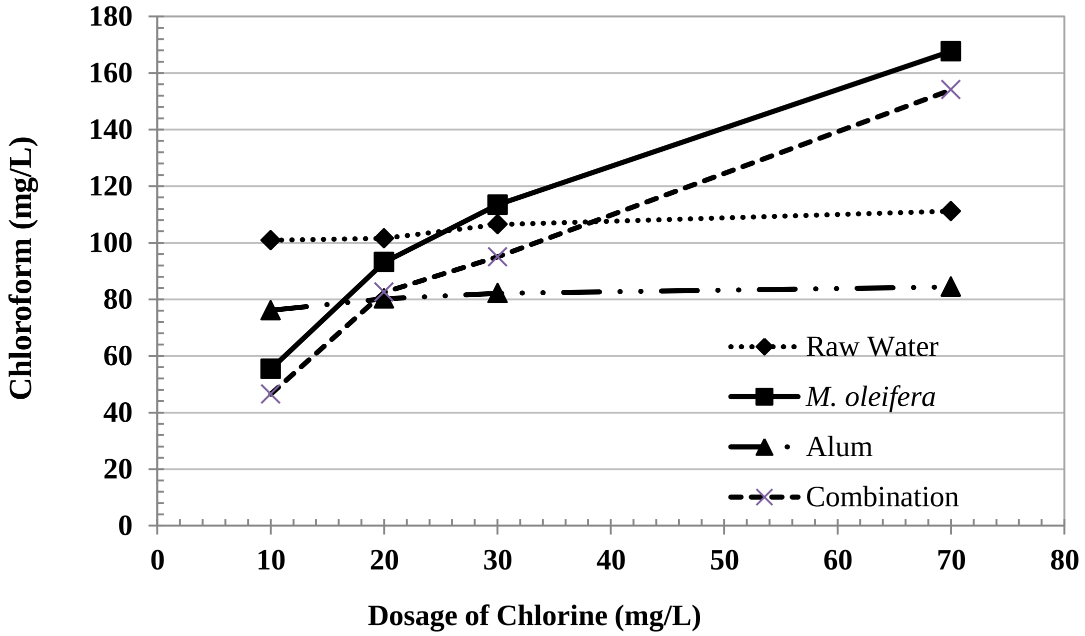


Fig. 4.33 Effect of chlorine dosage on chloroform formation

Compared to alum, *M. oleifera* extraction produced lower amount of chloroform in the treated water at the lowest dosage of chlorine (10 mg/L). Reason for this could be that at this dosage, chlorine was not enough to react with higher amount of organic matter in the water (as indicated by no residual chlorine in the treated water). Hence, less amount of chloroform was generated than in case of alum. At the chlorine dosage of 20 mg/L, the residual chlorine in the water treated with *M. oleifera* extraction as well as with the combination of *M. oleifera* and alum were 3 – 5 mg/L.

This indicates that the chlorine dosage was enough to react with the organic matter in the water.

As shown in Fig. 4.34, amount of BDCM increased substantially with increasing chlorine dosage in the water treated with *M. oleifera* extraction as well as with the combination of *M. oleifera* and alum, whereas in case of alum, it only increased slightly and gradually similar to chloroform. The reason of this is same as in case of chloroform. Compared to *M. oleifera* extraction as well as combination of *M. oleifera* and alum, the formation of BDCM with alum alone was pretty high at the lower chlorine dosage but was not significantly different at the highest dosage of chlorine (70 mg/L).

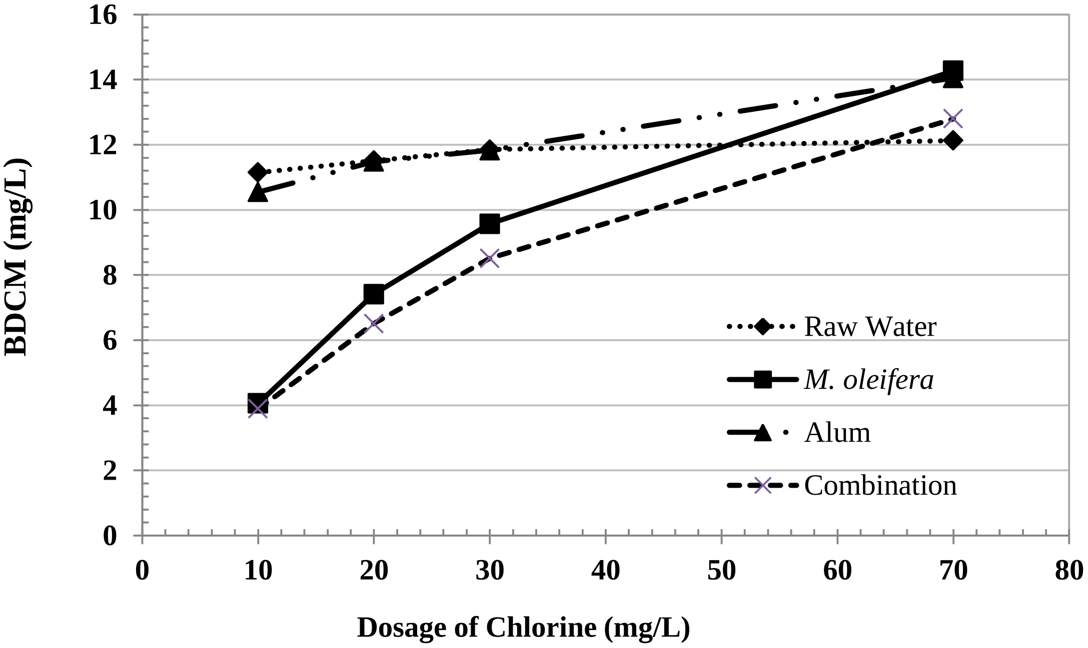


Fig. 4.34 Effect of chlorine dosage on BDCM formation

It can be seen in Fig. 4.35 that the pattern of THMs formation potential was similar to that of chloroform. This is due to the fact that chloroform was the principal occurring THMs.

