EFFICACY OF TREATING WASTEWATER FROM WASTEPAPER RECYCLING MILL USING A BLEND OF *Moringa oleifera* Lam AND SYNTHETIC COAGULANTS

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

To my beloved parents, Maj Samuel Ndung'u and Irene Maina and to my beloved grandparents Simon and Jane Maina.

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ABSTRACT

Wastepaper recycling is an imminent industry globally to cater for the growing demand for paper and related paper products. The wastepaper recycling industry is characterized by high concentrations of pollutants and toxic components emanating from defibering, deinking and papermaking processes. Inefficient treatment of the effluent from the mills would negatively impact the receiving water ecosystems and health of their users. This study focused on determining the efficiency of treating wastewater from a wastepaper recycling mill by blending *Moringa oleifera* Lam plant parts with some synthetic coagulants. The *Moringa oleifera* plant parts tested include fatted seed (FMos), defatted seeds (DMos) and bark (BMo), whereas chemical coagulants used were aluminium sulphate (alum) and polyaluminium chloride (PAC). Firstly, effective doses of individual and blended coagulants were established. Thereafter, efficacy of treatment and microbial load reduction of wastewater from wastepaper recycling using the effective doses for both individual and blended coagulants were determined. Samples of wastewater were obtained from Maz International Paper Mill, using grab sampling method. A completely randomized design was applied, to achieve the objectives of the study. A standard jar test procedure was used to determine the effective doses of individual and blended coagulants, whereas standard APHA procedures were employed to determine the efficacy of the treatment and reduction of microbial load from the wastewater. The data obtained was displayed in tables and figures where appropriate and analyzed using descriptive statistics and one-way ANOVA. The study revealed that effective doses were DMos; 32g/L (144.0NTU), FMos; 36g/L (250.2NTU), BMo; 80g/L (881.0NTU), alum; 1.5g/L (24.1NTU), PAC; 6.6g/L (162.2NTU), DMos/Alum; 20/80% (17.1NTU), FMos/Alum; 30/70% (25.2NTU), DMos/PAC; 70/30% (93.6NTU), and FMos/PAC; 70/30% (110.4NTU). However, there was no synergy noted for blending BMo/Alum and BMo/PAC. The various effective doses resulted in the reduction of wastewater pollution parameters wastepaper recycling mill. Among the individual coagulants' alum was most efficient whereas among the blended coagulants DMos/Alum was the most efficient. The blend of DMos and alum effectively treated wastewater from wastepaper recycling mill, by significantly reducing the BOD, color, TDS, EC, and TSS to 28.7 mg/L, 14.4 PCU, 267.8 mg/L, 495.6 µs/cm, and 5.8 mg/L, respectively. These final DMos/Alum treated parameters were within WHO, NEMA, and USEPA permissible drinking water thresholds. Additionally, the DMos/Alum blend resulted in the highest microbial load removal by 99.2%. This study shows, the wastewater from wastepaper recycling mill can be effectively treated using the blend of DMos and alum. Therefore, recommend that a blend of DMos and alum be applied in treating wastewater from wastepaper recycling mills.

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ACRONYMS AND ABBREVIATIONS

Alum	Aluminium Sulphate
ANOVA	Analysis of Variance
AOPs	Advanced Oxidation Processes
APHA	American Public Health Association
BMo	Bark of *Moringa oleifera*
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DMos	Defatted *Moringa oleifera* seed
FMos	Fatted *Moringa oleifera* seed
MIWPM	Maz International Wastepaper recycling Mill
Mo	*Moringa oleifera*
NEMA	National Environment Management Authority
NTU	Nephelometric Turbidity Unit
PAC	Polyaluminium chloride
PBCs	Plant-Based coagulants

TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USEPA	the United States Environmental Protection Agency
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Industrialization worldwide has steadily increased due to the demand for various products culminated by the increased human population (Sharma, 2022). In the recent past, demand for paper and allied products has highly accelerated, consequently requiring more fibres for their manufacture (Liu *et al*., 2020). Virgin pulp alone cannot meet this quest, necessitating the use of secondary fibres sources. Additionally, virgin pulp production is attributed to deforestation, costly and environmentally detrimental (Karthikeyan & Krishnamoorthy, 2021). Globally, sprouting of wastepaper recycling mills has been the trend as a source of secondary fibres to supplement the virgin fibres sources (Caltagirone *et al*., 2021). Recycling wastepaper has been termed as a technique to decrease the environment loading in a sustainable way and has led to the forest resource conservation (Yang *et al*., 2022).

Globally, more than 58% of wastepaper is recovered, however in developed economies over 70% of the total amount of wastepaper is recovered (Ozola, Vesere, Kalnins, & Blumberga, 2019). Recycling of paper is the reutilization of recovered paper after proper processing in form of new paper or other paper based products (Deshwal, Panjagari, & Alam, 2019). Recycling of wastepaper encompasses procurement of wastepaper, sorting, shredding, defibring, deinking, washing of the pulp, paper forming among other processes and operations (Liu *et al*., 2020). Defibring, deinking, washing of the pulp and paper forming are major processes that consume enormous amount of fresh water (50-60 m^3) to produce a ton of paper, subsequently, discharging huge volumes of wastewater which account to more than 40% of global industrial wastewater (Cai, Lei, Li & Chen, 2021).

Deinking is an operation/process for the removal of ink from the wastepaper that results to whitening and brightening of recycled wastepaper, impacts the strength of the recycled papers thus increasing the load in the wastewater generated (Singh, Varghese, Yadav, & Mahajan, 2020). The effluent generated have detrimental impacts on the environment, threatening aquatic ecosystems and human life. Wastewater discharged from wastepaper recycling mills have high levels of colour, turbidity, total suspended solids and chemical oxygen demand (Mosaddeghi, Pajoum, Vaziri, & Nabi, 2020). The organic particulate matter makes the wastewater very turbid, and turbidity removal becomes the major challenge. Suspended materials are usually present in most wastepaper recycling wastewater due to the fibres lost during papermaking (Jagaba *et al*., 2022).

Treatment of wastewater from a wastepaper recycling mill is a crucial activity that adds to total cost of final product (Singh *et al*., 2020). Conventional wastewater processes employed in treatment of wastepaper recycling mill effluent are mainly mechanical and biological treatments. These treatment processes include coagulation, flocculation, adsorption, flotation, activated sludge, trickling filters, membrane filtration, sedimentation, aerobic and anaerobic methods (Crini, Lichtfouse, Wilson, & Morin-Crini, 2019; Zainith, Chowdhary, & Bharagava, 2019). Synthetic coagulants are commonly referred to as inorganic chemical coagulants that are based on metals, such as aluminium and iron. Examples of inorganic coagulants include polyelectrolytes, aluminium sulphate, ferric chloride, ferrous sulphate and calcium hydroxide (Gandiwa *et al*., 2020). Application of synthetic coagulants in treatment of industrial wastewater has been reported to be effective in reduction of physiochemical parameters before discharge into receiving waters (Gautam & Saini, 2020). However, high sludge production Sharma, Purchase, & Chandra, (2021), relatively high cost of these coagulants have attributed to high cost of operations (Tripathi, Purchase, Chandra, Nadda, & Bhargava, 2022). Among the synthetic coagulants, aluminium sulphate has been widely used in treating water/wastewater, even though it has been reported to be neurotoxic if used in large quantities and might be involved in the development of Alzheimer's disease (Salem & AL-Musawi, 2021).

Plant-based coagulants (PBCs) have been reported to be more efficient, and environmentally friendly in comparison to the conventional coagulants, and low cost (El Bouaidi *et al*., 2022). Additionally, plant-based coagulants are emerging to be a substitute in wastewater treatment due to their potential abundance, non-toxic nature, and easily biodegradable in treating industrial wastewater (Desta & Bote, 2021). Plant-based coagulants have been reported to possess effective coagulating properties due to electrolyte bridges that is availed by the polysaccharides and cationic proteins (Mosaddeghi *et al*., 2020; Som Ramlee, Puasa, & Hamid, 2021). Among the widely, reported plant-based coagulants are; *Moringa oleifera* seeds, Cactus *opuntia Ficus indica* pads, okra seeds, nirmali seeds, mango seeds, *Ocimum basilicum*, *Tamarindus indica* among others (Gandiwa *et al*., 2020; Mosaddeghi *et al*., 2020). *Moringa oleifera* is a perennial plant of *Moringaceae* family that originates from India and has been known for its various uses. It has been categorized as plant-based coagulant since its seeds contain positively charged amino acids that are hydrophilic in nature (Bazzo et al., 2022). *Moringa oleifera* seed exhibits its ability to function effectively as a bio-coagulant as its dimetric cationic polypeptides deactivate and adsorb particles in water (Bazzo *et al*., 2022).

Blending of plant based and synthetic coagulants has been tested on water and wastewater treatment (Gandiwa *et al*., 2020). The blending of plant based and synthetic coagulants technique, may result to high efficiencies in water/wastewater treatments, low operational costs compared to chemical coagulants with minimal use of chemical coagulants (Mosaddeghi *et al*., 2020). However, only a few studies have reported on blending the plant coagulants and two synthetic coagulants to obtain high-performance coagulating effect in wastewater of complex characteristics.

1.2 Statement of the Problem

Globally, pulp and paper mills are regarded as intensive freshwater consumers, culminating in the discharge of massive volumes of wastewater into receiving ecosystems. Suboptimal wastewater treatment technologies have contributed to the challenges of meeting the stringent and ever-changing environmental standards for their discharge (Zainith *et al*., 2019). As a result, the wastewater pollutes the receiving ecosystems and affects human health. Wastepaper recycling plants confront similar wastewater treatment difficulties, notwithstanding their significant role for boosting paper product demand while halting deforestation.

Maz International Wastepaper Recycling Mill (MIWPM), located in Kisaju, Kajiado County, is the inaugural wastepaper recycling mill in Kenya. Prior to chemical deinking and bleaching the pulp slurry using sodium hydroxide and hydrogen peroxide, the mill pulps wastepaper. These processes influence the properties of the resulting effluent, which is highly pigmented, turbid, and contains fibers. Furthermore, the MIWPM source of wastepaper raw materials has been correlated to high pathogen contamination.

The mill employs stabilization ponds to partially clean its wastewater before releasing it into the environment. Nonetheless, the discharged wastewater from the ponds contains considerable quantities of contaminants that fail to meet the National Environment Management Authority (NEMA), World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) necessary wastewater discharge limits, which is a source of worry for the MIWPM management. Furthermore, the quality of surface and groundwater sources, which supply water for irrigation, livestock, industrial, and residence purposes, is impacted.

Large-scale utilization of synthetic coagulants including aluminum sulphate and polyaluminium chloride in the purification of pulp and paper mill wastewater have been advancing for decades. Nevertheless, utilizing them has elevated the cost of production and raised human health concerns (Gautam & Saini, 2020). As a result, *Moringa oleifera* has recently been identified as a bio-coagulant capable of replacing synthetic coagulants in wastewater treatment. Despite its efficacy in raw water treatment, *Moringa oleifera* has significant limitations in the successful treatment of various wastewater sources (Desta & Bote, 2021). To address these concerns, *Moringa oleifera* and aluminum sulphate, as well as various synthetic coagulants, have been advocated (Mosaddeghi *et al*., 2020). *Moringa oleifera* has additionally been demonstrated to exhibit antibacterial properties that would suppress pathogens in effluent from a wastepaper recycling mill.

1.3 Justification of the Study

Properly treated wastewater from the wastepaper recycling mill will not affect the quality of the receiving water resources on which the majority of Kisaju residents rely on. Receiving waters are primarily used for irrigation, livestock, domestic, and industrial purposes. The use of synthetic coagulants and *Moringa oleifera* would aid in the reduction of pollutants in wastewater in an environmentally sound way. Besides that, the use of *Moringa oleifera* will facilitate the reduction of pathogens in the wastewater discharged from the wastepaper recycling mill, consequently reducing water-borne diseases resulting from improper treatment.

1.4 Objectives of the Study

1.4.1 The General Objective of the Study

The general objective of the study is to investigate the efficiency of blending *Moringa oleifera* plant parts with polyaluminium chloride and aluminium sulphate in treatment of wastewater from wastepaper recycling mill.

1.4.2 Specific Objectives of the Study

1. To determine the effective doses of DMos, FMos, BMo, Alum and PAC coagulants in treating wastewater from MIWPRM.

2. To determine effective doses of blending DMos/Alum, FMos/Alum, BMo/Alum, DMos/PAC, FMos/PAC and BMo/PAC coagulants in treating wastewater from MIWPRM.

3. To determine the efficacy of the effective doses of individual and blended coagulants in the treatment of wastewater from MIWPRM.

4. To determine the efficacy of the effective doses of individual and blended coagulants in reduction of microbial load from wastewater from MIWPRM.

1.5 Hypotheses of the Study

Objective one

H_{01}: There were no significant differences among the individual coagulants' effective doses in turbidity reduction of wastewater from MIWPRM.

Objective Two

H_{01}: There were no significant differences among the blended coagulants effective doses in turbidity reduction of the wastewater from MIWPRM.

Objective Three

H_{01}: There were no significant differences in efficacy treatment of wastewater from MIWPRM using effective doses of individual and blended coagulants.

Objective Four

H_{01}: There were no significant differences in microbial load reduction efficiencies among individual and blended coagulants.

1.6 Scope of the Study

The research study aims at establishing optimum doses of *Moringa oleifera* defatted seed powder, fatted seed powder and bark powder as well as aluminium sulphate and polyaluminium chloride in coagulation and flocculation of the recycled wastepaper mill wastewater through turbidity removal within a pH range of 6.5 to 8.0 as well as room temperature. Moreover, the study focuses on determining the optimum doses of the plant-based and synthetic coagulants blend. The efficacy treatment of the wastewater from recycled wastepaper mill is established by determining turbidity, color, COD, BOD, TDS and TSS, removal efficiencies from the best synergy established by the blend dosage.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background on Wastepaper Recycling Mills

Human settlement and socioeconomic activities have been associated with the generation of different forms of waste, particularly in urban areas. Municipal Solid Waste (MSW) comprises of paper waste, food waste, plastic waste, metal and glass wastes that are mostly dependent on the population, income, and industrial activities of a given community (Nanda & Berruti, 2021). It is estimated that by 2050 about 3539 metric tons of MSW will be generated compared to 635 metric tons in 1965 globally with a significant increase in wastepaper (Chen, Bodirsky, Krueger, Mishra, & Popp, 2020). Wastepaper is generated mainly in offices, institutions, market places, and households. Universally about 400million tons of wastepaper are generated every year, where USA and Asia are among the leading generators of wastepaper (Ezeudu, Agunwamba, Ezeasor, & Madu, 2019). To reduce the environmental menace associated with wastepaper such as surface and groundwater pollution, and air pollution from wastepaper burning, several options of wastepaper management such as recycling, production of bioethanol and mixing in concrete have emerged (Annamalai *et al.*, 2020; Aponte *et al*., 2021).

Wastepaper recycling technique is one of the effective technologies being applied in solid waste management to produce secondary fibres and subsequently in paper production (Li *et al*., 2020). Virgin pulp alone has been reported not to meet the quest for paper products despite deforestation, high cost of production as well as environmental detrimental effects associated with virgin pulping (Karthikeyan &

Krishnamoorthy, 2021). Recycling of wastepaper into paper and paper products have been reported to be a significant aspect in reduction of solid waste from the environment (Cioffi *et al*., 2022). Moreover, wastepaper recycling has been a trend in production of secondary fibers to supplement virgin fibers use (Abd El-Sayed, El-Sakhawy, & El-Sakhawy, 2020; Caltagirone *et al*., 2021). Wastepaper recycling mills alike other industries worldwide have steadily increased due to the demand for paper and paper products culminated by the increased human population (Sharma, 2022). Moreover, recycling of wastepaper has been reported to accelerate gradually in most urban areas globally thus, consistent growth of wastepaper recycling and producing plants (Yang *et al*., 2020).

Globally, annual wastepaper recovery has been reported to be more than 58%, with developed economies recovering more than 70% of the wastepaper (de Oliveira *et al*., 2023). Thus, utilization of secondary fibers, recycled wastepaper plays a significant role in environment conservation. Importance of recycling wastepaper for paper production include: enhanced alleviation of forest degradation by reducing utilization of natural fibers, reduced cost of production, creation of fundamental socioeconomic benefits, reduction in energy consumption during paper processing as well as ecological balance through reduced emissions and air pollution (Kumar & Dutt, 2021).

2.2 Wastepaper Recycling Mills Processes

Wastepaper recycling encompasses various processes that lead to paper production. These processes entail long chain of multiple operations that facilitate turning waste papers into reusable paper products (Shang, Diao, Liu & Yu, 2021). Recycled wastepaper can be processed to useful products such as; tissues and toilet papers, napkins and towel papers, greeting cards, office paper, newspapers and magazines and cardboards. Classical processes in wastepaper recycling include; collection and transportation, sorting, pulping, screening, deinking, bleaching, and rolling (Zainith *et al*., 2019).

2.2.1 Collection and transportation

This is the initial step in wastepaper recycling process and it is crucial in determining the quality of the paper to be recycled. Wastepaper collected include; white office papers, magazines, old newspapers, printed advertisement papers, colored office paper, cardboard, white computer paper, catalogs, and phone books (Kumar, Pathak, & Bhardwaj, 2020). Commingled collection systems of wastepaper reduce the quality of the paper generated after recycling (Defalque, Marins, da Silva, & Rodríguez, 2021). Although, separate collection systems have been reported to increase the quality and resource efficiency of the wastepaper collected (Tallentire & Steubing, 2020). The collected wastepaper are then transported to the paper mills.

2.2.2 Sorting

The sorting operation involves separation and debaling of various wastepaper collected. The process is crucial as it helps in identification of the papers to be recycled and those to be discarded (Pluskal, Šomplák, Nevrlý, Smejkalová, & Pavlas, 2021). The structure and surface treatment of the wastepaper are the main segregation indicators used during sorting process hence, sorting helps in grading of the wastepaper to produce different paper products (Rezaee et al., 2022).

2.2.3 Pulping

Sorted wastepaper is cut into small bits though paper material shredding. Shredding helps in easy conversion of the paper material into pulps (Fyvie, 2018). Pulping process involves subjecting the shredded paper to enormous volumes of water and some chemicals through heating to form slurry (Tsatsis, Valta, Vlyssides, & Economides, 2019; Zainith *et al*., 2019). Repulping includes defibering which dissociates the fibers without damaging them although it decreases their strength. Pulping chemicals include caustic soda, sodium hydroxide, and sodium hypochlorite (Singh *et al*., 2020).

2.2.4 Screening

Screening operation involves passing the pulp through filters, screens and holes with spaces of different sizes and shape so as to filter out unwanted objects from the slurry. The process is repeated several times to remove contaminants such as bits of plastic and globs of glue from the fibers (Barnard, 2021).

2.2.5 Deinking

Deinking production process results to whitening and brightening of the secondary fibers (Dixit *et al*., 2022). Deinking technology involves two main steps in the process of removing ink from the fibers (Tsatsis *et al*., 2019). The first step involves detaching of ink from the surface of the disintegrated fibers and the second stage is removal of ink particles from the pulp slurry through screening, washing, centrifugal or flotation separation (Tsatsis *et al*., 2019; Dixit *et al*., 2022).

Air flotation deinking is the commonly applied method and it involves addition of surfactants or chemicals and subsequent introduction of air into the slurry. The recovered pulp hydrophobic components are floated by the air bubbles and are taken off as foam that rises up from the surface (Tsatsis, Papachristos, Valta, Vlyssides, & Economides, 2017; Tsatsis *et al*., 2019). Commonly used deinking chemicals include; sodium hydroxide, sodium carbonate, hydrogen peroxide, EDTA, magnesium sulphate and sodium silicate (Kumar *et al*., 2020; Singh *et al*., 2020). However, these chemicals have been reported to negatively affect aquatic and terrestrial ecosystem incase the wastewater is discharged into the environment without proper treatment. Thus, enzymatic and other environmentally friendly deinking have been reported as a substitute to curb these effects and enhance deinking process (Sango, Pathak, Bhardwaj, Dalal, & Sharma, 2021).

2.2.6 Bleaching

Bleaching process involves addition of bleaching agents to the already deink fibers so as to produce white paper (Tofani, Cornet, & Tavernier, 2022). The bleaching agents applied enhance purity, brightness and whiteness of the paper. However, this process applies only when white paper making is desired (Manandhar, Shrestha, Sciortino, Ariga, & Shrestha, 2022). Frequently used chemicals during pulp bleaching processes include chlorine dioxide, sodium hydroxide and hydrogen peroxide. Some of these chemicals have been found to be a source of environmental concern and other alternatives to traditional bleaching of secondary or virgin fibers are emerging (Gupta, Kapoor, & Shukla, 2020; Tofani *et al*., 2022).