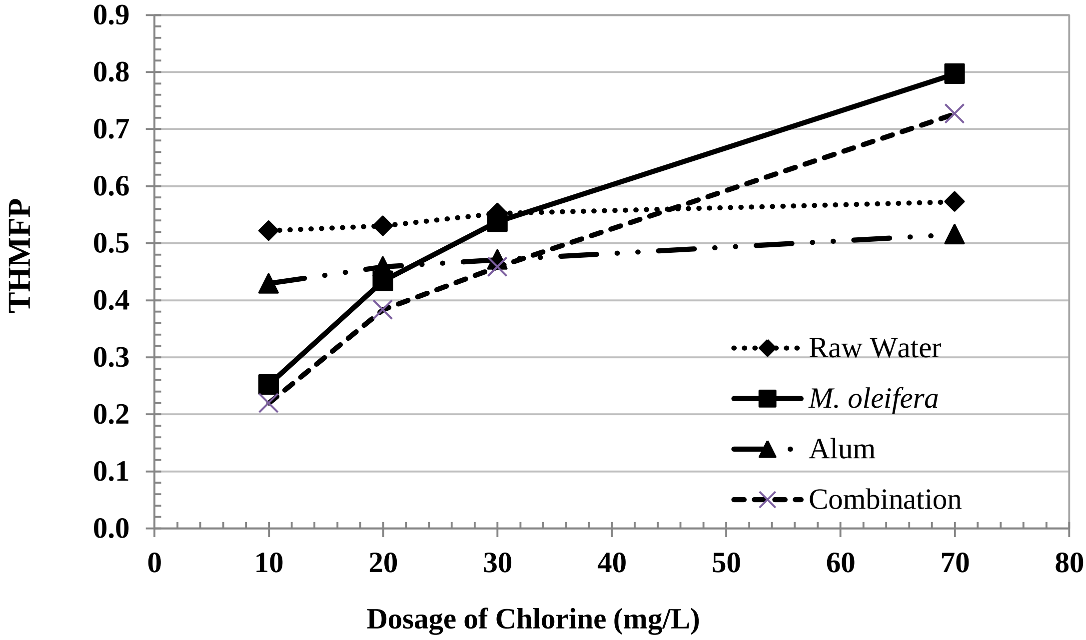


Fig. 4.35 Effect of chlorine dosage on THMFP

Based on these results, it seemed that the chlorine dosage of 20 mg/L was the optimum chlorine demand for the water treatment by *M. oleifera* coagulation as it caused the residual chlorine of about 3 – 5 mg/L. Although the excessive dosage of chlorine (70 mg/L) was added to the water treated with all the three coagulating agents in order to investigate more, the formation potential of trihalomethanes (THMFP) was still < 1 which is lower than the WHO guidelines for drinking water quality.

From the experimental results on the physical and chemical properties as well as on the formation potential of trihalomethanes (THMFP), it could be concluded that the quality of water after being treated by three types of coagulating agents including *M. oleifera*, alum, and the combination of *M. oleifera* and alum could be safe for drinking.

It can be said that the combination of 80 mg/L of *M. oleifera* extract along with 5 mg/L of alum seems to be the alternative solution. It did not only improve the performance of *M. oleifera* extract in term of turbidity removal but also reduce the usage of alum and thus minimizing the negative effects of alum in the treated water.

Based on all of these experimental results, it appeared that it is possible to replace alum, well-known chemical coagulant, with *M. oleifera* extract as a natural coagulant in water treatment process. However, although alum is considered to be more expensive as compared to *M. oleifera* seeds, in case of high volume of coagulant used in water treatment plant, alum appears to be substantially cheaper for bulk price. Hence, the principal reason for using the *M. oleifera* extract as coagulant in water treatment process is the concern about human health impact also environmental problems.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Present study was aimed at investigating the efficiency of *M. oleifera* as a natural coagulant for turbidity removal in water treatment process. Actual raw water was used for this study (instead of synthetic raw water that has been used in many studies as reported in literature).

The efficiency of different solvents including distilled water, 0.5 M NaCl, 0.5 M NaOH for extracting *M. oleifera* were investigated in jar tests. Based on the results of the evaluation of optimum solvent for *M. oleifera* extraction, it could be seen that 0.5 M NaCl required a lowest dosage among three solvents to achieve high turbidity removal. However, it did not appear to be a good solvent for *M. oleifera* extraction because of significant increase in conductivity of treated water with increasing dosages. NaOH also did not appear to be a good solvent for *M. oleifera* extraction as there was significant increase in both pH and alkalinity of the treated water with increasing dosages. Therefore, it appeared that distilled water is the most suitable solvent for *M. oleifera* extraction.

The efficiency of turbidity removal with *M. oleifera* extraction in distilled water was investigated by varying slow mixing speed of jar test, sedimentation time, and *M. oleifera* dosage. The optimum parameters for coagulation process using *M. oleifera* as coagulant were determined based on the sufficient turbidity removal to achieve the final turbidity of less than 4 NTU which is the WHO guidelines for drinking water quality. These experimental were conducted using raw water samples with medium and low turbidity at two different periods of time.

The results showed that the slow mixing speed of 20 rpm was too slow resulting in low efficiency of turbidity removal. The slower speed allowed less contact among suspended solids and thus provided less opportunity of flocs formation resulting in low reduction in turbidity. However, the mixing speed of 80 rpm was probably too fast causing flocs fragility and thus breaking of already formed flocs. Hence, it could be concluded that the optimum slow mixing speed in jar test for *M. oleifera* extraction in distilled water was 50 rpm for treating both medium and low turbidity raw water.