2.2.7 Paper Forming

This typically involves a paper forming machine of about 10-25 ft wide and as long as the mill can determine. The machine has two main components; wet end and dry end. The wet end has large mesh screen on which the pulp mixture and water are spread (Sharma *et al*., 2020). The gravity suction and mechanized vibration of the screen removes about 20% of the water, much of which is reused at the mill. Also, at the wet end is the press section to remove more water using wet felts. At the dry end, the thin, smooth sheet is dried to 2-6% moisture content using steam heated driers (Balea *et al*., 2020). Plate 1 shows the paper forming machined used by MIWPRM.

Plate 1: Paper forming machine for MIWPRM

2.2.8 Paper Winding

The paper is wound on a large reel caller winder. The reel of the paper is then transferred to the slitting section where the paper is cut into manageable sized rolls (Spina & Cavalcante, 2018).

2.3 Characteristics of Wastewater from Wastepaper Recycling Mills

The characteristic of wastewater from wastepaper recycling mills can have serious impacts on aquatic, biodiversity and nearby environment including public health especially when the wastewater is not treated according to standard environmental regulatory criteria. This type of wastewater usually contains impurities, toxic substances, and are heavily loaded with organic materials (Gupta & Gupta, 2019). Wastewater from wastepaper recycling mills often contain high concentrations of BOD, pH, COD, TDS, EC, TSS, AOX (adsorbable organic halides), phenolic compounds, heavy metals, plant materials. These pollutants, when discharge improperly from the industries, pose threats to aquatic and terrestrial lives (Haq & Raj, 2020).

High BOD, COD and heavy metals in wastewater from wastepaper recycling mills have detrimental effects to aquatic and terrestrial lives. The high levels of BOD, TDS, TSS, and COD, deplete the oxygen levels for aquatic life and microbial organism in soils. This attributes to high eutrophication and subsequently depreciate aquatic life. In terrestrial ecosystems, these parameters can negatively impact on plants and microbes in soils by potentially increasing toxic metals such mercury and cadmium in their biomass (Bui et al., 2022).

Wastewater from some wastepaper recycling mills, have been reported to contain genotoxic and cytotoxic materials. The materials have been reported to cause chromosomal aberration in plants through bioaccumulation of heavy metals from improperly treated wastewater from wastepaper recycling mills (Li & Achal, 2020). The genetic disrupters have also been reported to emanate from wastewater from wastepaper recycling mills (Sharma, Tripathi, Vadakedath & Chandra, 2021). Additionally, toxicity effects that are reported to emanate from high concentrations of heavy metals, phenolic compounds and organic halides in the wastewater from wastepaper recycling mills include; mutagenicity, genotoxic, carcinogenic and teratogenic (Khan *et al*., 2021).

Wastewater from some wastepaper recycling mills have also been reported to cause endocrine disruption in aquatic flora and fauna. They affect the reproductive organs, reduce the number of sex hormones, change secondary sexual characteristics in several organisms including fish as results of the organic and organometallic pollutants, such as phenolic compounds, furan in wastewater effluents when exposed for a long period of time (Sharma, Tripathi, Vadakedath, & Chandra, 2021). Reported effects of these contaminants in mammals included toxicity of male reproductive organs, stress and tissue damages (Khan *et al*., 2021). Infiltration of untreated wastewater from wastepaper recycling mills into ground water interferes with the potability of the water for human consumption. Consumption of this contaminated water has been reported to cause ulceration of internal organs linings, severe diarrhoea or even death (Hussain *et al*., 2021).

2.4 Treatment Technologies of Wastewater from Wastepaper Recycling Mills

Treatment of wastewater from mills is challenging, costly and complex due to high concentrations of organic loads; BOD and COD, solid contents, presence of toxic compounds, high turbidity, color, high pH (Gholipour, Zahabi, & Stefanakis, 2020). Wastewater treatment methods can be classified as physical, chemical, biological or combined methods. Although these treatment methods application differ based on the nature of wastewater generated (Ganiyu, Martinez-Huitle & Oturan, 2021). Other technologies utilized in removal of pollutants from wastewater from wastepaper recycling mills include; conventional methods like coagulation and flocculation, recovery methods like membrane filtration as well as removal methods like nanofiltration (Crini & Lichtfouse, 2019). Moreover, these methods are also categorized as pretreatment, primary treatment, secondary treatment and tertiary treatment methods (Sylwan & Thorin, 2021).

Physical treatment processes are utilized in removal of large particulate matters especially loose fibers that are easily eliminated from the wastewater (Puljko *et al*., 2022). While the removal of microorganisms and other organic matter is reported to be achieved through biological processes, chemical processes are termed efficient in removal of heavy metals, inorganic compounds and other toxic elements from wastepaper recycling mills wastewater (Sylwan & Thorin, 2021). However, depending on the type of raw materials, the grade of paper products, design of the treatment plant as well as toxicity of the wastewater (Han, Zhang, Hoang, Gray, & Xie, 2021).

2.4.1 Primary Wastewater Treatment Methods

Physical treatment methods are also referred to as primary treatment methods. They are designed for the pretreatment of the wastewater by removing suspended solids and hardness (Han *et al*., 2021; Zhang, Chen, & Li, 2020). Frequently applied methods include sedimentation/clarification/settling as well as flotation. This is achieved in an equalization basin through regulation of temperature and pH (Kumar *et al*., 2022).

2.4.1.1 Sedimentation

Sedimentation involves lowering the velocity of water below that of the suspension hence facilitating the settling out of suspended particles through gravity in form of sludge (Han *et al*., 2021). The efficiency of this process is factor to sedimentation tank design, condition of the equipment, detention time and temperature. Sedimentation process have been reported to remove 93% of total suspended solids from storm water and 80% from paper mill wastewater (Privette & Sawyer, 2023; Haq & Raj, 2020).

2.4.1.2 Flotation

Flotation process in recycled waste paper wastewater treatment is applied to recover the fine fibers from the screened section. The technique involves dispersed-air or dissolved air flotation methods. Dispersed-air flotation encompasses use of diffusers or revolving impeller to directly introduce the air into the liquid, causing turbulence which breaks up fragile particles. Dissolved-air flotation is the most applied technique in paper industry (Wang & Wang, 2022; Han *et al*., 2021). It entails intimately bringing air into contact with the wastewater at a pressure of several atmospheres when air is dissolved, this leads to lowering the liquid pressure to atmospheric level through a back-pressure valve hence, releasing micron-sized bubbles (Pirzadeh, 2022). Dissolved-air flotation has been reported to remove 95% of TSS from paper mill wastewater Zainith *et al*, (2019) as well as effective in removal of hydrophobic substances like ink (Han *et al*., 2021). Moreover, pretreatment of wastepaper recycling wastewater using DAF resulted in 98.1% TSS reduction (Ansari, Alavi & Yaseen, 2018).

2.4.2 Secondary Wastewater Treatment Technologies

Secondary treatment technologies are also categorized as biological treatment technologies and are used to remove contaminants through degradation by the microorganisms (Salgot & Folch, 2018; Zhang *et al*., 2020). The treatment utilizes presence of bacteria, algae, nematodes, fungi, protozoa to break down unstable organic matter into stable forms through normal cellular processes. Biological methods mainly utilized in treatment of paper mills include aerobic and anaerobic methods (Shankar, Ratnakar, Singh & Rawat, 2020; Liang *et al*., 2021).

2.4.2.1 Anaerobic biological treatment technologies

Anaerobic processes involve degradation of organic matter and contaminants using microorganisms in absence of oxygen. Wastewater is channelled into a bioreactor repository that contains sludge that is rich in anaerobes and capable to maintain oxygen free environment that supports anaerobic digestion (Shin, Tilmans, Chen, & Criddle, 2021). The anaerobic microorganisms digest biodegradable matter present in the wastewater thus, the resultant effluent has low levels of TSS, BOD and COD. Anaerobic wastewater treatment technologies are applied in pulp and paper, dairy, textile, food and beverage and municipal sewage wastewaters which are characterized by high organic contaminants (Daud *et al*., 2018; Liao *et al*., 2021).

The wastewater undergoes two phases during anaerobic treatment processes. The two phases namely; acidification and methane production, facilitate the breakdown of the contaminates in the wastewater. The acidification phase involves breakdown of organic matter into simpler short chain volatile organic acids while the methane phase entails acetogenesis and methanogenesis. Acetogenesis involves synthesize of the already formed organic acids to acetate, hydrogen gas and carbon dioxide while methanogenesis involves the microorganisms acting upon the newly formed molecules to methane gas and carbon dioxide (Liao *et al*., 2021). Commonly used anaerobic treatment processes include; anaerobic lagoons, anaerobic sludge reactors and anaerobic filter reactors.

Anaerobic lagoons are manmade ponds that allow wastewater to be piped into bottom of the lagoon where it settles out and forms the upper layer and the sludge layer settles at bottom (Harris & McCabe, 2020). The liquid layer prevents oxygen from reaching the sludge layer allowing anaerobic digestion of the organic materials in the wastewater at favourable warm temperatures and neutral pH hence reducing levels of COD (Musa & Idrus, 2021). The detention time varies from few weeks to six months at these optimal conditions. However, concentrations of elements like calcium, magnesium, potassium, sodium, fluctuations in BOD and COD limit the respiration activities (Hoffmann *et al*., 2020).

Anaerobic filter reactors utilize reactor tanks that are fitted with a number of filter substrates. The filter media develop to form well established biofilm (Gupta & Singh, 2019). The media is filled with anaerobic microorganisms which require months to fully establish themselves to the treatment capacity. Amongst the filter media materials are pumice, bricks, plastic films and gravel (Musa & Idrus, 2021). Wastewater is routed through filter media, which absorb materials from the wastewater and give an abundant surface area for biofilm to interact with organic matter. Backwashing and cleaning regularly aid in optimal performance by preventing clogging of the filter media with excess biofilm and particulate build up. The biological treatment of wastewater from a recycled paper mill resulted in efficient COD and TSS reduction (Han, Lei, Cai & Li, 2020). In addition, utilization of anaerobic filter reactors reduced COD by 80.76% and TS by 90% while treating recycled paper mill wastewater (Bakraoui *et al*., 2020).

Anaerobic sludge blanket reactors involve wastewater passing through free-floating blanket of suspended sludge particles (Ravichandran & Balaji, 2020). The anaerobes in the sludge digest the organic constituents in the wastewater where they multiply and collect in larger granules that settle at the bottom of the reactor tank. pH, uplow velocity, hydraulic residence duration and inert media are among the key controlling factors in anaerobic sludge blankets (Patel Bina, Pradipkumar & Drashti, 2021). The treated effluent flows upward and out of the unit. Anaerobic sludge blanket reactors are of different forms which include; anaerobic baffled reactors, uplow anaerobic sludge blankets and expanded granular sludge beds (Patel *et al*., 2021). For the treatment of paper mill effluent, the use of anaerobic sludge blanket resulted to 92.19% and 94.66% COD and TSS removal efficiencies (Ravichandran & Balaji, 2020).

2.4.2.2 Aerobic Biological Treatment Technologies

Aerobic wastewater treatment involve degradation of organic contaminants using microorganisms in present of oxygen (Hamza, Rabii, Ezzahraoui, Morgan & Iorhemen, 2022). Aerobic treatment processes include; trickling filters, membrane bioreactors, biofilm reactors and activated sludge. Activated sludge process utilizes high concentrations of microorganisms in a multi-chamber reactor that degrade organic matter and enhance removal of these compounds from the wastewater (Alvim, Bes-Piá, & Mendoza-Roca, 2020). High concentrations of microorganisms that include; bacteria, fungi, algae, metazoans, viruses and protozoa, which ensure the speed up of decomposition rate (Liang *et al*., 2021). Wastewater is channeled the suspended into the aeration tank that have suspended aerobes which decompose the organic matter thus forming biological solids which agglomerate to form large flocs (Liang *et al*., 2021).

Mechanical reactor allows air to be pumped into the chamber and this facilitates microbial growth thus high decomposition rate. The sludge is then separated into a settling tank through sedimentation (Jagaba *et al*., 2021). Activated sludge process is associated large space requirement and disposal of large amount of sludge that increase disposal cost (Alvim *et al*., 2020). In treatment of paper mill effluent, the use of activated sludge process achieved 98.7% to 99.3% removal of COD fractionation (Mustonen, 2022). Additionally, the use of activated sludge process in paper mill wastewater was reported to effectively lower BOD, COD and SS levels (Haq & Raj, 2020).

Biofilm reactors aerobic technology have often been utilized in wastewater treatment to remove nutrients and organic debris. The most applied biofilm reactors are moving bed biofilm reactors (MBBRs), membrane bioreactors (MBRs) and fixed bed biofilm reactors (FBBRs) technologies (Patel *et al*., 2021; Matheus *et al*., 2021). MBBRs are multi-chambered tanks with porous foam, plastic, and/or ceramic media packed tightly into the chambers. As the wastewater flows through the immobilized bed of media, biofilm carriers, primarily plastic media, are suspended throughout the bioreactor by aeration or mechanical mixing (Madan, Sangeeta, Richa & Athar, 2022). The media is engineered to have a high enough surface area to encourage a robust biofilm formation with long solids lifespan, resulting in low sludge formation and lowest sludge disposal costs (Bhattacharya & Mazumder, 2020). A well-engineered fixed-bed biofilm reactor allows wastewater to flow through the system without channelling or plugging. Chambers can be aerobic and still have anoxic zones to achieve aerobic carbonaceous removal and full anoxic denitrification at the same time (Wang *et al*., 2021). Moreover, sulphide reduction, denitrification, anammox, nitrification and desalination biological processes can be achieved using biofilm reactors due to their unique bacterial populations that colonize the biofilm media (Wu *et al*., 2022). Biofilm reactors are reported to be effective techniques in pulp and paper mills effluent treatment reducing impacts on the environment (Bui *et al*., 2022).

Membrane bioreactors technology encompasses suspended growth activated sludge with vacuum or pressure driven systems of microfiltration or ultrafiltration membranes to separate and recycle the suspended solids (Ejraei, Aroon, & Saravani, 2019). Membrane bioreactors operate with higher mixed liquor suspended solids and longer solids residence time hence reduced footprint of 30-50% in comparison to conventional activated sludge. Aerobic treatment tanks, membrane tanks, hollow or flat sheet ultrafiltration membranes and clean-in-place systems enable for effective solids reduction, eliminating the need for secondary sedimentation (Nur *et al*., 2018). Membrane bioreactors eucalyptus pulp and paper mill wastewater treatment resulted to effective COD and TSS reduction (Poojamnong *et al*., 2020).

Trickling filters comprises of a bed of high surface area filter media of high porosity where wastewater is sprayed into (Rezai & Allahkarami, 2021). The bed surface material is composed of crushed rocks, gravel, plastic or shredded PVC bottles that allow massive organisms growth to form a biofilm. The biofilm layer is made off ecological diversity life forms that include; eukaryotes, nematodes, annelid worms, insect larvae, prokaryotes, rotifers and even snail (Paixão Filho *et al*., 2023). The growth of microorganisms enhances the thickening of the biofilm layer thus increasing oxygen uptake within the biofilm. As the wastewater trickles into the media, it gets into contact with the filmy layers of the microorganisms (Arsalan *et al*., 2021). The aerobes or anaerobes adsorb organic matter in the wastewater and respire to produce water and carbon dioxide as well as nitrification process. Trickling filters reported to have efficiently reduce BOD_5, COD and turbidity at percentage reduction of 78%, 92% and 94% respectively from petroleum effluent treatment (Okan *et al*., 2022). Moreover, use of trickling filters in paper mill wastewater treatment achieved a removal efficiency of up to 85% of organic load from the wastewater (Rezai & Allahkarami, 2021).

2.4.3 Tertiary Wastewater Treatment Methods

Secondary treatment methods in wastewater treatment are reported to only eliminate a certain percentage of BOD, COD and TSS from the treated wastewater as well as residual concentration of polychlorinated biphenyls which affect the quality of the treated wastewater (Kehrein *et al*., 2020). Therefore, advanced treatment technologies are applied to purify the wastewater for recycling within the industries, discharge or utilization in agricultural sectors (Seifi, Ahmadi, Peyrovi, & Esfahanian, 2022). These technologies include: coagulation and flocculation, membrane filtration, advanced oxidation processes, reverse osmosis, dechlorination, ion exchange and carbon adsorption (Krishnan *et al*., 2022).

2.4.3.1 Coagulation and Flocculation Processes

Coagulation necessitate the addition of a primary coagulant to the wastewater in order to destabilize the particles, whereas flocculation involves the aggregating of already unstable particles to create enormously settable particles known as flocs (Bratby, 2016: Li, Dagnew & Ray, 2022). Coagulation and flocculation techniques are effective at reducing turbidity from wastewater due to their ability to eliminate colloidal particles and suspended solids (Okoro, Sharifi, Jesson & Bridgeman 2021). Adsorption and charge neutralization, bridge creation, compression of the electrical double layer, and precipitate enmeshment all contribute to particle destabilization during the coagulation process (Shabanizadeh & Taghavijeloudar, 2023). The formation of flocs from destabilized particles is influenced by particle Brownian movement, hydraulic processes, and contact and collisions of particle settling velocities (Li, Hu & Wang, 2021). The rapid mixing after primary coagulant application enhances flocs collision efficacy in wastewater as the gradual mixing enables flocs to expand in size and reduces floc breakup (Jeldres, Fawell & Florio, 2018). Coagulation efficiency is influenced by several factors: mixing rate, coagulant type, settling time, and coagulant dosage (Owodunni & Ismail, 2021). Coagulation and flocculation processes have been employed in most industrial wastewater treatment including waste paper recycling mills wastewater treatment (Li, Hu, & Wang, 2021; Seifi *et al*., 2022). Additionally, the use of aluminium sulphate alongside anionic coagulants was reported to efficiently remove TSS and reduce COD from paper mill effluent (Seifi *et al*., 2022).

2.4.3.2 Advanced Oxidation Processes

Advanced oxidation processes (AOPs) are water and wastewater processes that utilize hydroxyl radicals or sulphate radicals as oxidizing agent in sufficient quantity to purify the water by reducing toxins and organic pollutants (Babu, Srivastava, Nidheesh & Kumar, 2019; Ghime & Ghosh, 2020). Advanced oxidation processes also integrate UV irradiation, catalyst or ozone combinations for efficient wastewater treatment. Advanced oxidation processes utilized in paper mills industrial effluent treatment include; Fenton based techniques, ozonation, photocatalytic oxidation and electrocoagulation (Liu, Luo & Shukla, 2020; Tahreen, Jami & Ali, 2020). The hydroxyl and/or sulphate radicals react with target contaminants which include; microcystin, toxic metals, plasticizers resulting to their degradation. The efficient performance of AOPs is factor to initial concentration of oxidants, concentration of pollutants, initial solution pH light wavelength and intensity (Ghime & Ghosh, 2020). Combined coagulation and solar photocatalysis processes in treatment of paper mill effluent resulted in effective reduction of BOD and COD to 11.7 and 120 mg/L respectively to allowable National standards (John, Yesodharan & Achari, 2022). Moreover, Puri & Verma (2022) reported 91.6% color reduction from pulp and paper mill wastewater after concurrent fixed-bed dual technology using photo-Fenton and photocatalysis processes.

2.5 Coagulants in Wastewater Treatment

Coagulants are widely used in coagulation and flocculation processes in water and wastewater treatment technology and they are indispensable in the elimination of pollutants from wastewater (Abujazar, Karaağaç, Amr, Alazaiza & Bashir, 2022). Majorly, coagulants have been categorized as chemical or natural coagulants and their choice in coagulation and flocculation depend on their effectiveness in treatment of water and wastewater (Shewa & Dagnew, 2020; Abujazar *et al*., 2022).

2.5.1 Chemical Coagulants in Wastewater Treatment

Chemical coagulants have been substantially applied in treatment of industrial wastewater that include; textile, tanneries, petroleum and oil refineries, pulp and paper mills, dairy among others (Shewa & Dagnew, 2020). The effectiveness in turbidity, color, organic matter, heavy metals suspended solids, COD and BOD reduction have led to widely utilization of chemical coagulants in pulp and paper mills wastewater treatment (Mehmood *et al*., 2019). Chemical coagulants are classified into organic, inorganic and hybrid. Performance of chemical coagulants in colloidal particles destabilization is affected by coagulation mechanisms (Owodunni & Ismail, 2021). Chemical coagulants are polymeric with cationic, anionic or non-ionic polyelectrolytes (Bouchareb *et al*., 2020). Organic coagulants are cationic polymers that have no effect on pH, produce a small amount of sludge and are reported to be efficient in treating high turbid water and wastewater. They are comprised of pre-hydrolyzing salts that include; polyamines, poly diallyl dimethyl ammonium chloride and cationic polymers like amino methyl polyacrylamide, polyalkylene and polyethyleneimine as well as formaldehydes (Tetteh & Rathilal, 2019; Bouchareb *et al*., 2020).