For the investigation of the effect of sedimentation time on the efficiency of turbidity removal at selected slow mixing speed of 50 rpm, the efficiency of turbidity reduction with all the *M. oleifera* dosages was quite low at sedimentation time of 5 minutes. It could possibly be explained by the fact that even if the flocs were already formed in the water they need some time for sedimentation; and if the flocs formed by coagulation were quite small they would require longer time to settle. On the other hand, 5 minutes sedimentation time was not sufficient for flocs to settle down even with high *M. oleifera* dosage. Moreover, the results showed that the efficiency of turbidity removal was enhanced with increasing sedimentation time. However, there was no significant improvement in turbidity reduction beyond 45 minutes sedimentation time as almost all flocs would have settled down by then. Hence, based on the results of these experiments, it can be concluded that the 45 minutes was the optimum sedimentation time while using *M. oleifera* as a coagulant to treat low to medium turbidity raw water.

The effect of *M. oleifera* dosage on turbidity removal from low and medium turbidity raw water was also investigated for selected slow mixing speed (50 rpm) and sedimentation time (45 minutes. Based on the experimental results, it could be concluded that the optimum dosage *M. oleifera* was 70 mg/L for treating medium turbidity raw water; whereas, the *M. oleifera* dosage of 80 mg/L was found to be the optimum dosage to treat low turbidity raw water.

The efficiency of turbidity removal with alum, one of the well-known chemical coagulants, was also investigated by varying slow mixing speed of jar test, sedimentation time, and alum dosage. The slow mixing speed of jar test and the sedimentation time were conducted using low turbidity raw water samples. The alum dosages were conducted using raw water samples with medium and low turbidity.

Based on the experimental results, it could be concluded that while using alum as a coagulant to treat low turbidity raw water, the optimum slow mixing speed and the optimum sedimentation time were 50 rpm and 15 minutes, respectively. The dosage of 20 mg/L was the optimum dosage of alum for treating low to medium turbidity raw water.

To compare *M. oleifera* and alum as coagulants, the quality of the water after being treated by the *M. oleifera* extracted with distilled water as well as by alum was investigated. The optimum slow mixing speed and the sedimentation time for both *M. oleifera* (50 rpm, 45 minutes) and alum (50 rpm, 15 minutes) were used in these experiments with low turbidity raw water samples.

It was found that alum required a lower dosage than *M. oleifera* to achieve the final turbidity to be less than 4 NTU. Moreover, alum outperformed *M. oleifera* in case of turbidity reduction. Both *M. oleifera* and alum did not have any effect on the conductivity of treated water. The pH and alkalinity of treated water were significantly affected by alum; whereas, in case of *M. oleifera*, these remained constant with increasing dosages. The amount of organic matter in treated water, expressed as the UV absorbance at 254 nm, was considerably affected by *M. oleifera* dosage; while it was reduced by alum.

The process performance of the *M. oleifera* along with alum used as a co-coagulant was investigated for the optimum dosage of *M. oleifera* (80 mg/L) by varying the dosage of alum in the range of 0 – 25 mg/L. The slow mixing speed was kept at 50 rpm (optimum speed of slow mixing for both *M. oleifera* and alum). The raw water samples with low turbidity were used in this experiment.

Based on the experimental results, it could be concluded that a combination of 80 mg/L of *M. oleifera* along with 5 mg/L of alum was enough to improve the efficiency of turbidity removal. This means that alum used as a co-coagulant could improve the performance of *M. oleifera* extract. In addition, the combination of alum and *M. oleifera* extract can reduce the usage of alum and thus minimizing the negative effects of alum in the treated water.

To compare the efficiency of *M. oleifera*, alum and the combination of two used as co-coagulants, the quality of the raw water after being treated by three different types of coagulating agents was investigated while keeping the optimum parameters for each coagulation process. These experimental runs were conducted using low turbidity raw water samples.

Various physic-chemical parameters were determined in the raw water as well as the water after being treated by three different types of coagulating agents including turbidity, conductivity, pH, total alkalinity, total hardness, carbonate hardness, non-carbonate hardness, calcium, magnesium, chloride, sulfate, copper, zinc, lead, chromium, cadmium, silver, aluminum, arsenic, barium, manganese, nickel, antimony, selenium, UV Absorbance at 254 nm, and total organic carbon (TOC). The results showed that levels of all of these parameters were considerably less than the WHO guidelines for drinking water quality.

Due to some concern about increased organic matter in water after being treated by *M. oleifera* as coagulant, the formation potentials of trihalomethanes (THMs) was investigated. The excess of chlorine was added to the water sample and stored at room temperature for 24 hours to allow the complete reaction. Although the excessive dosage of chlorine (70 mg/L) was added to the water treated with all the three coagulating agents in order to investigate more, the formation potential of trihalomethanes (THMFP) was still less than 1 which is lower than the WHO guidelines for drinking water quality.

From the experimental results on the physical and chemical properties as well as on the formation potential of trihalomethanes (THMFP), it could be concluded that the quality of water after being treated by three types of coagulating agents including *M. oleifera*, alum, and the combination of *M. oleifera* and alum could be safe for drinking.

At present, the coagulant used in almost all water treatment plants is alum because of its quite good efficiency for turbidity reduction and also with very low price. However, there are several disadvantages associated with alum such as its potential for causing neurological disorders and Alzheimer disease. The only way to avoid such risks could be using an alternative coagulating agent such as plant based natural coagulant. Many plant based coagulants have been investigated for this purpose. The *M. oleifera* extractions into a solvent seem to be among the top three. Although *M. oleifera* is not as efficient coagulant as the alum it has several advantages over the alum to be used in water treatment process, such as lower sludge volume that is naturally biodegradable; and no risk of causing any neurological disorder or Alzheimer disease.

There are benefits and drawbacks associated with the use of *M. oleifera* extract and alum as coagulant in water treatment process, summarized in Table 5.1.