Aluminium and iron pre-hydrolyzed metallic salts dominate inorganic coagulants (Tolkou & Zouboulis, 2020). Due to their ability to form multi-charged polynuclear complexes with excellent adsorption properties, these inorganic coagulants are efficient in coagulation, and these complexes influence the pH of the solution. Further to that, the swift hydrolysis of metal ions via rapid mixing, coagulant dosage, and pH necessitates their effectiveness in water and wastewater treatment (Abujazar *et al*., 2022). Most extensively utilized inorganic coagulants are; aluminium sulphate, polyaluminium chloride, ferric chloride, ferrous sulphate, magnesium sulphate, aluminium chlorohydrate and polyaluminium ferric chloride (Abujazar *et al*., 2022).

Aluminium sulphate (alum) metallic based coagulant is the most widely used aluminium coagulant worldwide due to its effectiveness in reducing turbidity (Rocha *et al*., 2020). Positively charged aluminium hydroxide ions develop in presence of water thus, hydrolysing and neutralizing the negatively charged particles. In high concentrations, metal hydroxides precipitate indulging suspended particles and potentially causing them to settle (Gandiwa *et al*., 2020; Kumar, 2020). However, aluminium residuals in the treated water that are a potent agent for Alzheimer's disease, increased water corrosiveness, high TDS, and high sludge generation are some of the limitations of aluminium sulphate utilization (Priya, Mishra & Prasad, 2020). Aluminium sulphate effectively reduced COD and suspended solids from papermaking white wastewater treatment (Ming, Xianglan, Li & Wei, 2021). Additionally, alum resulted to 98% TSS, 96% color, 98% turbidity and 93% COD removal from pulp and paper industrial effluent after physicochemical treatment (Mehmood *et al*., 2019).

Polyaluminium Chloride (PAC) have been established as an effective coagulant in water and wastewater treatment plants Zhang *et al*, (2023), with applications ranging from removal of metal ions, hazardous metals, colloids, suspended particles, color and organic matter (Gao, Liu, Zhou, Zhang &Zhang, 2022). Polyaluminium chloride have high basicity that depress the pH and reduce dissolved organic carbon in the treated water and wastewater (El Foulani, Jamal & Lekhlif, 2022). In paper mills effluent treatment, PAC alongside polyacrylamide have been reported effective in reduction of turbidity, color and COD (Harif, Aboulhassan & Bammou, 2022).

2.5.2 Plant-based Coagulants in Wastewater Treatment

Plant-based coagulants (PBCs) have been reported as an alternative to chemical coagulants in industrial wastewater treatment (Alnawajha *et al*., 2022). Due to their biodegradability, reliable performance, remote applicability with minimum sludge production, non-toxicity and affordability (Ang & Mohammad, 2020; Owodunni & Ismail, 2021). Despite chemical coagulants being efficient, their utilization comes with huge economical, ecological and health consequences in the environment. The residues from the chemicals are non-biodegradable, hazardous and have reportedly caused diseases to aquatic and terrestrial ecosystems (Asharuddin *et al*., 2021).

Plant-based coagulants (PBCs) are among bio-coagulants and/or bio-flocculants utilized in water and wastewater treatment processes. The efficacy performance of bio-coagulants is based on the characteristics of the water to be treated, the mixing process and the characteristics of the coagulants (Ang & Mohammad, 2020; Nimesha *et al*., 2022). Several plants and plant-parts used in recent past in industrial wastewater treatment have shown efficiency, depending on their biomolecule and chemical compositions. These plants include; *Moringa oleifera,* Roselle seeds, Carica papaya, Banana pith, orange peel, *Jatropha curcas*, *cassia alata* Rice starch, *Plantago ovate*, nirmali seeds, jackfruit, *Cocos nucifera*, *Trigonella foenum graecum,* Cactus *strychnospotatorum* seeds, Opuntia *ficus indica, Ocimum basilicum,* peanut seeds, watermelon seeds and tannin (Saleem & Bachmann, 2019; Gandiwa *et al*., 2020; Mosaddeghi *et al*., 2020; Nimesha *et al*., 2022).

Recently, plant-based coagulants have been reported effective in removal of significance amounts of turbidity, BOD, COD, TSS and coliforms from industrial wastewater (Jagaba *et al*., 2020; Gautam & Saini, 2020; Owodunni & Ismail, 2021). However, the characteristics of industrial wastewater determine the effectiveness of these plant-based coagulants (Owodunni & Ismail, 2021; Lester-Card *et al*., 2023). Fully utilization of plant-based coagulants in pulp and paper mills wastewater treatment has emerged as substitute to chemical coagulants, although at it infant stages (Mosaddeghi *et al*., 2020; Marzougui *et al*., 2021). The seeds of *Moringa oleifera*, a plant-based coagulant showed high efficiency in primary treatment of wastepaper mill effluents, removing 96.02%, and 97.28% of turbidity and COD, respectively (Boulaadjoul, Zemmouri, Bendjama, & Drouiche, 2018). Additionally, the use of *Moringa oleifera* in domestic wastewater treatment resulted in a 99% reduction in bacterial load and a 92% removal in turbidity (Andrade, Palanca, de Oliveira, Ito & dos Reis, 2021).

Moringa oleifera seeds have been identified as one of the widely viable plant-based coagulants for water and wastewater treatment due to their efficacy in reduction of turbidity, heavy metals, algae, coliforms and surfactants (Ang & Mohammad, 2020; Gautam & Saini, 2020; Magalhães *et al*., 2021). *Moringa oleifera* is a deciduous perennial tree native to India that is widely cultivated in the tropical and subtropical regions of Asia and Africa (Bazzo *et al*., 2022). The tree has drooping open crown, brittle branches, thick-whitish grey corky bark and tripinnate pale green composite leaves. The tree is a member of the *Moringaceae* family which has 14 species is also known as Drumstick, Horseradish, or Ben oil tree and has been noted for its exceptional coagulating properties in water and wastewater treatment (Marzougui *et al*., 2021; Nisar & Koul, 2021).

The seeds of *Moringa oleifera* have cationic proteins which have low molecular weight and are soluble in water (Gandiwa *et al*., 2020). They contain naturally occurring polyelectrolytes which are positively charged ionized groups that aid in particle coagulation by dissociating in water and releasing opposing polymer chains in the solution (Nisar & Koul, 2021). These low-molecular-weight polymers are known as lectins and albumin proteins. Lectins are cationic proteins with trimer molecular weight that are distinguished by positive cationic charged ions and polar amino acids that participate in basic coagulation (Silveira *et al*., 2020). Furthermore, albumins are thermally stable proteins with a dimer molecular weight of less than 6.5kDa, and high arginine and histidine fractions with an isoelectric point of > 10, resulting in a basic coagulant (Saleem, Mussarat, Amtul & Bachmann, 2020; Taiwo, Adenike, Aderonke, 2020). Moreover, the powdered seeds have high concentrations of argentine, praline, and glutamine acids aid in effective coagulation (Faraj & Abudi, 2020).

The mechanisms for flocs formation culminate from the polymeric structures of cationic charged functional groups include adsorption, charge neutralization and particle bridging (Boulaadjoul *et al*., 2018; Alam *et al*., 2020). The presence of oils and other soluble coagulant-inactive seed materials could lead to increased dissolve organic matter therefore slowing the active amphiphilic cationic proteins in coagulating these particles (Boulaadjoul *et al*., 2018). Therefore, oil extraction from *Moringa oleifera* seeds enhance reduction of phenolic and aromatic compounds and fatty acid content thus, aiding the performance of cationic proteins that are retained Magalhães *et al*., 2021; Skaf *et al*., 2021). The existence of antimicrobial properties in *Moringa oleifera* cationic proteins encourages contact with microorganisms' cellular membranes resulting to impairment of intercellular constituents by the fusion of the inner and outer cell membranes. Furthermore, the optimized antibacterial elements eliminate microbial strains through minimizing resistance mechanisms (Boulaadjoul *et al*., 2018; Andrade *et al*., 2021).

Plant-based coagulants, like chemical coagulants, have downsides. These constraints include insufficient mass plantation for bulk processing, long storage durations that can lead to bio-coagulant decomposition, multiple steps for extraction, availability of raw materials, establishing optimum conditions and insufficient comprehensive studies assessing their efficacy performance for largescale treatment (Kurniawan *et al*., 2020; El Bouaidi *et al*., 2022; Gomes *et al*., 2022).

2.5.3 Blend of Chemical and Plant-based Coagulants in Wastewater Treatment

Combined performances of bio-coagulants/bio-flocculants and chemical coagulants for water and wastewater treatment have been emerging technologies in the recent times (Valverde, Paccola, Pomini, Yamaguchi & Bergamasco, 2018; Gandiwa *et al*., 2020). Fully substitution of chemical coagulants with plant-based coagulants in industrial wastewater treatment unlike in raw water treatment is still under investigation due to dynamic nature of industrial wastewater (Putra, Ayu & Amri, 2020; Nath *et al*., 2021). Therefore, incorporating plant-based bio-coagulants and chemical coagulants in the treatment of industrial wastewaters has been reported as a promising sustainable technology (Ahmad *et al*., 2022).

Moringa oleifera, plant-based coagulant combination with chemical coagulants has been suggested to be effective on higher optimum dosages in the treatment of industrial wastewater (Jagaba *et al*., 2020; Jagaba *et al*., 2021). The synergistic combination of *Moringa oleifera* and aluminium sulphate have been reported effective in reduction of TSS and overall dairy wastewater treatment (Elemile, Eze & Ogedengbe, 2021). In cosmetic industry effluent, the combination of *Moringa oleifera* and aluminium sulphate coagulants, effectively reduced COD, oil and grease levels (Araújo *et al*., 2022).

Precisely, optimization of *Moringa oleifera* seeds blended with polyaluminium chloride significantly improved the quality of treated hospital wastewater through reduction of COD and microorganisms (Nonfodji *et al*., 2020). Moreover, coagulation using *Moringa oleifera* and polyaluminium chloride, alongside nanofiltration processes effectively decreased color, COD and turbidity from wood processing effluent (Bouchareb *et al*., 2020). Despite the aforementioned blend of *Moringa oleifera* and chemical coagulants, less have been reported on their effectiveness in treatment of wastepaper recycling wastewater (Mosaddeghi *et al*., 2020).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Wastewater samples were collected from Maz International wastepaper Recycling mill (MIWPM), located on a latitude of 1°38'28.75''S and a longitude of 36°52'38.90''E. MIWPM is situated in Kisaju area, off Nairobi-Namanga road, in Kajiado East Sub-County, Kajiado County Kenya. The mill lies at an elevation of 1708 meters above sea level with relatively flat terrain. Figure 1 shows a map of the study area.

MIWPM is located on 2.4 acres of land near Himilo Agro farm. The region is semi-arid, with a bimodal rainfall pattern of 700-850mm per year and moisture deficits occurring every 7-9 months. As a result, the region is reliant on ground water reservoirs, water dams, and pans for farming, industrial, and domestic purposes. Other socioeconomic activities within the area include irrigation farming; Olari farm, Himilo Agro, industrial plants; Kanha Ji steel mill, Allied East Africa, schools; Islamic University of Kenya, St. Annes Kisaju, human settlement and seminomadic livestock keeping.

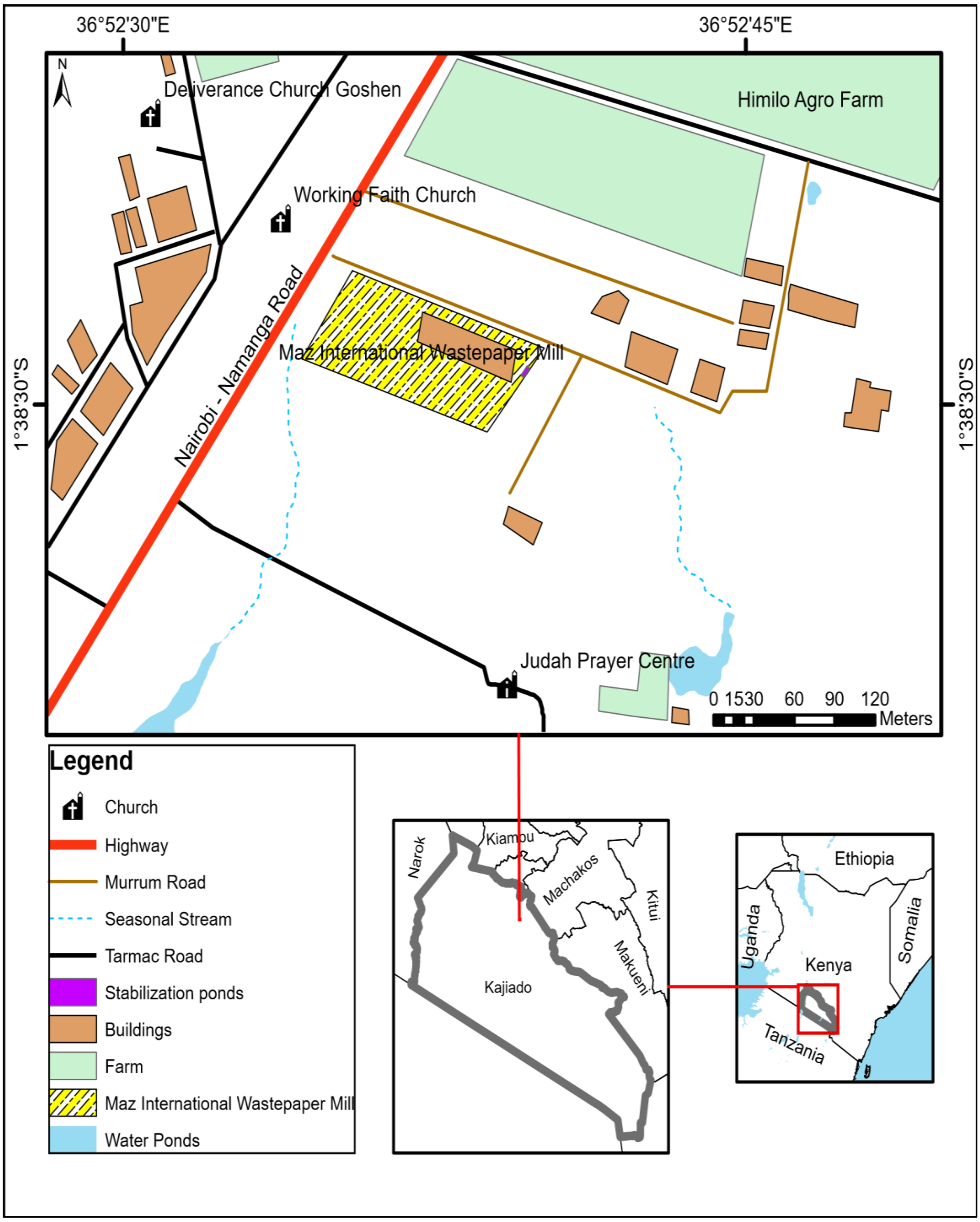

Figure 1: Location map of Maz international paper mill.

3.2 Materials

Reagents used during the study included; 16.5% minimum reagent grade of alum and 17% superior grade of PAC were sourced from Sigma-Aldrich chemicals company. Other reagents used during the experiments included: standard chloroplatinate solution, standard potassium dichromate solution, standard ferrous ammonium sulphate, standard phosphate buffer solution, analytical grade hexane, ethanol, 98% sulphuric acid, 36% hydrochloric acid and distilled water. The equipment used included; HANNA (HI-98194) multifunctional pH meter, 2303 flocculator Jar test apparatus, HANNA (HI98703) portable turbidity meter, oven, bench mill, domestic blender (FY-304 Lyons).

3.3 Study Methods

3.3.1 Study Design

To determine effective doses of defatted *Moringa oleifera* seeds (DMos), fatted *Moringa oleifera* seeds (FMos), *Moringa oleifera* bark (BMo), aluminium sulphate (alum) and polyaluminium chloride (PAC) in the treatment of MIWPM, a completely randomized design (CRD) was used. The CRD is a versatile design in which the number of treatments and replicates are only limited by the number of experimental variables available. From the first objective, variation in turbidity depended on coagulant type and dose level. For the second objective, turbidity variation depended on dose level and the type of coagulant blending. To achieve objective three and four, efficacy of wastewater treatment depended on the type of coagulant.

3.3.2 Sample Collection

During the collection of wastewater samples, grab sampling technique was utilized. A 1000ml beaker used to manually draw the sample at the site of outflow of the wastewater from the mill. The samples were subsequently placed in well-labelled PVC transparent bottles to avoid UV radiation damage. At the point of sampling, a HANNA pH multimeter was employed to assess the pH, temperature and electrical conductivity of the wastewater. Throughout the course of the study, wastewater samples were collected early in the morning and late at evening and combined to create a composite sample. The composite samples were subsequently transported to the University of Eldoret Biotechnology laboratory in insulated cooler boxes to avoid biological decomposition. During the course of the study, three composite samples were obtained. The samples were stored in the laboratory at low temperatures (below 4°C) to avoid biological degradation before analysis.

Ten kilograms of *Moringa oleifera* seeds kernels and ten kilograms of the bark were collected during dry months (August and September) in 2019, from isolated farms in Kirinyaga county near Kutus Town. The farms are located at a latitude of 0°34'39.59"S, and a longitude of 37°18'20.67"E. The mature *Moringa oleifera* pods, without any sign of discoloration and softening were plucked and the seed kernels detached from the pods. *Moringa oleifera* bark was obtained through debarking of the branches using sharp knife after pruning. Both the *Moringa oleifera* seed kernels and bark samples were transported in well ventilated sacks bags to the laboratory for further processing.

3.3.3 Laboratory Experiments

3.3.3.1 Preparation of *Moringa oleifera* Seed Powder

Moringa oleifera seed kernels were sun dried to constant weight, after which the seed kernels were mechanically dehusked to obtain the seeds. The seeds obtained were also sun dried to constant moisture of between 10% and 12%. Five (5) kg of the seeds were ground using a domestic blender (FY-304 Lyons) and the powder was sieved through a 600µm stainless steel sieve in order to reach maximum solubility of the active components in water. The resulting seed powder was divided into two equal portions, which were later used for the preparation of DMos and FMos stock solutions. The powder was stored in a cool and dry place at room temperature, awaiting further processing.

3.3.3.2 Extraction of Oil from Fatted *Moringa oleifera* seed Powder

Soxhlet oil extraction method was adopted for oil extraction from crude Moringa oleifera seeds (Ojewumi, Oyekunle, Emetere & Olanipekun, 2019). Plate 2 shows Soxhlet oil extraction apparatus. Twenty grams (20g) of unprocessed (FMos) powder were placed in a permeable thimble in a Soxhlet extractor equipped in a 500mL round bottom flask with 300mL analytical grade ethanol. The flask was then heated until its contents had been entirely eliminated of its oil. Following the solvent extraction, the seed cake was air-dried for 24 hours at room temperature to allow maximum ethanol evaporation. This method was repeated until sufficient defatted *Moringa oleifera* seed (DMos) powder for the study was obtained. For experimental purposes, the dry DMos powder was stored in a cool, dry environment.

Plate 2: Soxhlet oil extraction apparatus

(Source: Ojewumi *et al.*, 2019)

3.3.3.3 Preparation of *Moringa oleifera* Bark Powder

Five kilograms (5kg) of BMo samples were crushed using pestle and mortar to reduce their sizes with minimal loss. A bench mill was then used to grind the barks into fine powder which was then stored in a dry place at room temperature for experimental use.

3.3.3.4 Preparation of Stock Solutions

To prepare polyaluminium chloride stock solution, 12g of PAC was used to prepare the stock solution by diluting with 500ml of the recycled waste paper. The stock solution was used for wastewater treatment. To prepare aluminium sulphate stock solution, 5g of alum was added to 500ml wastewater and stirred by the use of stir to get 1%wt solution. This was done in line with conventional laboratory procedures for preparing alum stock solutions in water treatment. The resulting stock solution was used to coagulate and flocculate the wastewater.

A DMos stock solution was made via placing 100g of dried DMos powder in a conical flask and adding 500ml of wastewater; the combination was shaken for 24 hours on an electric shaker. The supernatant suspension was employed in the jar test batch procedure for wastewater treatment.

To prepare the FMos stock solution, 100g of dried fatted seed powder was added in a conical flask with 500ml of wastewater and the resultant mixture was shaken for 24 hours on an electric shaker. The supernatant suspension formed was utilized in the jar test batch procedure for wastewater treatment.

Two hundred grams (200g) of dry BMo powder was added in a conical flask to make BMo stock solution. Five hundred millilitres (500ml) of wastewater was transferred to a conical flask and agitated for 24 hours using an electric shaker for maximum extraction of key components. The resulting supernatant suspension served as a stock solution for wastewater coagulation and flocculation.

3.3.3.5 Standard Jar Test Procedure

Jar test is the most popular experimental technique used for coagulation-flocculation. A conventional Jar test apparatus was used in the experiments to coagulate wastewater samples obtained from MIWPM using individual and blended coagulants. Plate 3 shows the convectional coagulation-flocculation jar test equipment used in this study. The jar test was conducted as a batch experiment, with six beakers (1000 ml) at a time and six-spindle steel paddles. The wastewater sample was thoroughly mixed before the jar test, and a portion was drawn for preliminary physicochemical and bacteriological measurements. From the prepared stock solutions of the coagulants, varying doses were added in the beakers and topped to 500 ml using the wastewater. Dosing rates for coagulants were as shown in table 1 and table 2 for individual and blended coagulants respectively.