Table 5.1 The comparison of *M. oleifera* extract and alum in water treatment process

List	***M. oleifera* Extract**	**Alum**
Final turbidity*	Low (4 NTU)	Very low (2 NTU)
The amount of coagulant dosage*	High (80 mg/L)	Low (20 mg/L)
Sedimentation time*	High (45 min)	Low (15 min)
Aluminum in treated Water	Decreased	Increased
Organic matter in treated Water	Increased	Decreased
Quantity of sludge	Low	High
Biodegradability of sludge	High	Low
Possibly disease inducing by coagulant	-	Neurological disorder, Alzheimer disease

*when treating low turbidity raw water

Based on the results of this study, it appeared that although *M. oleifera* seemed to be less efficient coagulant as compared with alum in terms of dosage and sedimentation time, it could achieve the final turbidity in the treated water to be less than 4 NTU which is WHO guideline for drinking water quality. Moreover, the coagulation process performance of *M. oleifera* used along with alum as a co-coagulant could be more effective. Therefore, it could be concluded that *M. oleifera* could be used as an effective alternative natural coagulant for turbidity reduction from the raw water at the Bangkhen WTP of MWA.

5.2 Recommendations

More research is needed to try more plant extracts from the tropical region to be used as natural coagulants in water treatment process.

Further research should also be carried out for investigating the efficiency of *M. oleifera* for the removal of microorganism contamination in water treatment process such as *Escherichia coli* (*E.coli*) and faecal coliforms.

In addition, investigations should be carried out in the purification methods for *M. oleifera* extraction such as lyophilization, ion-exchange and dialysis to reduce the organic matter in the water after being treated by *M. oleifera*

To prevent the generation of THMs, further research work is required for investigating several alternative disinfection processes such as UV radiation, ozonation, solar disinfection, etc.

In order to successfully implement *M. oleifera* extract as a replacement coagulant in water treatment plant, there are still many aspects that should be recognized such as:

(a) Legal issues for the use of food product as a coagulant in water treatment plant

(b) Authorization from related organization such as Ministry of Interior that regulate MWA

(c) Supplier that can provide massive volume of *M. oleifera* seeds for continuous production of water supply

REFERENCES

Alexander, J. T., Hai, F. I., & Al-aboud, T. M. (2012). Chemical coagulation-based processes for trace organic contaminant removal: Current state and future potential. Journal of Environmental Management, 111, 195–207.

Ali, E. N., Muyibi, S. A., Salleh, H. M., Alam, M., & Salleh, M. M. (2010). Production of Natural Coagulant from *Moringa Oleifera* Seed for Application in Treatment of Low Turbidity Water. J. Water Resource and Protection(2), 259-266.

American Public Health Association (APHA), American Water Works Association, & Water Environment Federation. (2012). Standard Methods for the Examination of Water and Wastewater (22nd ed.). Washington, DC: American Public Health Association.

Bhatia, S., Othman, Z., & Ahmad, A. L. (2007). Coagulation–flocculation process for POME treatment using *Moringa oleifera* seeds extract: Optimization studies. Chemical Engineering Journal, 133(1-3), 205–212.

Bhuptawat, H., Folkardb, G. K., & Chaudhari, S. (2007). Innovative physico-chemical treatment of wastewater incorporating *Moringa oleifera* seed coagulant. Journal of Hazardous Materials, 142(1-2), 477–482.

Davis, M. L. (2010). Water and Wastewater Engineering: Design Principles and Practice. McGraw-Hill.

Diaz, A., Rincon, N., Escorihuela, A., Fernandez, N., Chacin, E., & Forster, C. F. (1999). A preliminary evaluation of turbidity removal by natural coagulants indigenous to Venezuela. Process Biochemistry, 35, 391–395.

Fatombi, J. K., Lartiges, B., Aminou, T., Barres, O., & Caillet, C. (2013). A natural coagulant protein from copra (Cocos nucifera): Isolation, characterization, and potential for water purification. Separation and Purification Technology, 116, 35–40.

Gassenschmidt, U., Jany, K. D., Tauscher, B., & Niebergall, H. (1995). Isolation and characterization of a flocculating protein from *Moringa oleifera* Lam. Biochimica et Biophysics Acta, 1243, 477-481.

Ghebremichael, K. A., Gunaratna, K. R., Henriksson, H., Brumer, H., & Dalhammar, G. (2005). A simple purification and activity assay of the coagulant protein from *Moringa oleifera* seed. Water Research, 39(11), 2338–2344.

Gidde, M. R., Bhalerao, A. R., & Malusare, C. N. (2012). Comparative Study of Different Forms of *Moringa Oleifera* Extracts for Turbidity Removal. International Journal of Engineering Research and Development, 2(1), 14-21.

Graham, N., Gang, F., Fowler, G., & Watts, M. (2008). Characterisation and coagulation performance of a tannin-based cationic polymer: A preliminary assessment. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 327(1–3), 9–16.

Gray, N. F. (2005). Water technology: an introduction for environmental scientists and engineers. (2nd, Ed.) Elsevier Science & Technology Books.

Joseph, L., Flora, J. R., Park, Y.-G., Badawy, M., Saleh, H., & Yoon, Y. (2012). Removal of natural organic matter from potential drinking water sources by combined coagulation and adsorption using carbon nanomaterials. Separation and Purification Technology, 95, 64–72.

Katayon, S., Megat Mohd Noor, M. J., Asma, M., Abdul Ghani, L. A., Thamer, A. M., Azni, I., et al. (2006). Effects of storage conditions of *Moringa oleifera* seeds on its performance in coagulation. Bioresource Technology, 97(13), 1455–1460.

Kituyi, J. L., Foulkes, M., Worsfold, P., Ongulu, R. A., Kiplagat, A., & Gachanja, A. (2013). Efficiency of pre-treated *Moringa oleifera* for the removal of Cd2+ and Zn2+ ions from wastewaters. Ecohydrology & Hydrobiology, 13(4), 267–271.