Plate 3: Digital Convectional jar test flocculator

Thereafter the gang stirrers were lowered slowly into the mixture, followed by rapid mixing (100rpm) for one minute and slow mixing (50rpm) for 15 minutes. The stirrers were switched off, pulled out of the mixture and the liquid allowed to settle for 45 minutes. Finally, a sample was withdrawn using a pipette from the middle of supernatant to determine effective doses of individual and blended coagulants as well as physicochemical and bacteriological parameters measurements. The whole procedures in the Jar test were conducted in similar mixing speed.

Table 1: Doses of the various individual coagulants

Coagulant stock solutions	Varying dosage
DMos (100g/500ml)	10 ml ranging from 0-150 ml
FMos (100g/500ml)	10 ml ranging from 0-150 ml
BMo (200g/500ml)	20 ml ranging from 0-300 ml
Alum (5g/500ml)	5 ml ranging from 0-100 ml
PAC (12g/500ml)	25 ml ranging from 0-300 ml

Table 2: Doses of the stock solution of the various blends of coagulants

% Dose	100/0	90/10	80/20	70/30	60/40	50/50	40/60	30/70	20/80	10/90	0/100
DMos	80	72	64	56	48	40	32	24	16	8	0
Alum	0	7.5	15	22.5	30	37.5	45	52.5	60	67.5	75
FMos	90	81	72	63	54	45	36	27	18	9	0
Alum	0	7.5	15	22.5	30	37.5	45	52.5	60	67.5	75
BMo	100	90	80	70	60	50	40	30	20	10	0
Alum	0	7.5	15	22.5	30	37.5	45	52.5	60	67.5	75
DMos	80	72	64	56	48	40	32	24	16	8	0
PAC	0	15	30	45	60	75	90	105	120	135	150
FMos	90	81	72	63	54	45	36	27	18	9	0
PAC	0	15	30	45	60	75	90	105	120	135	150
BMo	100	90	80	70	60	50	40	30	20	10	0
PAC	0	15	30	45	60	75	90	105	120	135	150

3.3.2.6 Turbidity

Turbidity is a significant parameter in determining effluent quality and it is measured as a reduction in the intensity of transmitted light or as a result of insoluble and soluble colored chemicals in the wastewater. Additionally, turbidity is used to determine effective doses of coagulants in jar test batch experiments at optimal pH ranges (Gandiwa *et al*., 2020; Boulaadjoul *et al*., 2018).

Nephelometric method APHA 2130 A was adopted to determine the turbidity of the wastewater (Rice *et al*., 2012). Fifteen millilitres (15ml) of the samples were drawn to fill the turbidity vial and cell capped. A lint-free cloth was used to wipe the cell so as to remove water spots. The turbidimeter was turned on and the sample vial placed in the instrument cell compartment so as its diamond mark aligned with the raised orientation mark in front of the cell compartment and the cover closed. By pressing the “Range key” and then the “Signal Average” turbidity (NTU) readings were recorded.

3.3.2.7 Color

Wastewater color was determined using a single-wavelength spectrophotometric method APHA 2120 C at a wavelength of 465 nm using platinum-cobalt as standard solution (Rice et al., 2012). A preprogrammed calibration curves for color were used after verification with platinum-cobalt standards. Initially the spectrophotometer was zeroed using distilled water. Wastewater sample was centrifuged at 10,000 rpm for 15 minutes to remove all suspended matter. The pH of supernatant wastewater was adjusted to near neutral (7.6 +/- 0.05) by adding 2M NaOH. The cell of the spectrophotometer was filled with the centrifuged wastewater then absorbance of the wastewater read at 465 nm. Platinum Colour units (PCUs) of the wastewater were determined from absorbance using the following equation.

$$\mathrm{PCU} = \frac{500 \times \mathrm{A}_1}{\mathrm{A}_2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{i}$$

Where A_1 is absorbance of 500 standard platinum cobalt solution and A_2 is absorbance of effluent samples.

3.3.2.8 Total Suspended Solids

Total suspended solids measure the undissolved solid matter in water or wastewater that remains on the surface of a glass filter after the water has evaporated. The standard APHA 2540 D gravimetric method was used to determine TSS (Rice *et al*., 2012). A 100ml of the sample was thoroughly mixed and transferred to a weighed Gooch crucible (W_a). The crucible and its contents were placed in a drying oven for one hour at 104˚C, after which the crucible and its contents were placed in a desiccator, cooled to room temperature and weighed (W_b). The total suspended solids were calculated using the equation (ii) as follows:

$$\text{TSS, mg/L} = \frac{(Wb - Wa)1000}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ ii}$$

Where W_b - is the weight of the residue and crucible (mg)
W_a - is the weight of the crucible (mg)
V -volume of the sample (mL)

3.3.2.9 Total Dissolved Solids

Total dissolved solids measure the dissolved matter in water or wastewater that remains after evaporating all water. Standard APHA 2540 C dried at 180˚C method was used to determine TDS of the wastewater samples (Rice *et al*., 2012). An acid rinsed and dried porcelain evaporating dish was weighed and the tared weight dish recorded as D using calibrated graduated cylinder, 100 ml of the sample was transferred into the evaporating dish via a glass filter. The sample was then evaporated to remove all the standing water sample and dried overnight in an oven at 180˚C to ensure a constant weight was achieved. The dish was removed from the oven, cooled at room temperature and weighed. The drying procedure was repeated until the change in weight between the final weight and previous weight was ≤0.5mg. The final 180˚C weight was recorded as A and the concentration of total dissolved solids was calculated using the equation below

TDS, mg/L = $\frac{(A-D)1000}{S}$ …………………………… iii

Where A = final 180˚C weight of the dried residue + the tared dish (mg)

D = tared dish weight (mg)

S = volume of the sample (mL)

3.3.2.10 Electrical conductivity

Water conductivity is a measure of its capacity to carry electrical current. The composition of dissolved electrolytes in the water and their effect on the alkalinity and hardness of the water are specifically correlated to its electrical conductivity. To determine the electrical conductivity of wastewater samples, APHA 2510 B laboratory method was adopted (Rice *et al*., 2012). A HANNA conductivity meter was used to measure electrical conductivity. The meter was initially calibrated using conductivity standard solution, after which the probe was thoroughly rinsed using distilled water. The calibrated conductivity meter probe was immersed into the wastewater sample of room temperature 25˚C and the readings determined.

3.3.2.11 Chemical Oxygen Demand

Chemical oxygen demand is the measure of the capacity of water to consume oxygen during the decomposition of organic matter in water. The amount of oxidation that will take place and the amount of organic matter in a water sample are ascertained using chemical oxygen demand testing. The COD of wastewater samples was determined from closed reflux titrimetric method of APHA 5220 C (Rice *et al*., 2012).

Using 250 ml refluxing flask with boiling chips, a sample of 25 ml wastewater was added and 1g of mercuric sulphate was added. The addition of a standard prepared solution of 500 ml of concentrated sulfuric acid and 22g of silver sulphate was done gradually while cooling. Afterwards, 25 ml of standard potassium dichromate prepared of at 0.1 N was added, and the mixture "refluxed" for two hours. The resultant mixture was then diluted to twice its volume and chilled to ambient temperature. With 0.1N ferrous ammonium sulphate and ferroin indicator, the entire amount was titrated to a reddish-brown endpoint. After combining sulphuric acid/silver sulphate with 0.1N standard ferrous ammonium sulphate, 25 ml of 0.1N standard potassium dichromate was titrated to produce the blank. The following equation was used to determine COD:

COD, mg/L = $\frac{(A-B)N \times 8000}{V}$ ……………………….. iv

Where; A is the volume of (FAS) consumed by sample (mL),
B is the volume (FAS) utilized by blank (mL)
N is Molarity of ammonium sulphate
8000 express COD milliequivalent weight of oxygen
V is volume of the sample (mL).

3.3.2.12 Biochemical Oxygen Demand

Biological Oxygen Demand quantifies how much oxygen a microbial culture that has become accustomed to the water sample absorbs over a specified period. It is used to assess the amount of oxygen that will be depleted if the effluent stream under evaluation is discharged into a natural watercourse. The standard APHA 5210 B 5-day BOD test method was used to determine BOD levels of the wastewater (Rice *et al*., 2012).

Two litres of standard dilution water were siphoned into a plastic container, part of this water was then siphoned into two 300ml-BOD bottles (control). To the remaining dilution water (1.4 litres), 1.4ml of each nutrient and 7ml (0.5%) seed was then added and mixed well-avoiding air entrainment. Nutrients, phosphate buffer solution standard made with magnesium sulphate solution, calcium chloride solution, and ferric chloride solution. The mixed dilution was siphoned into 1 litre volumetric flask containing 20 ml of sample acidified with sulphuric and filled to mark. The mixture was then quickly siphoned from the volumetric flask into two BOD bottles - one for incubation and the other for determination of initial DO in the mixture. The bottles were stoppered tightly and incubated for 5 days at 20^{o}C. The BOD bottles were water-sealed throughout the five-day period, after which the DO was determined. The equation below was used to determine BOD after determining the initial and final dissolved oxygen of the blank and sample.

$$BOD_5, \text{mg/L} = \frac{(D1-D2)-(B1-B2)f}{P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ v}$$

D_1 is dissolved oxygen in the sample at 15 minutes after preparation, mg/L.
D_2 is dissolved oxygen concentration in the sample after 5 days in incubation at 20˚C, mg/L.
B_1 is dissolved oxygen of seeded dilution water before incubation,
B_2 is dissolved oxygen of seeded dilution water after incubation at 20^{o}C for five days
f is seed volume ratio
p is wastewater decimal ratio

3.3.2.13 Microbial load

Standard total coliform APHA 9221 B fermentation technique was applied for microbial load enumeration (Rice *et al*., 2012). Viable coliforms present in the treated and raw wastepaper recycling mill wastewater were determined via plate colony count. Serial dilutions of up to 10^{-3} ten-fold in the preliminary study experiments yielded colonies within the ideal range of 30-300 colonies per plate. This dilution factor was used in this research experiment.

Ten milliliters (10ml) of the sample were drawn and placed in a test tube, which was shaken vigorously with a vortex to allow thorough mixing, and three test tubes each containing 9 ml of 0.9% saline sterile diluents were taken. Using a sterile pipette, 1ml of the sample drawn and added to the first test tube, resulting in a total volume of 10 ml thus providing initial dilution of 10^{-1}. A vortex was used to fully mix the dilution and 1 ml of the mixture was extracted and emptied into the second test tube with a pipette. This procedure was repeated for the third test tube resulting in final dilution of 10^{-3} ten-fold. In sterile petri dishes, 0.5 ml of the diluted sample was spread on the prepared nutrient agar and incubated at 28˚C for 24 hours. The microbial load was determined by counting the colonies formed. The microbial load in Colony Forming Units (CFU), was then expressed as Colony Forming Units per milliliter of the wastewater sample (CFU/mL) using the following equation.

CFU/mL = $\frac{n \times f}{V}$ ………………………………… vi

Where; n is number of colonies formed (CFU)

f is the dilution factor

V is the volume of the cultured plate sample(mL).

3.4 Statistical Data Analysis

The data obtained for the various objectives was summarized descriptively and analyzed using Stratigraphics version 16. The turbidity obtained for the effective doses for various individual and blended coagulants were subjected to one-way analysis of variance (ANOVA) and the means were separated using Fisher's Least Significant Difference (LSD) test. The efficacy of the various coagulants effective doses in wastewater treatment and microbial load reduction were subjected to multivariate analysis of variance (MANOVA) and means were separated using Fisher's LSD test.

Effective doses of individual and blended coagulants were presented using trend figures and tables were used to illustrate efficacy treatment of the wastepaper recycling mill wastewater.

CHAPTER FOUR

RESULTS

4.1 Effective doses of individual Coagulants

The effective doses of PAC, alum, DMos, FMos and BMo coagulants were determined from the lowest turbidity levels presented. The turbidity reduction trends for the individual coagulants in treatment of wastewater from MIWPM were also presented.

4.1.1 Effective doses of chemical coagulants

The trend of turbidity levels variations with increased dose of PAC in the wastewater was as shown in Figure 2. The turbidity levels of the wastewater decreased from 1800.02±0.99 NTU to 162.67±3.89 NTU at an efficiency of 90.99% within pH mean of 6.7. This reduction resulted from increase in the amount of PAC coagulant from 6.0×10^5 ppm to 36×10^5 ppm respectively. Thereafter, the turbidity of the wastewater increased with increased dose amount of PAC. An effective dose of 36×10^5 ppm of PAC resulted to minimum turbidity of 162.67±3.89NTU, which was however higher than WHO, NEMA and USEPA drinking water permissible limits. The best relationship between turbidity of wastewater and polyaluminium chloride dose was polynomial with an equation of $T_w = 0.7739D_p^2 - 70.489D_p + 1760.3$ ($R^2 = 0.9845$, $p<0001$), where T_w is the turbidity of wastewater and D_p is the dose of polyaluminium chloride.

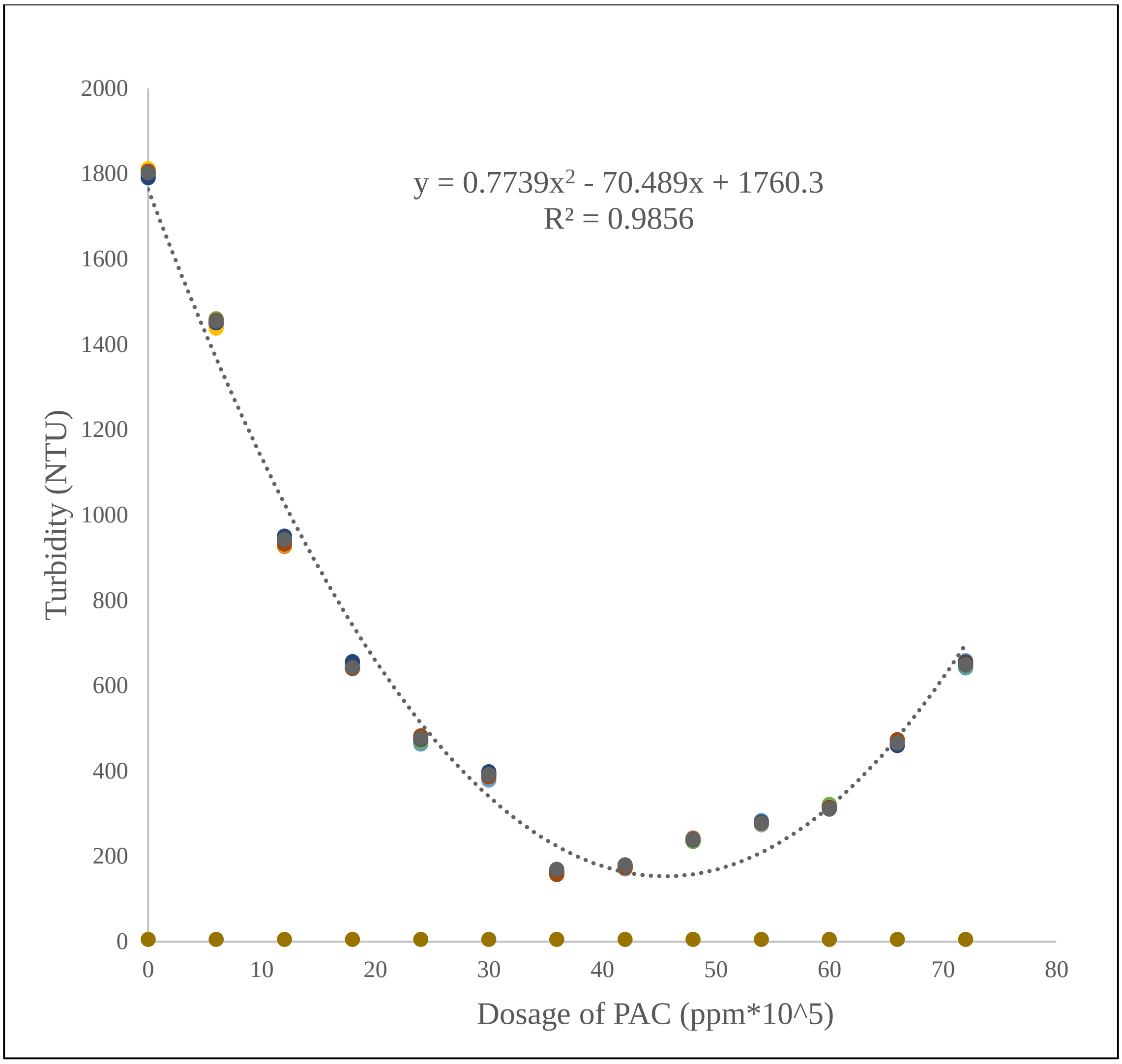

Figure 2: Variation in turbidity of wastewater with varying doses of Polyaluminium Chloride

The variation of turbidity of wastewater from wastepaper recycling mill with varying amount of alum coagulant was as shown in Figure 3. The turbidity of wastewater reduced from the original mean value 1805.3±1.00NTU to the minimum value of 24.03±4.32NTU corresponding to alum dose of 75×10^4 ppm at mean pH value of 7.1. Thereafter, the wastewater turbidity increased marginally as alum dose was increased. This effective dose achieved a reduction efficiency of 98.67%, although the reduced value exceeded the permissible drinking water limits of WHO, NEMA and USEPA.

The best relationship between the turbidity of wastewater and dose of alum was polynomial, with an equation of $T_w = 30.345D_a^2 - 432.23D_a + 1537.9$ ($R^2=0.9715$, $p<0.0001$), where T_w is the turbidity of wastewater and D_a is the amount of aluminium sulphate coagulant dosed.

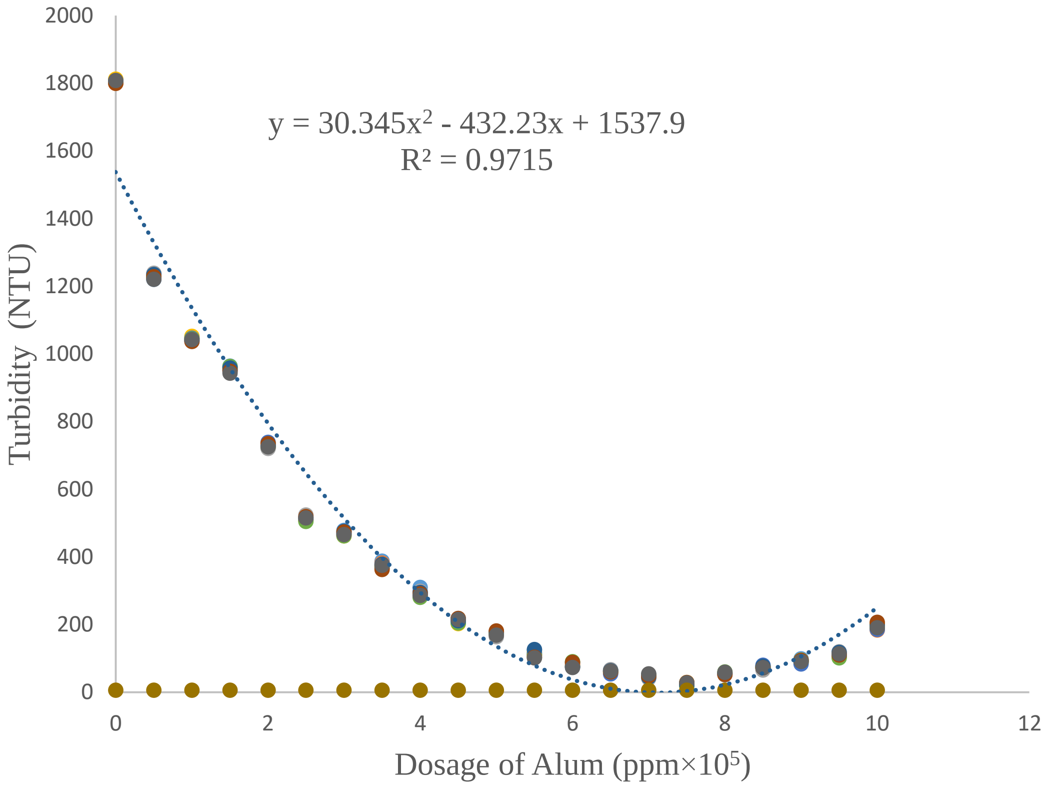

Figure 3: Variation of turbidity of wastewater with varying doses of aluminium sulphate

4.1.2 Effective Doses of Bio-coagulants

The changes in turbidity of wastewater from wastepaper recycling mill with varying doses of DMos coagulant dose as illustrated in Figure 4. Turbidity of the wastewater reduced from the initial mean value of 1800.02±5.12NTU to the minimum mean value of 144.00±2.98NTU as the amount of DMos increased to an effective dose of 16×10^6ppm at a reduction efficiency of 92% at mean pH of 7.5. Thereafter, the turbidity of the wastewater slightly increased as the DMos amount increased. The best relationship between turbidity of wastewater and dose of DMos was polynomial, with an equation of $T_w = 4.4011D_d^2 - 158.35D_d + 1633.9$ ($R^2 = 0.941$, $p<0.0001$), where T_w is the turbidity of wastewater and D_d is the amount DMos coagulant as illustrated.