Kwaambwa, H. M., & Maikokera, R. (2007). A fluorescence spectroscopic study of a coagulating protein extracted from *Moringa oleifera* seeds. Colloids and Surfaces B: Biointerfaces, 60(2), 213–220.

Matilainen, A., Vepsäläinen, M., & Sillanpää, M. (2010). Natural organic matter removal by coagulation during drinking water treatment: A review. Advances in Colloid and Interface Science, 159(2), 189–197.

Mcconnachie, G. L., Folkard, G. K., Mtawali, M. A., & Sutherland, J. P. (1999). Field Trials of Appropriate Hydraulic Flocculation Processes. Wat. Res., 33(6), 1425-1434.

Md. Asrafuzzaman, Fakhruddin, A. M., & Md. Hossain, A. (2011). Reduction of Turbidity of Water Using Locally Available Natural Coagulants. ISRN Microbiology, 2011.

Muthuraman, G., & Sasikala, S. (2013). Removal of turbidity from drinking water using natural coagulants. Journal of Industrial and Engineering Chemistry.

Muyibi, S. A., & Evison, L. M. (1995a). *Moringa oleifera* seeds for softening hardwater. War. Res., 29, 1099-1105.

Muyibi, S. A., & Evison, L. M. (1995b). Optimizing Physical Parameters Affecting Coagulation of Turbid Water with *Moringa oleifera* seeds. Wat. Res., 29, 2689-2695.

Ndabigengesere, A., & Narasiah, K. S. (1998). Quality of water treated by coagulation using *Moringa oleifera* seeds. Wat. Res., 32, 781-791.

Ndabigengesere, A., Narasiah, K. S., & Talbot, B. G. (1995). Active agents and mechanism of coagulation of turbid waters using *Moringa oleifera*. War. Res., 29, 703-710.

Okuda, T., Baes, A. U., Nishijima, W., & Okada, M. (1999). Improvement of Extraction Method of Coagulation Active Components from *Moringa Oleifera* Seed. Wat. Res., 33(15), 3373-3378.

Okuda, T., Baes, A. U., Nishijima, W., & Okada, M. (2001a). Isolation and Characterization of Coagulant Extracted from *Moringa Oleifera* Seed by Salt Solution. Wat. Res., 35(2), 405-410.

Okuda, T., Baes, A. U., Nishijima, W., & Okada, M. (2001b). Coagulation Mechanism of Salt Solution-Extracted Active Component in *Moringa Oleifera* Seeds. Wat. Res., 35(3), 830-834.

Pritchard, M., Craven, T., Mkandawire, T., Edmondson, A. S., & O'Neill, J. G. (2010a). A study of the parameters affecting the effectiveness of *Moringa oleifera* in drinking water purification. Physics and Chemistry of the Earth, Parts A/B/C, 35(13-14), 791–797.

Pritchard, M., Craven, T., Mkandawire, T., Edmondson, A. S., & O'Neill, J. G. (2010b). A comparison between *Moringa oleifera* and chemical coagulants in the purification of drinking water – An alternative sustainable solution for developing countries. Physics and Chemistry of the Earth, Parts A/B/C, 35(13-14), 798–805.

Pritchard, M., Mkandawire, T., Edmondson, A., O'Neill, J. G., & Kululanga, G. (2009). Potential of using plant extracts for purification of shallow well water in Malawi. Physics and Chemistry of the Earth, Parts A/B/C, 34(13-16), 799–805.

Sánchez-Martín, J., Beltrán-Heredia, J., & Peres, J. A. (2012). Improvement of the Flocculation Process in Water Treatment by Using *Moringa oleifera* Seeds Extract. Brazilian Journal of Chemical Engineering, 29(03), 495 - 501.

Sánchez-Martín, J., Ghebremichael, K., & Beltrán-Heredia, J. (2010). Comparison of single-step and two-step purified coagulants from *Moringa oleifera* seed for turbidity and DOC removal. Bioresource Technology, 101(15), 6259–6261.

Sengupta, M. E., Keraita, B., Olsena, A., Boateng, O. K., Thamsborg, S. M., Pálsdóttir, G. R., et al. (2012). Use of *Moringa oleifera* seed extracts to reduce helminth egg numbers and turbidity in irrigation water. Water Research, 46(11), 3646–3656.

Sharma, P., Kumari, P., Srivastava, M. M., & Srivastava, S. (2006). Removal of cadmium from aqueous system by shelled *Moringa oleifera* Lam. seed powder. Bioresource Technology, 97(2), 299–305.

Thailand Industrial Standard (TIS). (1999). TIS. 225-2542 Standard for Hypochlorite.

USEPA (Office of Water). (2004). Drinking Water Treatment. U.S. Environmental Protection Agency.

USEPA (Office of Water). (2006). Voluntary Estuary Monitoring Manual, Chapter 15: Turbidity and Total Solids (2nd ed.). Washington, DC: U.S. Environmental Protection Agency.

World Health Organization (WHO). (2011). Guidelines for drinking-water quality (4th ed.).

Yin, C.-Y. (2010). Emerging usage of plant-based coagulants for water and wastewater treatment. Process Biochemistry, 45(9), 1437–1444.

Zhang, J., Zhang, F., Luo, Y., & Yang, H. (2006). A preliminary study on cactus as coagulant in water treatment. Process Biochemistry, 41(3), 730–733.