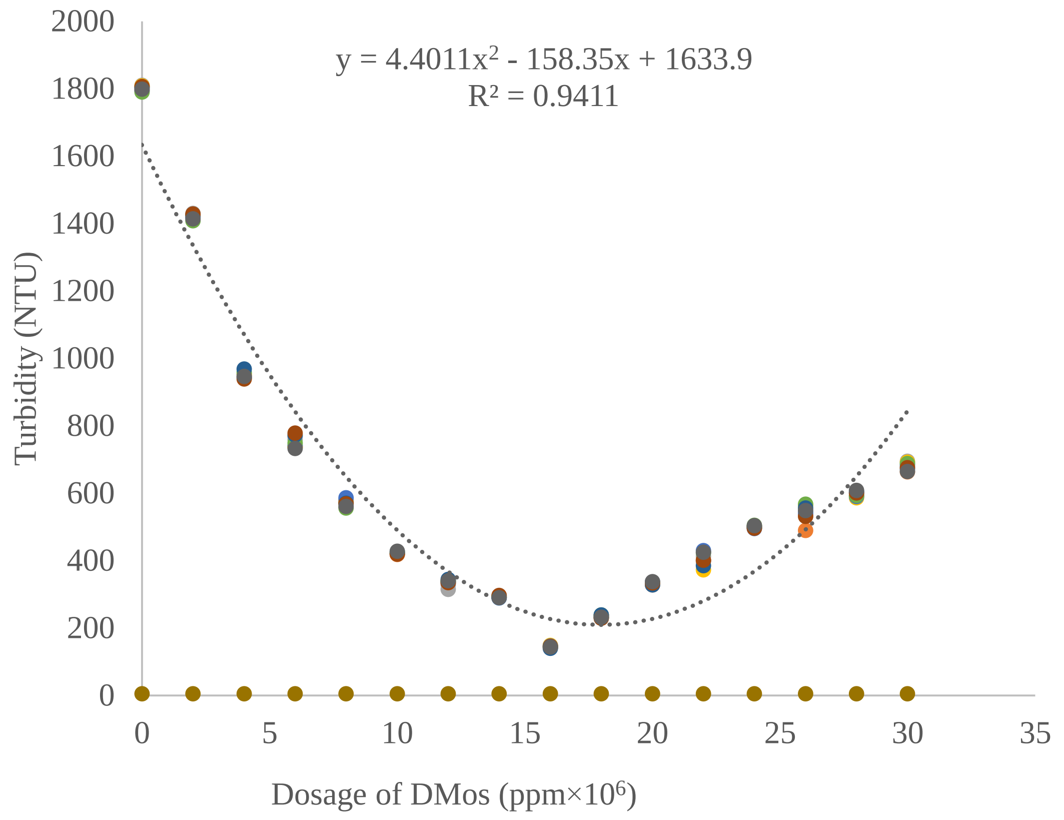

Figure 4: Variation of turbidity of wastewater with varying DMos doses

The change in turbidity of the wastewater with varying doses of FMos coagulant as shown in Figure 5. Turbidity of wastewater reduced from the mean value of 1800.90.00±0.41 to the minimum mean value of 250.67±3.10NTU as the coagulant dose increased to 18×10^6ppm at a mean pH of 6.9. An increase in turbidity of the wastewater was then noted with an increase in FMos dose. The best relationship between turbidity of wastewater and dose of FMos was polynomial, with an equation of T_w = 5.4852D_f^2 - 183.24D_f+1886.7 (R^2 = 0.9744, p<0.00001), where T_w is the turbidity of wastewater and D_f is the amount FMos coagulant.

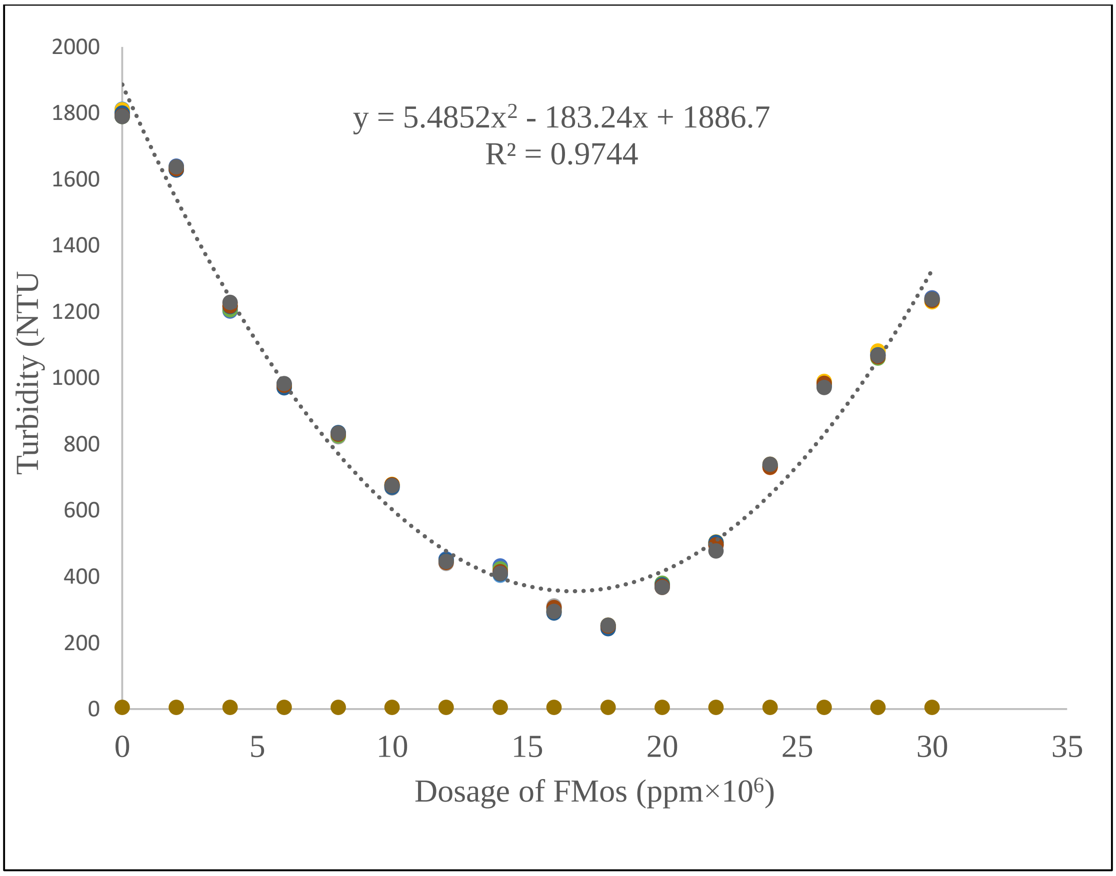

Figure 5: Variation in turbidity of wastewater with varying dosages of FMos

Variation in turbidity of the wastewater with varying amounts of BMo coagulant is shown in Figure 6. The turbidity of wastewater reduced to minimum mean value of 811.00±3.78 NTU with an increase of dosage of BMo from 8×10^6 ppm to 40×10^6 ppm at pH mean value of 7.6. Thereafter, an increase in turbidity of the wastewater was then noticed with an increase in BMo dose. The best relationship between turbidity of wastewater with dosage of BMo was polynomial, with an equation of T_w = 0.2272D_b^2 - 28.462D_b+ 1827.1 (R^2 = 0.8530), p<0001), where T_w is the turbidity of wastewater and D_b is the amount of BMo coagulant.

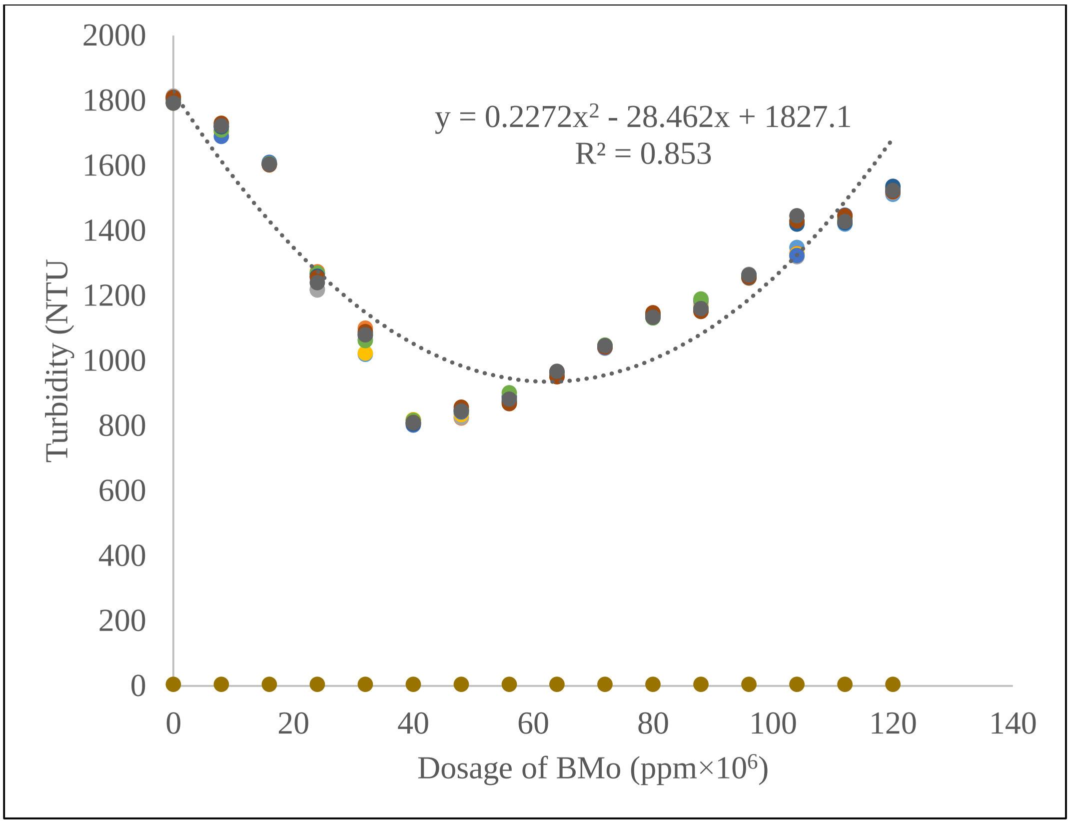

Figure 6: Varying turbidity of wastewater with changing dosages of BMo coagulant

4.2 Blend of *Moringa oleifera* Plant Parts and Chemical Coagulants

Plant based coagulants (BMo, FMos and DMos) and chemical coagulants Aluminium sulphate (Alum) and Polyaluminium chloride (PAC) were combined. The aim of blending was to establish whether there was any synergy that would aid in achieving higher efficiency in treating the wastewater. The results obtained from blending of the coagulants were presented.

4.2.1 Defatted *Moringa oleifera* Seeds Blended with Aluminum Sulphate

Turbidity of wastewater variations with varying combined doses of DMos with alum was as shown in Figure 7. The turbidity of wastewater decreased as the amount of aluminium sulphate increased to reach the minimum mean value turbidity level of 17.13±1.33NTU, corresponding to a blend of 20% DMos and 80% alum which was significantly different ($p=0$) from the other blends with a mean pH of 7.6.

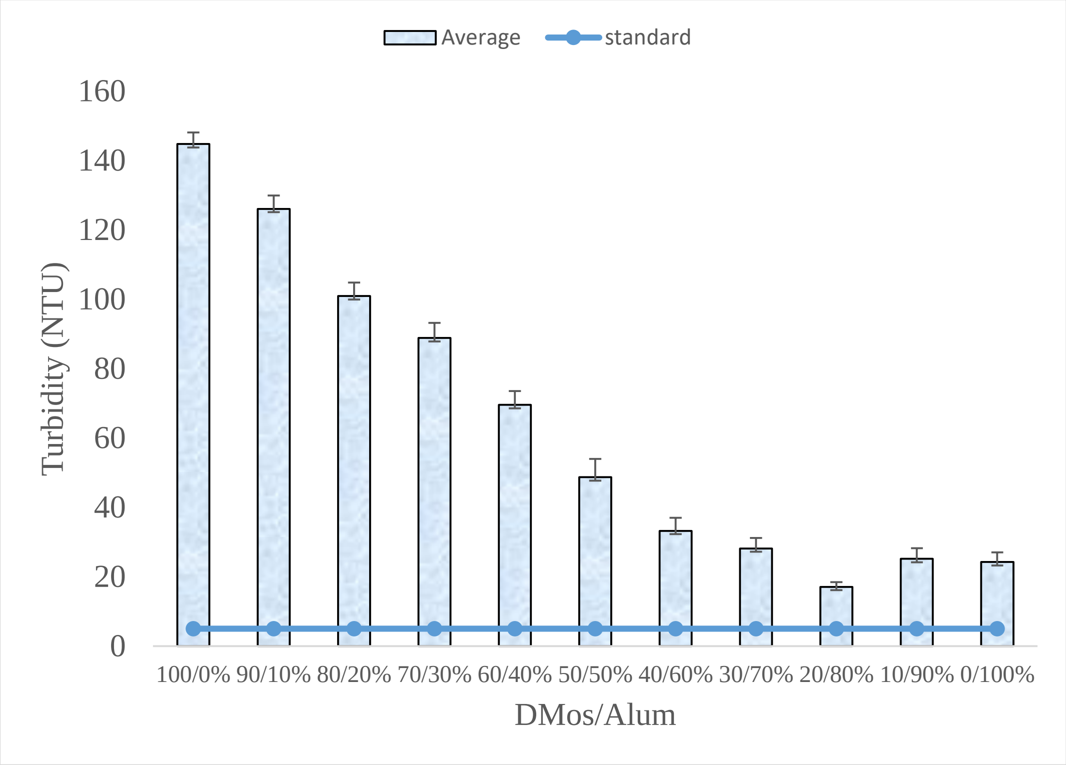

Figure 7: Variation of turbidity of wastewater with varying combinations of DMos and alum coagulants

Afterwards, the turbidity of the wastewater increased marginally as the amount of alum increased with a decrease in DMos. There was a significant difference ($p<0.0001$) in turbidity of the wastewater with most of the combinations of DMos with aluminium sulphate. However, there was no significant difference in the turbidity of the wastewater at the following combinations; 30% DMos and 70% aluminium sulphate, 10% DMos and 90% aluminium sulphate, 0% DMos and 100% aluminium sulphate. Therefore, the best synergy was attained at a combination of 20% DMos and 80% aluminium sulphate, although the minimum mean turbidity value was higher than 5NTU WHO, NEMA and USEPA drinking water permissible limits.

4.2.2 Fatted *Moringa oleifera* Seeds Blended with Aluminum Sulphate

Variations in turbidity of wastewater with varying combined doses of FMos and alum coagulants were as shown in Figure 8.

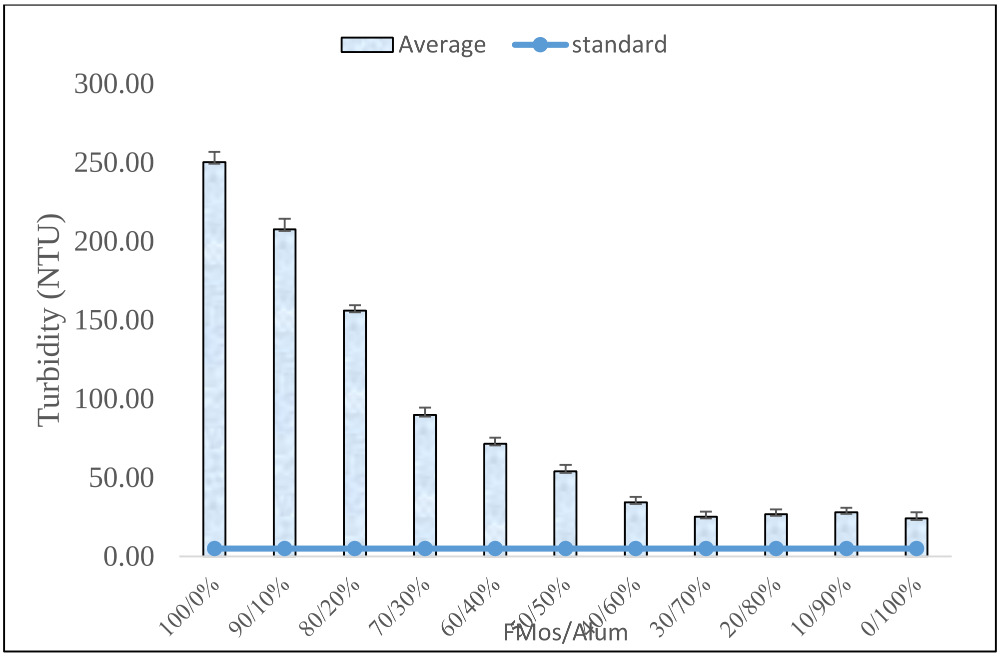

Figure 8: Variation of turbidity of wastewater with varying blends of FMos and alum coagulants

Turbidity of wastewater decreased as the doses amount of alum increased with a decrease in FMos doses at a blend ratio of 30% FMos and 70% alum at a mean pH of 7.1. Thereafter, the turbidity of wastewater remained marginally constant as the amount of aluminium sulphate increased with a decrease in FMos. The lowest mean turbidity level of the wastewater was 25.17±3.26 NTU at 30%:70% FMos and alum blend. However, this minimum turbidity value obtained was greater than 5NTU permissible drinking water limits by WHO, NEMA and USEPA. There was a significant difference ($p<0.0001$) in most combinations of FMos with aluminium sulphate. However, there was no significant difference among the following combinations; 40% FMos and 60% aluminium sulphate30% FMos and 70% aluminium sulphate, 20% FMos and 80% aluminium sulphate, 10% FMos and 90% aluminium sulphate and 0% FMos and 100% aluminium sulphate.

4.2.3 Bark of *Moringa oleifera* Blended with Aluminum Sulphate

Variations in turbidity of wastewater with varying doses of combinations of BMo with alum was as shown in Figure 9. Turbidity of wastewater decreased as the amount of alum increased contrarily to BMo coagulant to the highest concentration of alum at a ratio of 100%:0% blend of alum and BMo with a mean pH of 7.1. The minimum mean turbidity value of the wastewater was 24.01±2.62 NTU which exceeded the permissible drinking water thresholds of WHO, NEMA and USEPA. The turbidity values of wastewater for all the blends of BMo and alum were significantly different ($p<0.0001$). There was no effective coagulation observed from the blend of BMo and alum.

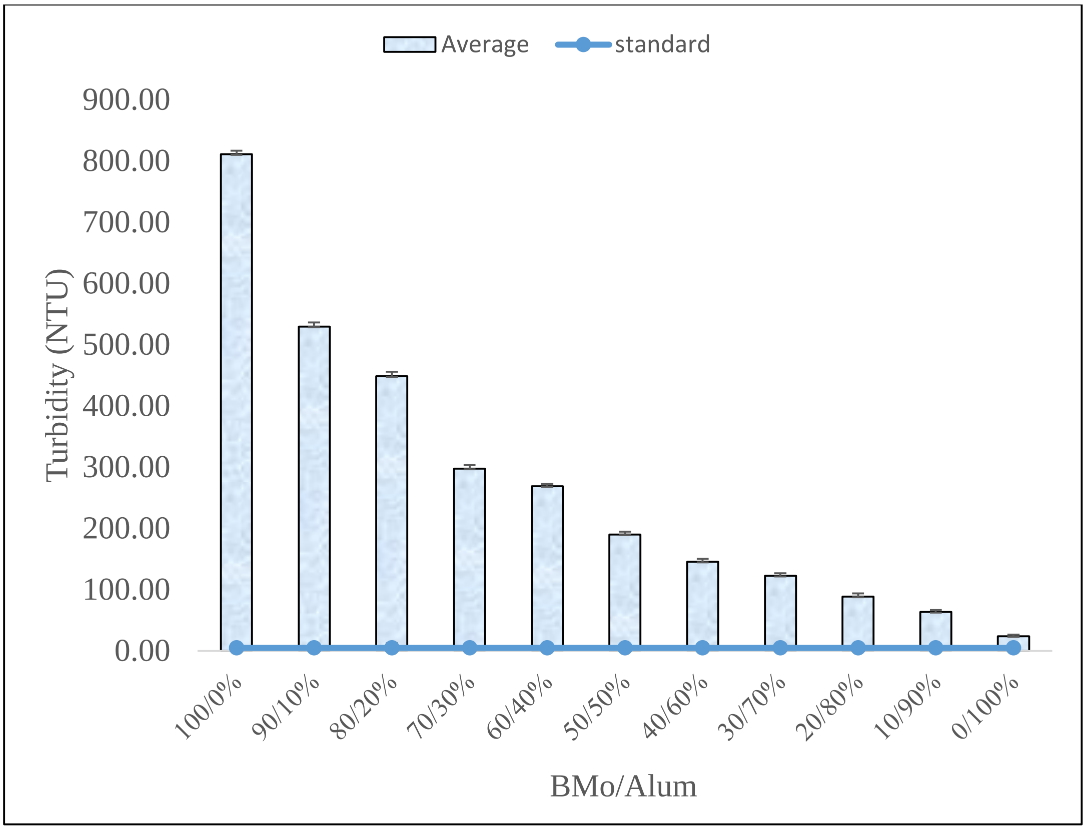

Figure 9: The variation of wastewater turbidity with varying doses of BMo and alum coagulants blend

4.2.4 Defatted *Moringa oleifera* Seed Blended with Polyaluminium Chloride

Variation in turbidity of wastewater with varying combinations of DMos and PAC was as shown in Figure 10. Turbidity of wastewater reduced with increase in the doses amount of DMos and decrease in PAC doses. The turbidity of the wastewater decreased to minimum mean value of 93.57±3.65 NTU, corresponding to 70% of DMos coagulant and 30% PAC at mean pH value of 7.2 and thereafter, the turbidity of wastewater increased with decrease in DMos as PAC increased to the maximum of 100% dosage. However, the minimum mean value exceeded WHO, NEMA and USEPA turbidity for drinking water thresholds. The blend dose ratio of 100% PAC and 0% DMos coincided with turbidity levels of 161.1±2.62 NTU.