APPENDIX

Results of jar test operation

Table A.1 Quality of water treated by *M. oleifera* extractions in three solvents including distilled water, 0.5 M NaCl, and 0.5 M NaOH

Parameter	**Raw Water**		**Dosage of *M. oleifera* (mg/L)**									
			0		**30**		**60**		**80**		**100**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
Distilled Water Turbidity (NTU)	46.5	0.5	30.1	0.3	8.2	0.2	4.5	0.2	3.5	0.2	3.5	0.1
Conductivity (μS/cm)	403	2	402	2	400	2	402	2	401	3	403	3
pH	7.63	0.03	7.65	0.03	7.72	0.03	7.68	0.03	7.70	0.04	7.70	0.03
Alkalinity (mg/L)	101	1	100	2	102	2	101	2	102	1	102	2
0.5 M NaCl Turbidity (NTU)	46.5	0.5	30.1	0.3	4.2	0.2	5.4	0.3	5.4	0.2	5.4	0.2
Conductivity (μS/cm)	403	2	402	2	430	3	462	3	485	3	506	3
pH	7.63	0.03	7.65	0.03	7.64	0.03	7.60	0.04	7.62	0.03	7.64	0.02
Alkalinity (mg/L)	101	1	100	2	102	2	101	1	102	2	103	2
0.5 M NaOH Turbidity (NTU)	46.5	0.5	30.1	0.3	13.8	0.3	9.6	0.2	8.8	0.2	7.2	0.2
Conductivity (μS/cm)	403	2	402	2	413	3	427	2	436	3	445	3
pH	7.63	0.03	7.65	0.03	8.22	0.04	8.66	0.05	8.93	0.04	9.14	0.05
Alkalinity (mg/L)	101	1	100	2	113	2	120	2	130	2	135	2

Note: These results were averaged from three repetitions

Table A.2 Turbidity of water treated by *M. oleifera* extractions with various slow mixing speed, sedimentation time, and *M. oleifera* dosage (for medium turbidity raw water)

	Turbidity (NTU)													
Slow Mixing Speed (rpm)	**Raw Water**		**Dosage of *M. oleifera* (mg/L)**											
			0		**50**		**60**		**70**		**80**		**90**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
Slow mixing speed of 20 rpm														
Sed time 5 min	46.3	0.4	37.4	0.3	25.9	0.3	25.1	0.3	23.5	0.3	21.2	0.1	19.0	0.1
Sed time 15 min	46.3	0.4	35.3	0.2	20.0	0.1	17.3	0.2	17.1	0.1	15.4	0.1	13.0	0.2
Sed time 25 min	46.3	0.4	33.8	0.2	15.7	0.1	14.3	0.1	13.0	0.1	12.4	0.1	10.8	0.1
Sed time 35 min	46.3	0.4	32.3	0.3	13.4	0.2	12.4	0.1	11.6	0.1	10.9	0.2	9.6	0.1
Sed time 45 min	46.3	0.4	31.3	0.3	11.9	0.1	10.9	0.2	10.2	0.1	10.0	0.1	9.0	0.1
Sed time 55 min	46.3	0.4	29.5	0.2	10.9	0.1	9.9	0.1	9.6	0.1	9.4	0.1	8.4	0.1
Slow mixing speed of 50 rpm														
Sed time 5 min	46.3	0.4	38.1	0.2	26.6	0.4	22.6	0.4	19.4	0.2	17.9	0.4	16.3	0.3
Sed time 15 min	46.3	0.4	36.2	0.4	11.0	0.2	9.6	0.1	8.4	0.1	7.7	0.1	6.9	0.1
Sed time 25 min	46.3	0.4	35.7	0.2	7.0	0.1	5.9	0.1	5.2	0.1	5.1	0.1	4.0	0.1
Sed time 35 min	46.3	0.4	30.8	0.3	5.4	0.1	4.4	0.1	4.1	0.1	3.9	0.1	3.1	0.1
Sed time 45 min	46.3	0.4	31.2	0.2	4.5	0.1	4.0	0.1	3.7	0.1	3.6	0.1	2.9	0.1
Sed time 55 min	46.3	0.4	29.6	0.2	4.1	0.1	3.6	0.1	3.2	0.1	3.0	0.1	2.6	0.1
Slow mixing speed of 80 rpm														
Sed time 5 min	46.3	0.4	38.4	0.5	33.8	0.4	32.3	0.3	31.8	0.2	29.0	0.2	27.7	0.3
Sed time 15 min	46.3	0.4	37.7	0.2	16.6	0.2	15.9	0.2	13.2	0.1	12.6	0.1	12.1	0.2
Sed time 25 min	46.3	0.4	34.2	0.2	9.2	0.1	8.2	0.1	6.8	0.1	6.7	0.1	6.5	0.1
Sed time 35 min	46.3	0.4	32.4	0.3	6.4	0.1	5.0	0.1	4.5	0.1	4.2	0.1	4.1	0.1
Sed time 45 min	46.3	0.4	31.0	0.5	5.7	0.1	5.2	0.1	4.4	0.1	4.1	0.1	4.0	0.1
Sed time 55 min	46.3	0.4	30.0	0.3	4.9	0.1	3.9	0.1	3.7	0.1	3.6	0.1	3.3	0.1

Note: These results were averaged from three repetitions

Table A.3 **Turbidity reduction in water treated by *M. oleifera* extraction with various slow mixing speed, sedimentation time, and dosage of *M. oleifera* (for low turbidity raw water)**

	Turbidity (NTU)													
Slow Mixing Speed (rpm)	**Raw Water**		**Dosage of *M. oleifera* (mg/L)**											
			0		**20**		**40**		**60**		**80**		**100**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
Slow mixing speed of 20 rpm														
Sed time 5 min	27.1	0.4	22.5	0.2	22.9	0.3	23.8	0.3	24.4	0.3	24.6	0.2	22.1	0.2
Sed time 15 min	27.1	0.4	21.6	0.2	21.9	0.2	21.7	0.1	20.8	0.1	17.6	0.1	14.0	0.1
Sed time 25 min	27.1	0.4	21.4	0.1	21.5	0.1	20.8	0.2	18.1	0.2	14.2	0.1	11.0	0.1
Sed time 35 min	27.1	0.4	20.7	0.2	20.5	0.1	19.3	0.3	15.5	0.1	11.9	0.1	9.3	0.1
Sed time 45 min	27.1	0.4	20.2	0.1	19.6	0.2	17.3	0.1	13.7	0.1	10.6	0.1	8.4	0.1
Sed time 55 min	27.1	0.4	19.6	0.2	18.8	0.1	15.8	0.1	12.3	0.1	9.5	0.1	8.1	0.1
Slow mixing speed of 50 rpm														
Sed time 5 min	27.1	0.4	22.9	0.2	22.9	0.2	22.0	0.1	22.7	0.3	22.3	0.1	21.2	0.1
Sed time 15 min	27.1	0.4	22.4	0.1	19.8	0.2	16.1	0.2	13.9	0.1	10.2	0.1	9.3	0.1
Sed time 25 min	27.1	0.4	22.2	0.1	18.6	0.3	12.3	0.1	9.8	0.1	6.7	0.1	6.0	0.1
Sed time 35 min	27.1	0.4	21.3	0.1	16.9	0.1	10.1	0.1	7.6	0.1	5.1	0.1	4.9	0.1
Sed time 45 min	27.1	0.4	20.8	0.2	15.6	0.1	8.7	0.1	6.1	0.1	3.9	0.1	3.8	0.1
Sed time 55 min	27.1	0.4	20.2	0.1	14.3	0.2	7.6	0.1	5.5	0.1	3.7	0.1	3.7	0.1
Slow mixing speed of 80 rpm														
Sed time 5 min	27.1	0.4	22.5	0.3	21.8	0.1	23.1	0.1	23.3	0.1	23.4	0.1	25.7	0.1
Sed time 15 min	27.1	0.4	21.2	0.2	16.5	0.1	16.1	0.2	14.9	0.1	14.3	0.1	14.1	0.1
Sed time 25 min	27.1	0.4	21.1	0.2	14.1	0.1	12.4	0.1	11.1	0.1	9.7	0.1	9.8	0.1
Sed time 35 min	27.1	0.4	20.7	0.1	11.8	0.1	9.7	0.1	8.2	0.1	7.0	0.1	6.8	0.1
Sed time 45 min	27.1	0.4	20.1	0.1	10.1	0.1	7.5	0.1	6.0	0.1	5.0	0.1	4.5	0.1
Sed time 55 min	27.1	0.4	19.8	0.2	8.8	0.1	6.2	0.1	5.5	0.1	4.5	0.1	4.5	0.1

Note: These results were averaged from three repetitions

Table A.4 Turbidity reduction in water treated by alum with various slow mixing speed, sedimentation time, and dosage of alum (for low turbidity raw water)

	Turbidity (NTU)													
Slow Mixing Speed (rpm)	**Raw Water**		**Dosage of Alum (mg/L)**											
			0		**10**		**20**		**30**		**40**		**50**	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Slow mixing speed of 20 rpm														
Sed time 5 min	26.7	0.3	22.5	0.3	15.6	0.4	7.9	0.1	4.5	0.1	3.8	0.1	3.2	0.1
Sed time 15 min	26.7	0.3	21.6	0.1	14.2	0.1	4.8	0.1	2.7	0.1	1.4	0.1	1.0	0.1
Sed time 25 min	26.7	0.3	21.2	0.1	13.2	0.1	4.2	0.1	2.5	0.1	1.3	0.1	0.9	0.1
Sed time 35 min	26.7	0.3	20.5	0.1	11.9	0.1	3.7	0.1	2.3	0.1	1.3	0.1	0.8	0.1
Sed time 45 min	26.7	0.3	20.1	0.1	10.6	0.1	3.5	0.1	2.3	0.1	1.3	0.1	0.8	0.1
Sed time 55 min	26.7	0.3	19.7	0.2	10.1	0.1	3.3	0.1	2.2	0.1	1.3	0.1	0.8	0.1
Slow mixing speed of 50 rpm														
Sed time 5 min	26.7	0.3	23.4	0.4	10.7	0.1	4.3	0.1	3.5	0.1	3.1	0.2	2.8	0.1
Sed time 15 min	26.7	0.3	22.5	0.1	7.2	0.1	2.0	0.1	1.1	0.1	0.7	0.1	0.6	0.1
Sed time 25 min	26.7	0.3	22.2	0.1	6.4	0.1	1.6	0.1	0.8	0.1	0.5	0.1	0.3	0.1
Sed time 35 min	26.7	0.3	21.5	0.1	5.3	0.1	1.4	0.1	0.7	0.1	0.4	0.1	0.3	0.1
Sed time 45 min	26.7	0.3	20.9	0.1	4.8	0.1	1.2	0.1	0.7	0.1	0.4	0.1	0.3	0.1
Sed time 55 min	26.7	0.3	20.2	0.1	4.6	0.1	1.0	0.1	0.7	0.1	0.4	0.1	0.3	0.1
Slow mixing speed of 80 rpm														
Sed time 5 min	26.7	0.3	22.4	0.2	11.8	0.3	6.7	0.1	5.5	0.1	3.7	0.1	3.7	0.1
Sed time 15 min	26.7	0.3	21.3	0.1	5.8	0.1	1.8	0.1	1.5	0.1	1.7	0.1	1.7	0.1
Sed time 25 min	26.7	0.3	21.0	0.1	4.4	0.1	1.0	0.1	0.9	0.1	0.7	0.1	0.7	0.1
Sed time 35 min	26.7	0.3	20.6	0.1	3.6	0.1	0.9	0.1	0.5	0.1	0.5	0.1	0.4	0.1
Sed time 45 min	26.7	0.3	20.1	0.1	3.3	0.1	0.9	0.1	0.5	0.1	0.5	0.1	0.4	0.1
Sed time 55 min	26.7	0.3	19.8	0.1	3.2	0.1	0.9	0.1	0.5	0.1	0.5	0.1	0.4	0.1