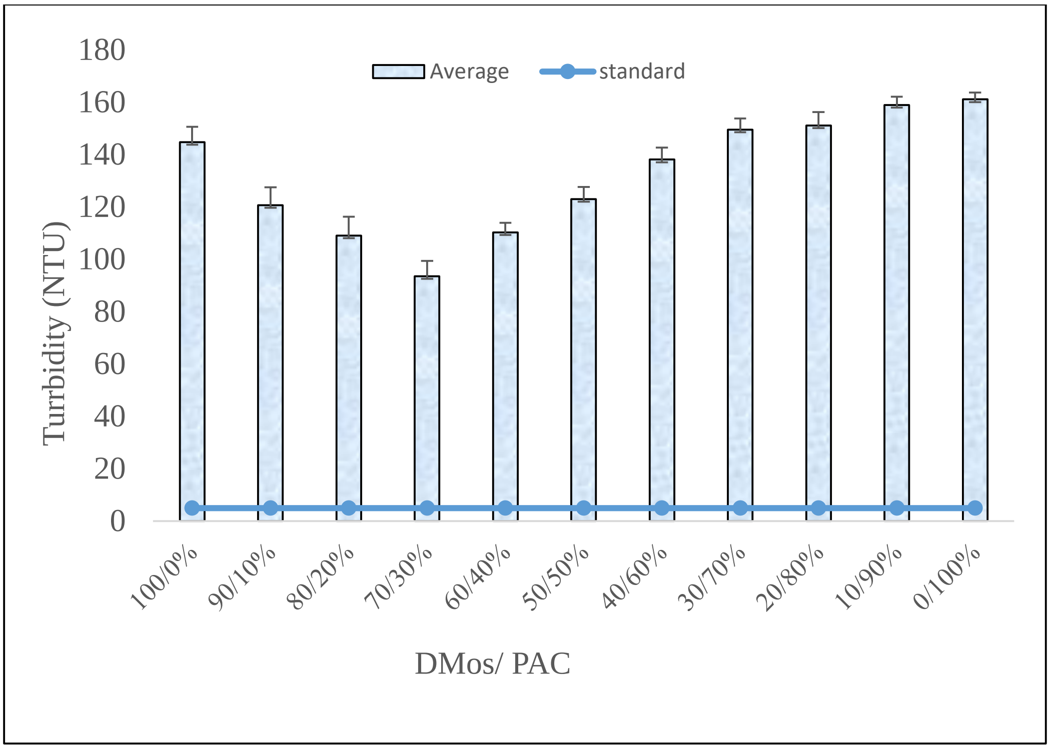

Figure 10: Variation in turbidity of wastewater with varying blended doses of DMos and PAC.

There was a significant difference ($p<0.0001$) in values of turbidity for most blended ratios of DMos and PAC. However, there was no significant difference in turbidity of wastewater, between blended coagulants ratios of 80% of DMos with 20% PAC and 60% of DMos with 40% PAC. Furthermore, there was no significant difference in turbidity of wastewater, between the blended coagulants ratios of 0% of DMos with 100% PAC and 90% of DMos with 10% PAC. Therefore, the best synergy was achieved at a combination of 70% DMos and 30% polyaluminium chloride corresponding to 93.57±3.65 NTU.

4.2.5 Fatted *Moringa oleifera* Seed Blended with Polyaluminium Chloride

Variation in turbidity of wastewater with varying doses blends of FMos and PAC shown in Figure 11. There was a decrease in the turbidity of wastewater as the amount of PAC increased with a decrease in FMos coagulant, to a minimum mean value of 113.44±4.16NTU corresponding to dosage ratio of 70% FMos and 30% PAC at a mean pH value of 6.7. However, the reduced turbidity value exceeded the drinking limits of WHO, NEMA and USEPA.

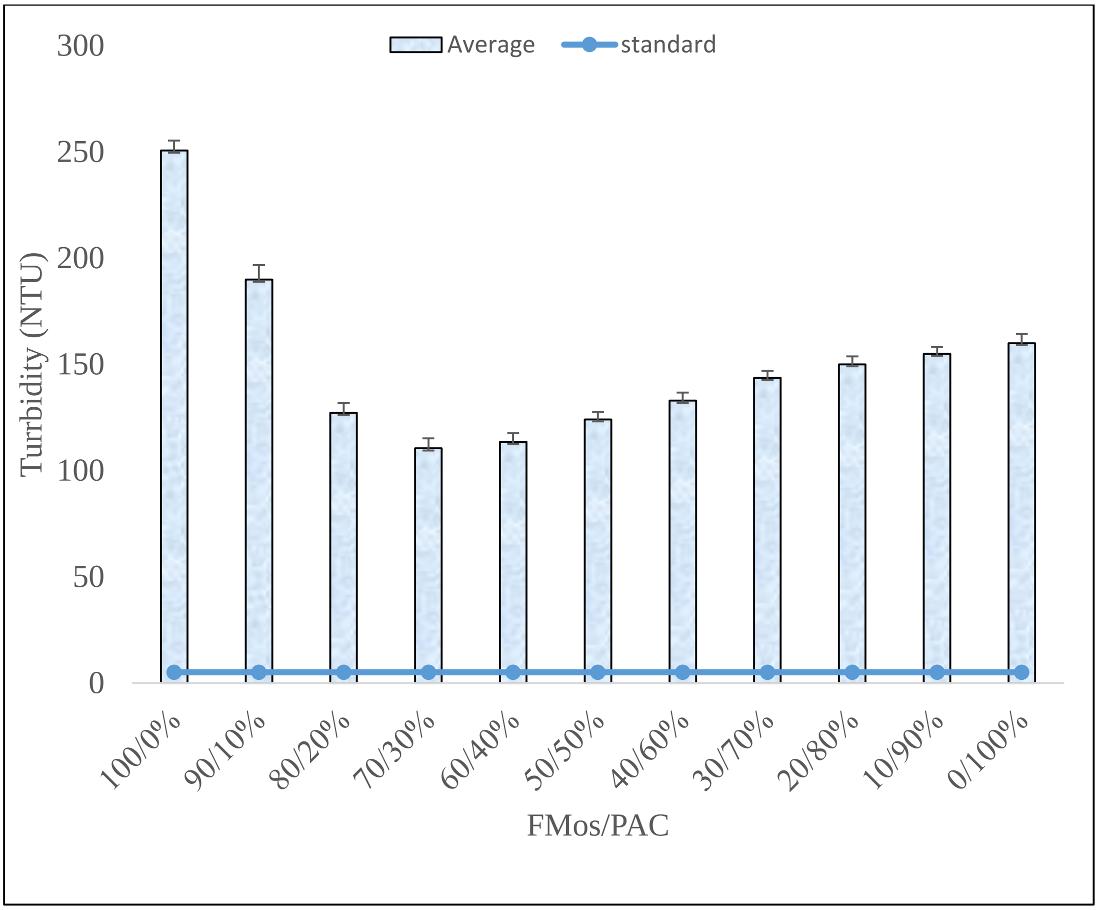

Figure 11: Variation in turbidity of wastewater with varying combinations of FMos blended with polyaluminium chloride

Afterwards, there was an increase in turbidity of wastewater with increase in % PAC and decrease in %FMos coagulants blends. The increase in turbidity of wastewater reached a maximum mean value of 160.0±4.27NTU coinciding to coagulants blends of 0% FMos and 100% PAC. There were no significant differences in the turbidity of the wastewater for the blends of 70% FMos with 30% PAC and 60% FMos with 40% PAC. However, all other combinations were significantly different ($p<0.0001$) in turbidity reduction of the wastewater.

4.2.6 Bark of *Moringa oleifera* Blended with Polyaluminium Chloride

Variation in turbidity of wastewater with varying combinations of BMo blended with polyaluminium chloride is shown in Figure 12. There was a steady decrease in turbidity of wastewater from 0% PAC combined with 100% BMo to the blend of 100% PAC with 0% BMo at mean pH value of 6.7.

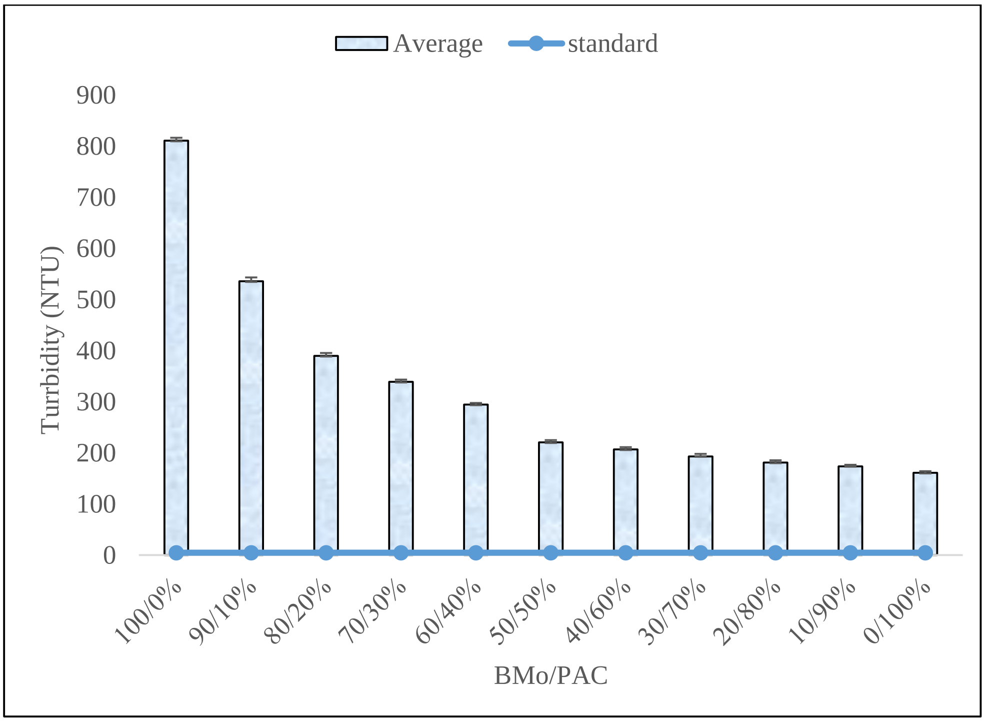

Figure 12: Variation in turbidity of wastewater with varying blended doses of BMo and PAC.

There was a significant difference ($p<0.0001$) in turbidity of the wastewater for all combinations. There was no synergy in the blended doses of BMo and PAC coagulants.

4.3 Efficacy of Treating Wastewater using blended of *Moringa oleifera* and Chemical Coagulants

4.3.1 Biological Oxygen Demand

Biological oxygen demand (BOD) was established for both plant and chemical-based coagulants. The highest BOD reduction among individual coagulants was of alum at 327.78±9.82 mg/L with efficiency of 90.93% followed by PAC 294.44±10.76 mg/L with efficiency of 81.78%. The lowest BOD reduction was by BMo coagulant as 220.67±9.11 mg/L at an efficiency of 61.17%. There was a significant difference in BOD reduction among all individual coagulants ($p<0.0001$) as portrayed in table 3. Among the blended coagulants doses the highest BOD reduction of 332.00±5.20 mg/L with efficiency of 92.05% was established by the blend of DMos/Alum followed by FMos/Alum (328.67±5.57 mg/L), DMos/PAC (327.33±7.94 mg/L) with efficiencies of 91.30 and 90.59% respectively. The lowest significant BOD reduction was by the blend of FMos/PAC at 305.33±8.94 mg/L with efficiency of 84.59% ($F_{0.05\ (3,\ 32)}$ =26.48, $p<0.0001$) as portrayed in table 3. Despite the achieved reductions by individual and blended coagulants, only the blend of DMos/Alum reduced BOD to levels within (20-30 mg/L) WHO, NEMA and USEPA drinking water standards.

Table 3: Biological Oxygen Demand of treated wastewater by various coagulant

Coagulant	Initial (mg/L)	Final (mg/L)	Reduction(mg/L)	Efficiency (%)
Alum	360.4±7.3	32.7±4.7	327.8	90.9
PAC	360.0±7.0	65.6±6.7	294.4	81.8
DMos	360.9±7.7	78.4±6.1	282.4	78.3
FMos	361.6±9.3	88.7±4.7	272.9	75.5
BMo	360.7±6.3	140.0±5.5	220.7	61.2
DMos/Alum	360.7±5.0	28.7±3.2	332.0	92.1
FMos/Alum	360.0±5.5	31.3±4.0	328.7	91.3
DMos/PAC	361.3±6.9	34.0±3.7	327.3	90.6
FMos/PAC	360.9±7.4	55.6±3.1	305.3	84.6

4.3.2 Chemical Oxygen Demand

Alum portrayed a high Chemical oxygen demand (COD) reduction of 468.89±11.54 mg/L with a reduction efficiency of 78.32% followed by PAC 421.33±10.05 mg/L with 69.96% efficiency. For *Moringa oleifera*, DMos achieved a reduction of 384.89±7.94 mg/L at an efficiency of 64.22% while FMos had a reduction of 364.44±12.20 mg/L at an efficiency of 61.09%. The least COD reduction was by BMo with an efficiency of 50.45% at COD reduction levels of 301.33±14.28 mg/L. COD reductions among all individual coagulants were significantly different ($p<0.0001$) as shown in table 4.

Table 4: Chemical Oxygen Demand of treated wastewater by various coagulant

Coagulant	Initial (mg/L)	Final (mg/L)	Reduction(mg/L)	Efficacy (%)
Alum	598.7±8.8	129.8±5.9	468.9	78.3
PAC	602.2±8.8	180.9±6.4	421.3	70.0
DMos	599.3±9.1	214.4±6.9	384.9	64.2
FMos	596.4±9.2	232.0±7.1	364.4	61.1
BMo	597.1±13.8	295.8±9.5	301.3	50.5
DMos/Alum	599.8±9.4	113.8±4.1	486.0	81.0
FMos/Alum	598.2±8.4	127.6±6.0	470.7	78.7
DMos/PAC	598.2±12.5	118.0±5.5	480.2	80.3
FMos/PAC	600.0±7.9	168.0±4.9	432.0	72.0

Among the blended coagulants COD reductions were high in DMos/Alum (486.00±11.40 mg/L), DMos/PAC (480.22±11.85 mg/L) and FMos/Alum (470.67±8.31 mg/L) reduction efficiencies of 81.02%, 80.27% and 78.68% respectively. The blend of FMos/PAC had significantly low COD reduction of 72.00 mg/L ($p<0.0001$) as portrayed in table 4. However, the reduced COD levels exceeded the WHO, NEMA and USEPA drinking water limits of less than 90 mg/L COD.

4.3.3 Color

Alum, as an individual coagulant had the color reduction efficiency of 96.61% at an average of 869.67±52.45 PCU. DMos followed with a reduction of 833.17±22.68 PCU at an efficiency of 94.98%. FMos had color reduction efficiency of 80.22% while PAC Colour reduction efficiency was 73.34%. BMo had the lowest color reduction of mean value of 133.33±45.35 PCU at an efficiency of 15.43% and was significantly different from other coagulants ($p<0.0001$) as portrayed in table 5.

Table 5: Color of treated wastewater by various coagulant

Coagulant	Initial (PCU)	Final (PCU))	Reduction (PCU))	Efficacy (%)
Alum	900.0±50.2	30.3±3.9	869.7	96.6
PAC	881.7±27.4	235.0±13.7	646.7	73.3
DMos	877.2±22.2	44.1±2.9	833.2	95.0
FMos	859.4±37.0	170.0±12.5	689.4	80.2
BMo	863.9±30.7	730.6±35.8	133.3	15.4
DMos/Alum	876.4±36.3	14.4±2.9	634.5	98.3
FMos/Alum	891.7±17.7	27.7±3.9	864.0	96.9
DMos/PAC	873.3±47.0	40.2±4.6	833.2	95.4
FMos/PAC	881.1±19.5	167.8±13.5	713.3	81.0

Among the blended coagulants, color reduction was high in the blends of DMos/Alum, FMos/Alum, DMos/PAC with reductions averages of 845.44±27.71 PCU, 864.00±18.55 PCU and 833.17±48.36 PCU with efficiencies of 98.29%, 96.90%, and 95.38% as shown in table 5. The blend of FMos/PAC had the lowest color reduction of 713.33±23.98 PCU with an efficiency of 80.95% significantly different from other combinations ($p<0.0001$). DMos/Alum reduced color to less than 15 PCU which are allowable drinking water limits of WHO, NEMA and USEPA.

4.3.4 Total dissolved solids

TDS reduction was high in DMos treatment with an average of 1564.44±43.91 mg/L at a reduction efficiency of 86.07% followed by FMos (1394.44±79.23 mg/L) and alum (1363.33±68.01 mg/L) with reduction efficiencies of 78.51% and 74.89% respectively as portrayed in table 6. BMo and PAC individual coagulants resulted in the lowest TDS reductions of 964.44±27.44 mg/L and 500.00±56.57 mg/L with efficiencies of 53.72%

and 28.04% respectively. There was a significant difference in TDS reductions among all individual coagulants ($p<0.0001$).

Table 6: Total Dissolved Solids of treated wastewater by various coagulant

Coagulant	Initial (mg/L)	Final (mg/L)	Reduction(mg/L)	Efficacy (%)
Alum	1820.0 ± 51.5	770.0 ± 39.69	1050.0	57.7
PAC	1781.1 ± 35.9	1281.1 ± 41.7	500.0	28.1
DMos	1817.8 ± 41.2	253.3 ± 31.6	1564.4	86.1
FMos	1775.6 ± 32.1	381.1 ± 60.7	1394.4	78.5
BMo	1795.6 ± 34.3	831.1 ± 32.6	964.4	53.7
DMos/Alum	1784.4 ± 39.1	267.8 ± 28.6	1516.7	85.0
FMos/Alum	1778.9 ± 29.3	355.6 ± 41.0	1423.3	80.0
DMos/PAC	1815.6 ± 39.1	286.7 ± 32.8	1528.9	84.2
FMos/PAC	1803.3 ± 38.1	447.8 ± 41.5	1355.6	75.2

The reductions of TDS were high in the blends of DMos/Alum (1516.67±55.23 mg/L) and DMos/PAC (1528.89±45.12 mg/L) with no significant difference ($p>0.05$) with reduction efficiencies of 84.98% and 84.21% respectively. The blends of FMos/Alum and FMos/PAC were significantly different ($p<0.0001$) with TDS reductions of 1423.33±60.21 mg/L and 1355.56±51.51 mg/L respectively as shown in table 6. Despite the efficient TDS reductions obtained, PAC reduced levels exceeded the TDS drinking water limits of less than 1000 mg/L by WHO and NEMA.

4.3.5 Electrical Conductivity

The highest EC reduction achieved by DMos coagulant with a mean value of 2032.22±36.67 µs/cm at an efficiency of 82.36% followed by a blend of FMos/Alum and FMos with reductions of 1776.67±53.39 µs/cm and 1773.33±58.95 µs/cm at efficiencies of 71.71% and 70.98%. BMo and PAC coagulants had the lowest EC reductions of 1191.11±24.21 µs/cm and 572.22±66.85 µs/cm with reduction efficiencies of 48.11% and 23.01% respectively. There was a significant difference in EC reductions among the individual coagulants ($p<0.0001$). Albeit, the EC reduced levels by PAC coagulant exceeded WHO, NEMA and USEPA drinking water EC allowable limits. For the blended coagulants DMos/Alum had the highest EC reduction of 1981.11 ± 66.04 µs/cm followed by DMos/PAC combination (1964.44±50.77) with efficiencies of 79.98% and 79.32% respectively, which were significantly different ($p<0.0001$) from EC reductions other blends as shown in table 7.