Note: These results were averaged from three repetitions

Table A.5 **Turbidity reduction in water treated by alum with various dosage of alum (for medium turbidity raw water)**

	Turbidity (NTU)													
Sedimentation Time (min)	**Raw Water**		**Dosage of Alum (mg/L)**											
			0		**10**		**20**		**30**		**40**		**50**	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
5 min	45.5	0.4	38.1	0.3	16.4	0.1	5.7	0.1	4.0	0.1	3.5	0.1	3.0	0.1
15 min	45.5	0.4	33.0	0.3	11.7	0.1	4.0	0.1	2.8	0.1	2.6	0.1	2.0	0.1
25 min	45.5	0.4	31.1	0.2	9.4	0.1	3.9	0.1	2.2	0.1	2.1	0.1	1.8	0.1
35 min	45.5	0.4	29.9	0.3	7.4	0.1	3.3	0.1	1.9	0.1	1.6	0.1	1.3	0.1
45 min	45.5	0.4	29.1	0.3	6.1	0.1	3.0	0.1	1.3	0.1	1.2	0.1	1.0	0.1
55 min	45.5	0.4	28.5	0.2	5.2	0.1	2.6	0.1	1.1	0.1	1.0	0.1	0.9	0.1

Note: These results were averaged from three repetitions

Table A.6 **Quality of water after being treated by *M. oleifera* extraction with the optimum slow mixing speed (50 rpm) and the sedimentation time (45 minutes) with low turbidity raw water samples**

Dosage of *M. oleifera* (mg/L)	**Parameter**									
	Turbidity (NTU)		**Conductivity (µS/cm)**		**pH**		**Alkalinity (mg/L)**		**UV absorbance at 254 nm**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
Raw Water	27.1	0.4	298	2	7.64	0.03	100	2	0.1010	0.0005
0	20.8	0.2	299	2	7.65	0.02	100	2	0.1012	0.0005
20	15.6	0.1	298	3	7.64	0.03	101	1	0.1018	0.0006
40	8.7	0.1	299	2	7.65	0.04	101	2	0.1025	0.0004
60	6.1	0.1	296	2	7.63	0.03	102	2	0.1043	0.0005
80	3.9	0.1	298	2	7.62	0.02	101	1	0.1068	0.0005
100	3.8	0.1	300	3	7.64	0.03	100	2	0.1095	0.0006

Note: These results were averaged from three repetitions

Table A.7 **Quality of water after being treated by alum with the optimum slow mixing speed (50 rpm) and the sedimentation time (15 minutes) with low turbidity raw water samples**

Dosage of Alum (mg/L)	Parameter									
	Turbidity (NTU)		Conductivity (µS/cm)		pH		Alkalinity (mg/L)		UV absorbance at 254 nm	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Raw Water	26.7	0.3	298	2	7.60	0.03	101	2	0.1010	0.0005
0	22.5	0.1	298	2	7.61	0.03	101	2	0.1015	0.0005
10	7.2	0.1	299	2	7.49	0.04	96	2	0.0891	0.0004
20	2.0	0.1	300	3	7.33	0.03	92	1	0.0818	0.0005
30	1.1	0.1	298	2	7.21	0.02	88	2	0.0604	0.0004
40	0.7	0.1	299	2	7.10	0.03	83	1	0.0536	0.0005
50	0.6	0.1	297	3	7.02	0.02	79	2	0.0468	0.0005

Note: These results were averaged from three repetitions

Table A.8 **Turbidity of water treated with the combination of *M. oleifera* extraction (at fixed dosage of 80 mg/L) and various dosages of alum**

	Turbidity (NTU)													
Sedimentation Time (min)	Raw Water		Dosage of Alum (mg/L)											
			0		5		10		15		20		25	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
5 min	26.3	0.4	23.3	0.2	12.9	0.2	9.7	0.1	6.8	0.1	4.2	0.1	3.9	0.1
15 min	26.3	0.4	12.7	0.1	5.7	0.1	4.3	0.1	2.6	0.1	1.8	0.1	1.3	0.1
25 min	26.3	0.4	8.0	0.1	3.9	0.1	3.5	0.1	2.3	0.1	1.6	0.1	1.1	0.1
35 min	26.3	0.4	6.0	0.1	3.0	0.1	2.5	0.1	1.7	0.1	1.4	0.1	0.9	0.1
45 min	26.3	0.4	3.9	0.1	2.2	0.1	2.0	0.1	1.6	0.1	1.3	0.1	0.9	0.1
55 min	26.3	0.4	3.7	0.1	1.9	0.1	1.7	0.1	1.4	0.1	1.1	0.1	0.8	0.1

Note: These results were averaged from three repetitions

BIOGRAPHY

NAME	Mr. Nuttaphon Phuaprasert
DATE OF BIRTH	20 January 1981
PLACE OF BIRTH	Bangkok, Thailand
INSTITUTIONS ATTENDED	Mahidol University, 1998-2002 Bachelor of Engineering (Computer Engineering) Mahidol University, 2013-2015 Master of Engineering (Environmental and Water Resource Engineering)
HOME ADDRESS	19/66 Soi 4/1, Chaengwattana 41 Road, Khlong Kluea, Pak Kret, Nonthaburi, Thailand, 11120 Tel. 08-6533-1745 E-mail : u4113057@hotmail.com
EMPLOYMENT ADDRESS	Metropolitan Waterworks Authority 400 Prachacheun Road, Tungsonghong, Laksi, Bangkok 10210

PUBLICATION / PRESENTATION

1. **N. Phuaprasert**, R. Jindal and N. Surinkul (2014). "Investigation of *Moringa Oleifera* used as Natural Coagulant in Water Treatment Process". The 1st Environment and Natural Resources International Conference (ENRIC 2014): Global Climate Change and Sustainability Pathways, 6 – 7 November 2014, Bangkok, Thailand.