Table 7: Electrical conductivity of treated wastewater by various coagulant

Coagulant	Initial (µs/cm)	Final (µs/cm)	Reduction(µs/cm)	Efficacy (%)
Alum	2477.8 ± 42.4	885.6 ± 30.9	1776.7	64.3
PAC	2486.7 ± 32.0	1914.4 ± 47.2	572.2	23.0
DMos	2467.8 ± 38.0	435.6 ± 34.7	2032.2	82.4
FMos	2497.8 ± 38.0	724.4 ± 28.8	1773.3	71.0
BMo	2476.7 ± 41.8	1285.6 ± 51.0	1191.1	48.1
DMos/Alum	2476.7 ± 44.7	495.6 ± 39.1	1981.1	80.0
FMos/Alum	2467.8 ± 38.0	691.1 ± 39.5	1776.7	72.0
DMos/PAC	2476.7 ± 45.6	512.2 ± 33.5	1964.4	79.3
FMos/PAC	2497.8 ± 38.0	650.0 ± 48.7	1847.8	74.0

4.3.6 Total Suspended solids

Wastewater from MIWPM was characterized with fibres that formed part of the total suspended solids. TSS reduction by individual coagulants was high in Alum (558.33±28.53 mg/L), DMos (523.56±20.80 mg/L), FMos (529.56±44.36 mg/L) and PAC (522.8±20.72mg/L) with reduction efficiencies of 96.64%, 95.07%, 93.78% and 91.47% respectively. BMo had the lowest TSS reduction (300.00±13.69 mg/L) with a significant difference ($p<0.0001$) as shown in table 8. However, the reduced TSS levels by PAC, FMos and BMo exceeded the allowable drinking water thresholds of 30mg/L in accordance to WHO, NEMA and USEPA. The blended coagulants achieved TSS reductions as follows; DMos/Alum (558.67±43.42 mg/L), FMos/Alum (549.00±23.59 mg/L), DMos/PAC (546.11±17.96 mg/L) and FMos/PAC (544.56±26.19 mg/L). All the blends were significantly different ($p<0.0001$) in total suspended solids reduction as illustrated in table 8.

Table 8: Total suspended solids of treated wastewater by various coagulant

Coagulant	Initial (mg/L)	Final (mg/L)	Reduction(mg/L)	Efficacy (%)
Alum	577.8 ± 30.3	19.4 ± 3.7	558.3	96.6
PAC	571.6 ± 22.4	48.8 ± 4.9	522.8	91.5
DMos	550.7 ± 19.6	27.1 ± 3.1	523.6	95.1
FMos	564.4 ± 43.9	34.9 ± 3.7	529.6	93.8
BMo	556.1 ± 16.7	256.1 ± 12.2	300.0	53.9
DMos/Alum	564.4 ± 43.9	5.8 ± 2.1	558.7	99.0
FMos/Alum	566.0 ± 23.5	17.0 ± 4.6	549.0	97.0
DMos/PAC	557.2 ± 17.0	11.1 ± 3.2	546.1	98.0
FMos/PAC	573.3 ± 27.8	28.8 ± 6.1	544.6	95.0

4.4 Efficacy in Microbial load Reduction

Microbial load reduction was determined for the individual and blended coagulants. The initial average microbial load in the wastewater from wastepaper recycling mill was 529778.0±15699.8 CFU/ml. For individual coagulants, DMos had the lowest final load (13111.1±3480.1 CFU/ml) with the reduction efficiency of 97.51% followed by FMos (31777.8±3800.6 CFU/ml) with a reduction efficiency of 93.99%, while PAC (120888.8±13233.0 CFU/ml) had the least reduction efficiency of 77.19%. There was a significant difference (p=0.0000) in microbial load reduction among all individual coagulants treatments as shown in figure 13.

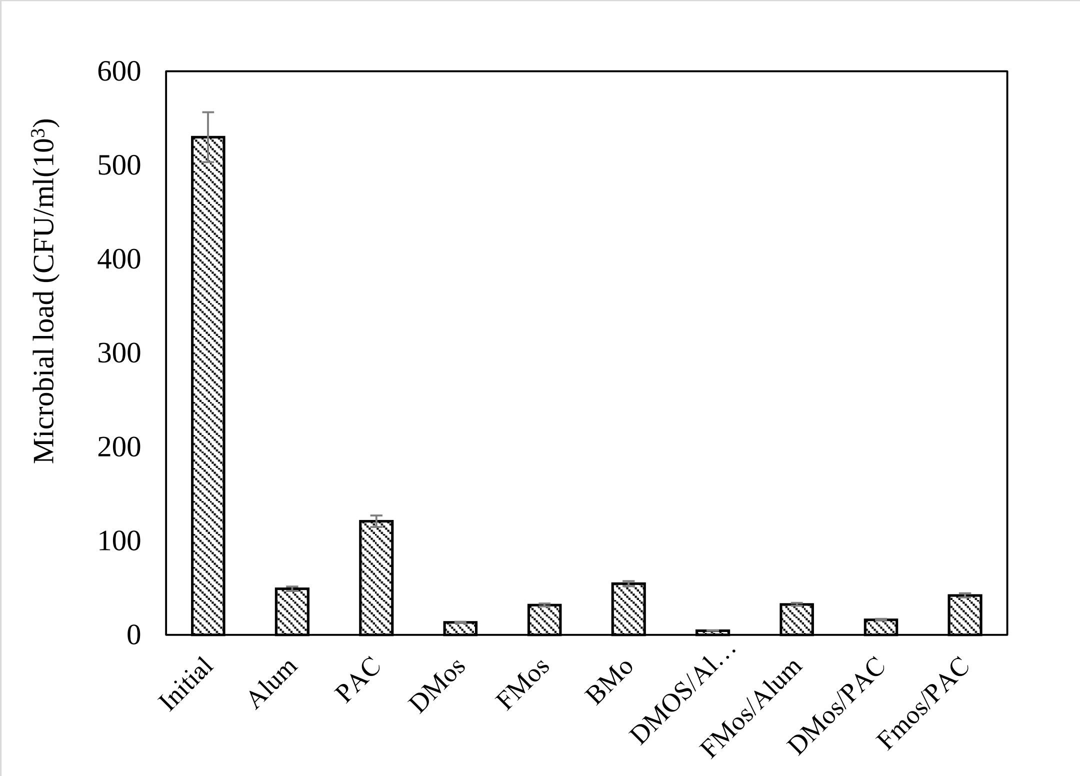

Figure 13: Microbial load reduction by individual and blended coagulants

For the blends, DMOS/Alum had the lowest microbial load of 4444.4±12806.2 CFU/ml with a reduction efficiency of 99.16% followed by DMos/PAC (16000.0±3972.1 CFU/ml) with a reduction efficiency of 96.99%. FMos/Alum (32444.4±2185.8 CFU/ml) was third with a reduction with efficiency of 93.87% with a significant difference. The highest final microbial load was with FMos/PAC (42000.0±3464.1 CFU/ml) with a reduction with efficiency of 93.87%. There was a significant difference ($F_{0.05\ (4,\ 40)}$ =10203.97, p=0.0000) in all the final microbial load for all blends of coagulants. However, the reduction efficiencies of the individuals and blends exceeded the WHO, NEMA and USEPA drinking water limits of Nil CFU/ml.

CHAPTER FIVE

DISCUSSIONS

5.1 Effective Doses of Individual Coagulants

The effective doses for individual coagulants gave varying final turbidity of the wastepaper recycling mill. Alum, chemical coagulant and DMos bio-coagulant had the most effective turbidity reduction. Aluminium sulphate was effective due to hydrolysed aluminium ions that adsorbed colloidal particles and chemically neutralized their charges, therefore achieving best final turbidity (Naceradska, Pivokonska, & Pivokonsky, 2019). Through compression of the diffusing double layer mechanism surrounding individual particles, the positively charged hydrolyzed metal ions in the solution reduced repulsive negatively charged forces between colloids, causing these particles to shift to each other. This led to subsequent agglomeration (Boulaadjoul *et al*., 2018; Mehmood *et al*., 2019). Rapid mixing of the alum concentrations could have facilitated rapid hydrolysis, contact between the ions and colloidal substances which led the formation of large flocs (Sun, Zhao, Yan, Jia, & Yang, 2020).

Due to maximum destabilization of colloidal particles by aluminium ions, the effective dose was established and doses exceeding effective dosage point resulted in reversed electrical charges around the colloidal particles. This prevented destabilization and induced restabilization as particles repelled each other, resulting in turbidity increase (Boulaadjoul *et al*., 2018; Soros, Amburgey, Stauber, Sobsey & Casanova, 2019). The efficiency of turbidity reduction levels from this study were in consistence with the findings of Boulaadjoul *et al*. (2018) who reported 97.1% turbidity reduction using alum in treatment of paper mill effluent. Additionally, Öztürk & Özcan. (2021) reported 97% removal efficiency for turbidity using alum in chemical coagulation of paper industry wastewater.

The gradual increment of DMos coagulant dose resulted in the decrease of the turbidity levels until the effective dose was established. Presence of lectins and albumins in DMos might have caused cationic polymers to bind themselves together with colloidal particles in the wastewater via adsorption and particle bridging mechanisms, leading to the formation of flocs (Desta & Bote, 2021). With adequate agitation, the bound particulates grew in size, forming larger flocs that settled through gravity (Valverde *et al*., 2018; Villaseñor-Basulto et al., 2018). In addition to cationic proteins, the presence of -Fe2O3-MO composed of hematite nanoparticles in *Moringa oleifera* seeds might have influenced coagulation by adsorption and charge neutralization mechanisms (Nordmark, Przybycien, & Tilton, 2016).

The findings were in line with those of Skaf et al, (2021) who observed that *Moringa oleifera* defatted seed powder had a turbidity removal efficiency of 90%. Consequently, utilization of *Moringa oleifera* defatted seed powder was reported to achieve turbidity reduction efficiency of 97.48% from coal plant wastewater making it an effective bio-coagulant substitute for metallic-based coagulants (Kapse & Samadder, 2021). Moreover, Desta & Bote. (2021), reported turbidity reduction of 98.5% and 95% at basic and acidic pH conditions respectively in treatment of domestic wastewater using defatted *Moringa oleifera* seed powder.

The turbidity reduction by polyaluminium chloride was due to polymeric species that are highly cationic thus the coagulation mechanisms and zeta potential of the flocs. The dosage of PAC led to charge neutralization and sweep coagulation mechanisms which enabled the multivalent aluminium ions of Al_c species and Al_a species to neutralize the colloidal particles in the water, resulting in low residual turbidity (Nti, Buamah, & Atebiya, 2021; Zhang et al., 2018). Stabilization, charge neutralization destabilization, and sweep zones all occurred successfully as polyaluminium chloride doses increased until an effective dose was established. After charge neutralization, zeta potential dominance increased PAC precipitation (El Foulani, Jamal-eddine, & Lekhlif, 2022) Additional of PAC dose beyond the effective dose increased the turbidity of wastewater (El Foulani *et al*., 2022). This was due to the decreased zeta potential of PAC hydrolysed precipitates beyond the charge neutralization, destabilization and sweep coagulation zones, forming a saturation point (Maldhure, Khadse & Labhasetwar, 2022). The research findings are in line with those of Yang, Li, Zhang, Wen, & Ni (2019) who reported 95.8% turbidity removal using polyaluminium chloride in steel mill waste pickling liquor. However, these results were in contrast with those reported by Ansari, Alavi & Yaseen. (2018) in that PAC at 1500mg/L optimum dosage achieved 44% turbidity reduction from wastepaper-recycled wastewater.

The use of FMos reduced turbidity, but only to a lesser extent in comparison with DMos. Increased doses of FMos led to lowered levels of turbidity until an effective dose was established. This was probably as a result of the cationic proteins of lectins and albumins functional groups in *Moringa oleifera* seeds (Nimesha *et al*., 2021; Okuda & Ali, 2019). These cationic proteins acted as a crosslink to water colloids, neutralizing their negative charges and weakening electrostatic double layer. The coagulation mechanisms were achieved through adsorption, particle bridging, surface complexation and particles precipitation that led to flocs formation (Hoa & Hue, 2018). These flocs were trapped and deposited as sludge at the bottom of the beakers. However, the presence of high-oleic oils of high monosaturated fatty acids representing 36.7% of the seed weight inhibited the dissolving of the active cationic polyelectrolytes that facilitate coagulation (Hoa & Hue, 2018; Magalhães *et al*., 2021). The oil generated an emulsion that suppressed the formation of flocs by inhibiting contact during the coagulant adsorption mechanism (Rai *et al*., 2022). The findings were in line with those of

Andrade *et al*. (2021) who observed that *Moringa oleifera* fatted seed powder at 600mg/L had a turbidity removal efficiency of 92% from domestic wastewater tertiary treatment although lower than that of defatted seeds. Additionally, Boulaadjoul *et al*, (2018) reported 96.02% turbidity reduction from paper mill effluent primary treatment using activated crude *Moringa oleifera* seeds. Furthermore, *Moringa oleifera* crude seed powder as a bio-coagulant resulted to less than 5 NTU turbidity levels in raw water (Zaid *et al*., 2019).

Moringa oleifera bark (BMo) powder reduced turbidity by 54.94% although this turbidity removal efficiency was the least achieved by the other individual coagulants. The bark of *Moringa oleifera* is reported to have 1.33% protein content which could contribute to coagulating impacts thus reduced turbidity. Adsorption mechanism of the cationic proteins and bioactive compounds facilitated charge neutralization of the colloidal particles in wastewater (George *et al*., 2016). This study findings were in line with those of (George *et al*., 2016) who reported visible 33.4% and 77.3% turbidity decrease from Hebbal lake water and Bellandur lake water respectively using the bark of *Moringa oleifera*.

5.2 Effective Doses of the Blended Coagulants

The blend of DMos/alum at effective dose ratio of 20/80% resulted in high turbidity reductions at a removal efficiency. The effective coagulation might have been facilitated by cationic proteins in DMos and the hydrolysed aluminium hydroxide ions in alum as reported by Mehmood *et al*., 2019; Magalhães *et al*., 2021. Rapid mixing aided in the hydrolysis of aluminium ions alongside lectins and albumins leading to effective coagulation of the wastepaper recycling mill wastewater. Particles destabilization was achieved via adsorption, charge neutralization and compression of double layer mechanisms aided in formation of enormous flocs (Sun *et al*., 2020; Desta

& Bote, 2021). The blending effect facilitated efficient turbidity removal in comparison with individual coagulants. The research results are consistent with those of Jagaba *et al*. (2018) who reported a turbidity reduction efficiency of 91.40% from combined alum and defatted *Moringa oleifera* seeds for the treatment of palm oil manufacturing effluent. In addition, Elemile *et al*. (2021), reported that the blend of defatted *Moringa oleifera* seeds and aluminium sulphate at optimum dosage and one hour settling time reduced turbidity of dairy wastewater with 89.81% efficiency.

The blend of FMos and alum at effective dose ratio of 30/70% yielded the best turbidity removal efficiency of 98.65%. Through particle adsorption, bridging effect, and charge neutralization mechanisms of the FMos and alum, the availability of hydrolyzed unstable aluminium species dimers and cationic proteins contributed to the formation of precipitated solids. However, the oil content of the fatted *Moringa oleifera* seeds hampered the seeds' efficient coagulation effect (Magalhães *et al*., 2021). This research findings were consistent with those of Cardoso Valverde *et al*., (2018) who reported synergic effectiveness in turbidity reduction of up to 70% achieved by dosing 15mg/L alum and 17.5mg/L *Moringa oleifera* seeds in surface water coagulation. Moreover, the utilization of crude *Moringa oleifera* seeds and aluminium sulphate at 50:50 ratio resulted to more than 90% turbidity removal from municipal wastewater (Kane *et al*., 2016). A combined concentration of 0.9 g/L fatted *Moringa oleifera* seeds and 0.03 g/L aluminium sulphate reduced turbidity in raw water by 80% Anderson *et al*., (2021) and these results are confirmed by the findings of this study.

The blend of defatted *Moringa oleifera* seed and polyaluminium chloride (DMos/ PAC) attained 94.08% turbidity removal at 70/30% effective dose. The presence of cationic proteins and polyelectrolytes in defatted Moringa seeds and polymeric species of polyaluminium chloride that are strongly cationic, might have contributed to flocs formation and settling, reducing turbidity. DMos enhanced adsorption of colloidal charged particles while PAC facilitated interparticle bridging and sweep coagulation mechanisms which resulted to charge neutralization thus settling of precipitated flocs at the bottom through gravity (Saleem & Bachmann, 2019). Additionally, rapid mixing enhanced polymerisation of PAC species zeta potential and the presence of cationic lectins, albumins and hematite nanoparticles polyelectrolytes achieved the synergic coagulation resulting in low residual turbidity (Saleem & Bachmann, 2019; El Foulani et al., 2022). These research findings were consistent with those of Valverde *et al*., (2018) who reported 92% turbidity removal efficiency at dosage ratio of 60%/40% at optimal dose of 50 mg/L of defatted *Moringa oleifera* seeds combined with 12.5 mg/L of PAC in treatment of raw water. Furthermore, a composite coagulant of *Moringa oleifera* polypeptides and polyaluminium chloride lowered turbidity by 86.11 % at 4.32 mg/L coagulant dosage which was more efficient compared to *Moringa oleifera* seeds that removed 38.36 % at 320 mg/L dosage in treatment of hospital wastewater (Yousefi et al., 2022) (Nonfodji *et al*., 2020).

Combined FMos and PAC effectively reduced turbidity although, lower in comparison to the DMos/PAC blended coagulant. Availability of cationic polymers of hydrolyzed polyaluminium chloride alongside hemagglutinating polypeptides trimers and dimers of albumins in fatted *Moringa oleifera* seeds may have led to destabilization of colloidal particles in the wastewater owing to adsorption, sweep coagulation, interparticle bridging and charge neutralization mechanisms (Saleem & Bachmann, 2019). Despite the availability of polypeptides and polymeric cationic Polyaluminium chloride species, presence of 30% and above oil content in crude *Moringa oleifera* seed might have hampered efficacious coagulation (Magalhães *et al*., 2021). This was supported by Olagbemide & Alikwe (2014) who asserted that the crude *Moringa oleifera* seed powder have substantially higher oil content than defatted moringa seed powder from moringa seed elemental composition. In agreement with this study findings, the combination of chitosan bio-coagulant at 9.28 mg/L and polyaluminium chloride at 7.6 mg/L resulted to 99.85% turbidity reduction efficiency from raw water coagulation (Yousefi, Jabbari & Sedighi, 2022).

5.3 Efficacy Treatment of Wastepaper Recycling Mill Wastewater by Individual and Blended coagulants Effective Doses

5.3.1 Biological oxygen demand (BOD)

Individual and blended coagulants at their effective doses contributed to precipitation of the highly unstable colloidal particles from the treated wastewater as well as reduction of easily biodegradable matter, which aided in BOD reduction levels. The effectual coagulation acquired through compaction of the double layer, particle adsorption, interparticle bridging, and charge neutralization mechanisms from the blend of DMos and alum might have contributed in the effectiveness in BOD reduction (Mehmood *et al*., 2019). The lowest BOD reduction was due to the inadequate coagulation attributed to low polypeptides concentration in BMo, which facilitate colloidal particles destabilization when compared to DMos and FMos bio-coagulants. Defatted and fatted *Moringa oleifera* seeds lowered BOD levels effectively due to the presence of polyelectrolytes in the seeds. This might have led to coagulation effect via adsorption and interparticle bridging, which resulted in charge neutralization and thus a decrease in organic load from the treated wastepaper recycling mill wastewater. Regardless, the oil content in the fatted seeds impeded effectual coagulation and contributed to biodegradable matter hence lower BOD reduction as compared to defatted seeds (Boulaadjoul *et al*., 2018).

The presence of multivalent aluminum species in polyaluminium chloride, charge neutralization occurred via sweep coagulation and charge neutralization destabilization mechanisms (Nti *et al*., 2021). Efficient coagulation at effective dose of PAC resulted in the elimination of colloidal particles and organic load. However, the blended DMos/PAC and FMos/PAC resulted in higher BOD removal efficiencies. Compared to individual coagulants, the blended coagulants yielded high reduction efficiencies. The findings were in accordance with those of Al-Jadabi *et al*. (2021) who described significantly higher BOD reductions with aluminium sulphate as likened to fatted *Moringa oleifera* seeds at 75.5% and 72% respectively from domestic wastewater treatment through coagulation process. Additionally, treatment of municipal wastewater using defatted *Moringa oleifera* seeds reduced BOD levels by 91.81%, which was slightly higher than the findings of this study due to the nature of wastewater involved (Adelodun *et al*., 2019). In contrast with these research findings, Elemile *et al*. (2021) concluded that the combination of alum and defatted *Moringa oleifera* seeds were not effective in BOD level reductions from dairy wastewater even after 1 hour settling time.

5.3.2 Chemical Oxygen Demand (COD)

The combinations of effective doses of DMos/Alum and DMos/PAC had relatively high chemical oxygen demand removal efficiencies. This was due to the prevalence of polymerized metal ionic species generated by alum and PAC as well as positively charged polypeptides of defatted *Moringa oleifera* seeds that led to effective coagulation. This eliminated both inorganic and organic pollutants by embedding adsorption of particulates consequently forming flocs thus high COD reduction efficacy was achieved (Naceradska *et al*., 2019; Desta & Bote, 2021). The effective doses ratio of FMos/Alum and FMos/PAC blends led to COD reduction effectiveness although lower than defatted seeds blends. Despite the availability of active proteins functional groups for adsorption mechanism in *Moringa oleifera* seeds, COD reduction percentage effectiveness were lower compared to chemically synthesized coagulants (Hoa & Hue, 2018). This could be indicative of the presence of pre-hydrolyzed multivalent aluminium ions in polyaluminium chloride and solubilized metal ions, which facilitated subsequent particle agglomeration after the amorphous aluminium hydroxide ions in aluminium sulphate limited the repulsive charges of colloidal particles (Sun *et al*., 2020). The concentration of organic material in *Moringa oleifera* seeds and bark influenced low COD reductions. Furthermore, the oil content of crude *Moringa oleifera* seeds limited COD removal efficiencies by increasing organic compounds in the coagulant.

These study findings were consistent with those of Dehghani & Alizadeh (2016) who reported that defatted *Moringa oleifera* seeds coagulant had a lower COD removal efficiency of 38.60 % compared to aluminium sulphate, with a COD removal rate of 51.72 % in treatment of oil refinery wastewater. Whilst the blend of alum and defatted Moringa seeds in a 2:1 dosage ratio resulted in a 50.41 % COD reduction from refinery industrial wastewater. In addition to that, *Moringa oleifera* defatted seeds had a lesser COD decrement of 72 % than aluminium sulphate, which whittled down COD by 75.5 % at a dosage of 150 mg/L in treating domestic wastewater (Al-Jadabi *et al*., 2021). In contrast with these findings, Hoa & Hue, (2018) reported 82.4% COD removal using protein extracted *Moringa oleifera* crude seeds from municipal wastewater. Moreover, Rifi *et al*. (2022) reported 88% COD removal using *Moringa oleifera* seeds in the treatment of wastewater from an olive oil mill which contrasted to this study findings.

5.3.3 Color

The addition of effective doses of blended DMos/Alum to the wastepaper recycling mill wastewater led to the highest color removal. The efficient color removal was attributed to positively charged proteins in defatted *Moringa oleifera* seeds which enabled adsorption and interparticle bridging coagulation mechanisms, destabilizing colloidal particles via charge neutralization (Wagh *et al*., 2022). Furthermore, the monomeric aluminium solubilized species in aluminium sulphate figured prominently in destabilization of negatively charged particles via electrostatic interactions. Precipitation of colloidal particles reduced the color levels in the treated wastewater (Mehmood *et al*., 2019). Through the clustering of the precipitated particles, the efficacious coagulation from defatted Moringa seeds and the amorphous hydrolysate ions were attributed to reduced color levels (Boulaadjoul *et al*., 2018).

The lowest removal efficiency was achieved by the coagulation of BMo due to low coagulation performance and the existence of color from the bark's components contributed. Despite the influence of multivalent aluminium complexes formed by PAC, the resultant color removal efficiency was lower than that of alum. The negatively charged colloidal particles might have enmeshed by the hydrolysate aluminium ions via charge neutralization and adsorption, culminating in their agglomeration and settling. Compared to defatted Moringa seeds, fatted *Moringa oleifera* seeds color removal was hindered by the oil present in the seed powder. Consistent with this research findings, the use of defatted *Moringa oleifera* in synthetic dairy wastewater treatment effectively reduced color levels by 94% as reported by Wagh *et al*, (2022). Additionally, Dotto *et al*. (2019) reported 82.2% apparent color removal efficiency using fatted *Moringa oleifera* seeds from textile wastewater. In alignment with the research findings, 95% color removal was reported for aluminium sulphate coagulation on paper industry wastewater (Öztürk & Özcan, 2021). In contrast, polyaluminium chloride was reported to remove 95% of color from textile dyeing effluents under optimal conditions (Islam & Mostafa, 2020).

5.3.4 Total Dissolved Solids

Defatted Moringa oleifera seeds effective dose achieved the highest TDS reduction efficiency preceded by DMos/Alum, DMos/PAC and FMos/Alum. The organic polypeptides in defatted DMos adsorbed the dissolved solids in the water through particle adsorption and bridging mechanisms hence neutralizing the charges this led to their reduction as they clumped together forming flocs (Shan *et al*., 2017). Both the blends of DMos/Alum and DMos/PAC, demonstrated the response of *Moringa oleifera* seeds significantly. Aluminium sulphate and PAC coagulation failed to effectively remove the dissolved materials as compared to *Moringa oleifera* seeds. This was factor to the existence of multivalent, solubilized, and absorbable aluminium ions, that made up a significant portion of the dissolved solids. However, during coagulation mechanisms some of these neutralized ions, were not completely eliminated as flocs clustered.

These study results confirmed with those of Panhwar *et al*. (2020) who reported TDS reduction from 2630 mg/L to 1640 mg/L using alum as a chemical coagulant in treatment of food-agro industry effluent. Moreover, aluminium sulphate at an optimal dose of 110mg/L reduced total dissolved solids by 49% from slaughterhouse wastewater (Zamani *et al*., 2019). Contrary to the findings within the study, the treatment of textile dyeing effluent with polyaluminium chloride was reported to yield 85.7% TDS reduction efficiency (Islam & Mostafa, 2020). However, in agreement with the study, treating raw water with a 60:40 dosage ratio mixture of defatted *Moringa* *oleifera* seeds and polyaluminium chloride reduced TDS levels from 171 mg/L to 43 mg/L(Cardoso Valverde *et al*., 2018).

5.3.5 Electrical Conductivity

Defatted *Moringa oleifera* seeds significantly decreased the EC levels. The removal of dissolved electrolytes could be credited to the cationic proteins functional group in the defatted seeds (Desta & Bote, 2021). These proteins adsorbed and neutralized the colloidal particles through interparticle bridging, facilitating their agglomeration and removal from the treated effluent. Similarly, 86.28% electrical conductivity reduction was reported after using defatted *Moringa oleifera* in phytoremediation of commercial laundry wastewater (Hakeem *et al*., 2019). Fatted *Moringa oleifera* seeds had a reduction efficiency lower than that of defatted seeds, this was characterized by ineffective coagulation brought about by oil availability. These study findings were consistent with Balaji & Ashwin. (2018), who reported that fatted *Moringa oleifera* achieved a reduction efficiency of 72.75% from treating textile effluent.

Moringa oleifera bark, aluminum sulphate and polyaluminium chloride had the low electrical conductivity reduction efficiencies. The existence of residual aluminium ions dissolved in water from hydrolyzed multivalent aluminium species could explain the inefficient electrical conductivity reduction using polyaluminium chloride. These research findings were in contrast with those of Islam & Mostafa, (2020) who reported 83.66% reduction efficiency of electrical conductivity in treatment of textile dyeing effluent using PAC. Notwithstanding, the findings of Marzougui *et al*. (2021) who reported 29.7% best removal efficiency of EC using defatted *Moringa oleifera* seeds at a dosage of 150 mg/L in treatment of urban wastewater. The effective doses of the blends of defatted Moringa oleifera seeds had higher EC reduction efficiencies compared to the blends of fatted Moringa oleifera seeds due to their ion adsorption ability and effective coagulation (Shan *et al*., 2017;Magalhães *et al.*, 2021). The research findings were in line with those of Gandiwa *et al*. (2020), who reported decrease in electrical conductivity to a final value of 308.2 using combination of crude *Moringa oleifera* seeds and alum in raw water treatment.

5.3.6 Total Suspended Solids (TSS)

The compacting of the double layer coagulation mechanism by positively charged aluminium ions aided the effective removal of TSS by aluminium sulphate coagulation. This lowered electrostatic repulsion between colloidal particles, causing them to switch to each other and subsequently aggregation (Naceradska *et al*., 2019). Besides, defatted *Moringa oleifera* seeds contained soluble cationic polypeptides that whittled down TSS efficiently via adsorption, interparticle bridging, and charge neutralization mechanisms (Marzougui et al., 2021). The addition of DMos destabilized the electrical interactions of the colloidal particles, causing them to cluster. The presence of oil in fatted *Moringa oleifera* seeds and low protein content in *Moringa oleifera* bark, impeded efficient TSS removal through coagulation process (Desta & Bote, 2021). Polyaluminium chloride significant TSS reduction was attributed to the prevalence of long polymeric chains of aluminium ions with a strong positive electrical charge. These ions neutralized the electrical charge on the surface of colloidal particles and reduced the force of repulsion between the particles, culminating in flocs formation that settled out (El Foulani *et al*., 2022).

The blended coagulants at their achieved their efficiencies due to presence of cationic polypeptides from *Moringa oleifera* seeds and polymeric hydrolysed ions of polyaluminium chloride and amorphous ions in aluminium sulphate that conducted coagulation. The study findings were in consistent with Jagaba *et al*. (2018), who reported 97.19% TSS removal efficiency in treatment of palm oil mill wastewater using combined dosage of 4g/L of alum and 2g/L of *Moringa oleifera* seeds. Moreover, the comparative coagulation efficacy using defatted *Moringa oleifera* seeds and aluminium sulphate for domestic wastewater achieved 95.5% and 96.8% TSS reduction (Al-Jadabi *et al*., 2021). While incorporating crude *Moringa oleifera* seeds as a Phyto coagulant at a dosage of 100mg/L on a vertically designed subsurface flow wetland for an 8-day retention time lowered TSS with 99.63 % efficiency in the treatment of coffee processing wastewater (Rahmadyanti *et al*., 2020). Additionally, defatted *Moringa oleifera* seeds removed 97.4% total suspended solids from treatment of coal beneficiation plant effluent (Kapse & Samadder, 2021).

5.4 Efficacy of Microbial load Reduction

The removal of pathogens from the wastepaper recycling mill wastewater was effectively achieved by the coagulation effect of effective doses of DMos followed by FMos and BMo bio-coagulants. The bioactive components in *Moringa oleifera* seeds, such as 4-[(4′-O-acetyl-L-rhamnosyloxy)-benzyl] isothiocyanate complexes and fatty acids, enabled the antimicrobial effects by destroying the exterior microbial cell membranes. This resulted in an increase in the discharges of solutes from the microbial cells, thus their death (Prajapati *et al*., 2022). Additionally, the influence of minerals, ketones, esters, and aromatic amines in the seeds precluded the early stages of bacterial cell wall synthesis and buildup onto cellular membrane that made them impermeable, this impeded the metabolism of the bacteria and caused cell death (Taiwo *et al*., 2020). Effective coagulation properties of *Moringa oleifera* seeds through adsorption, interparticle bridging, and charge neutralization techniques accomplished efficient removal of bacterial load as agglomerated flocs. In addition, the availability of sterol glycosides compounds in the branches bark of *Moringa oleifera* inhibited the growth of all gram-positive bacteria thus the effective microbial load reduction from the treated wastewater (Azad & Hassan, 2020).

The combination of DMos/Alum at their effective dose ratio had the highest microbial load reduction efficiency this was factor to antimicrobial properties of *Moringa oleifera* seeds and ability of alum to coagulate total suspended solids that could form part of the microbial load. Additionally, microbial growth inhabitation could have resulted from lowered pH levels from coagulation effects of aluminium ions (Taiwo *et al*., 2020). In accordance with study results, utilizing defatted *Moringa oleifera* seeds and aluminium sulphate in tertiary treatment of domestic wastewater resulted in total coliforms reduction efficiencies of 99.6% and 99.5 %, respectively (Andrade *et al*., 2021). Moreso, the use of aqueous *Moringa oleifera* seeds reduced bacterial load by 97.3% compared to aluminium sulphate reduction efficiency of 96.7% in the treatment of domestic wastewater (Vunain *et al*., 2019). In contrast with the study findings, Njewa *et al*. (2021) reported increase of microbial load while using *Moringa oleifera* seeds in clarification of sewage wastewater as compared to *Jatropha curcas* and rice husks ashes. Polyaluminium chloride analysis on microbial diversity resulted to 70.8% reduction effect from urban rivers (Liu *et al*., 2021).

CHAPER SIX

CONCLUSIONS AND RECOMMEDATIONS

6.1 Conclusions

The study demonstrated that the most effective coagulant to reduce turbidity of wastewater from a wastepaper recycling mill was DMos among the bio-coagulant and alum for synthetic coagulants. DMos most effective dose was found to be at 16×10^6 ppm resulting in final turbidity of 144.0 NTU. Whilst the effective dose for alum was 75×10^4 ppm with final turbidity of 24.1 NTU

The most effective blend of coagulants to reduce turbidity of wastewater from wastepaper recycling mill was found to DMos and alum. The blend constituted 20% of DMos and 80% of alum. The blend of DMos and alum result in the final turbidity of 17.1 NTU

The most efficient coagulant among the bio-coagulants was DMos while among synthetic coagulants was alum. The study revealed among the blended coagulants DMos/alum was the most efficient in most wastewater characteristics.

In microbial load reduction from the wastewater from wastepaper recycling mill, the study showed that the blend of DMos and alum was the best coagulant. It was also found *Moringa oleifera* reduced the microbial load from the wastewater from the wastepaper recycling mill at higher rates than synthetic coagulants studied.

6.2 Recommendations

6.2.1 Recommendations for the Study

1. The study recommends the treatment of wastewater from MIWPRM using a blend of DMos and alum.

2. The study recommends the use of DMos and Alum blend for wastewater treatment to remove microbial loads from wastepaper recycling mills.

6.2.2 Recommendations for the Study

3. Further research should be done to evaluate effects of extraction of oil and/or extraction of active components using saline solution for efficient coagulation of *Moringa oleifera* seeds in treatment of industrial wastewater.
4. Further research should be conducted on cost effectiveness of blending Moringa oleifera and/or other plant-based coagulants and synthetic coagulants in industrial wastewater.

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APPENDICES

Appendix 1: Effective dose of Aluminium Sulphate

Summary statistics

	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
0	9	1805.33	4.24264	0.24%	1800	1812	12
0.5	9	1228	6.9282	0.56%	1220	1238	18
1	9	1043.33	5	0.48%	1036	1052	16
1.5	9	955	7.05337	0.74%	943	964	21
2	9	729	6.10328	0.84%	720	738	18
2.5	9	512.778	6.03692	1.18%	504	523	19
3	9	469	5.54527	1.18%	462	478	16
3.5	9	374.222	7.51295	2.01%	362	387	25
4	9	291	8.61684	2.96%	280	309	29
4.5	9	211.111	6.07134	2.88%	202	218	16
5	9	173.778	5.56277	3.20%	164	181	17
5.5	9	112.889	8.62329	7.64%	101	126	25
6	9	80.3222	6.37902	7.94%	73	89.3	16.3
6.5	9	60.9889	3.59738	5.90%	54	66.5	12.5
7	9	47.4222	3.98804	8.41%	40.2	53.6	13.4
7.5	9	24.1222	3.78807	15.70%	17.7	28.6	10.9
8	9	54.9667	2.75061	5.00%	50.8	59.4	8.6
8.5	9	73.1444	4.25738	5.82%	64.8	79.4	14.6
9	9	91.4444	4.27993	4.68%	83.4	98	14.6
9.5	9	110	5.91608	5.38%	101	119	18

10	9	193.667	8.03119	4.15%	183	206	23

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	4.16E+07	20	2.08E+06	58538.11	0
Within groups	5963.61	168	35.4977		
Total (Corr.)	4.16E+07	188			

Appendix 2: Effective Dose of Polyaluminium Chloride

Summary statistics

	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
0	9	1800.22	7.10243	0.39%	1790	1812	22
6	9	1449.78	7.31057	0.50%	1438	1460	22
12	9	938.333	8.26136	0.88%	926	950	24
18	9	646.556	5.83333	0.90%	639	656	17
24	9	472.556	6.48288	1.37%	463	482	19
30	9	388.444	6.89404	1.77%	378	398	20
36	9	162.222	3.89801	2.40%	157	169	12
42	9	174.889	3.78961	2.17%	170	180	10
48	9	238.222	2.86259	1.20%	234	243	9
54	9	278.667	3.39116	1.22%	273	284	11
60	9	315	3.42783	1.09%	310	321	11
66	9	464.778	4.57651	0.98%	459	473	14
72	9	649.222	5.73973	0.88%	641	659	18
Total	117	613.761	486.186	79.21%	157	1812	1655

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2.74E+07	12	2.28E+06	72333.94	0
Within groups	3284.89	104	31.5855		
Total (Corr.)	2.74E+07	116			

Appendix 3: Effective Dose of Defatted *Moringa oleifera* seeds (DMos)

SummaryStatistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
0	9	1800.89	6.79052	0.38%	1790	1810	20
2	9	1421.11	7.00793	0.49%	1408	1430	22
4	9	949.556	9.27512	0.98%	939	968	29
6	9	752.667	17.0953	2.27%	732	778	46
8	9	571.667	9.48683	1.66%	556	586	30
10	9	422.222	3.11359	0.74%	418	427	9
12	9	334.222	8.64259	2.59%	314	344	30
14	9	292.222	2.43812	0.83%	289	296	7
16	9	144	2.73861	1.90%	140	148	8
18	9	233.667	3.4641	1.48%	229	238	9
20	9	332.111	3.21887	0.97%	328	337	9
22	9	405	19.1311	4.72%	372	429	57
24	9	499.444	3.2059	0.64%	495	504	9
26	9	541.111	23.369	4.32%	489	567	78
28	9	596.889	7.1317	1.19%	586	608	22
30	9	678.778	11.5193	1.70%	663	694	31
Total	144	623.472	428.994	68.81%	140	1810	1670

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2.63E+07	15	1.75E+06	15677.08	0
Within groups	14317.1	128	111.852		
Total (Corr.)	2.63E+07	143			

Appendix 4: Effective Dose of Fatted *Moringa oleifera* seeds (FMos)

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
0	9	1800	8.30662	0.46%	1790	1812	22
2	9	1632.67	4.3589	0.27%	1628	1640	12
4	9	1214.22	9.35117	0.77%	1202	1228	26
6	9	976.778	4.49382	0.46%	970	983	13
8	9	829.333	3.74166	0.45%	823	835	12
10	9	674.222	3.73423	0.55%	668	679	11
12	9	448	4.58258	1.02%	440	454	14
14	9	416.778	9.51023	2.28%	404	432	28
16	9	300.333	7.59934	2.53%	290	312	22
18	9	250.111	3.68932	1.48%	243	254	11
20	9	372.667	3.87298	1.04%	368	380	12
22	9	497.222	8.19722	1.65%	478	505	27
24	9	734.889	3.78961	0.52%	730	740	10
26	9	982	6.16441	0.63%	971	990	19
28	9	1071.11	7.2188	0.67%	1060	1082	22
30	9	1236.89	4.25572	0.34%	1230	1242	12
Total	144	839.826	454.823	54.16%	243	1812	1569

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2.96E+07	15	1.97E+06	51620.08	0
Within groups	4889.33	128	38.1979		
Total (Corr.)	2.96E+07	143			

Appendix 5: Effective Dose of Bark of *Moringa oleifera* powder

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
0	9	1802.44	8.5894	0.48%	1792	1814	22
8	9	1714.44	12.9529	0.76%	1690	1730	40
16	9	1605.33	2.44949	0.15%	1602	1610	8
24	9	1252.44	21.3957	1.71%	1218	1274	56
32	9	1067.11	28.0198	2.63%	1020	1100	80
40	9	811	5.80948	0.72%	802	819	17
48	9	840.222	10.7561	1.28%	824	857	33
56	9	882.333	11.5326	1.31%	868	902	34
64	9	959.444	6.32675	0.66%	951	968	17
72	9	1042.67	3.16228	0.30%	1038	1048	10
80	9	1138.22	5.42627	0.48%	1132	1148	16
88	9	1168.67	14.5258	1.24%	1152	1190	38
96	9	1259.78	4.17665	0.33%	1254	1266	12
104	9	1374.89	54.1859	3.94%	1320	1446	126
112	9	1433.56	9.83757	0.69%	1420	1448	28
120	9	1523.78	7.17248	0.47%	1512	1536	24
Total	144	1242.27	302.188	24.33%	802	1814	1012

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1.30E+07	15	867804	2688.19	0
Within groups	41321.1	128	322.821		
Total (Corr.)	1.31E+07	143			

Appendix 6: Effective Dose of the blend of DMos/Alum

Summary Statistics						
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum
100/0%	9	144.778	3.34581	2.31%	140	150
90/10%	9	126.111	3.85501	3.06%	121	132
80/20%	9	100.933	3.86749	3.83%	96.3	108
70/30%	9	88.8889	4.36877	4.91%	80.3	95
60/40%	9	69.6222	3.91049	5.62%	63	73.1
50/50%	9	48.7333	5.27873	10.83%	42.6	57.7
40/60%	9	33.2778	3.72685	11.20%	28.3	39
30/70%	9	28.2	3.02531	10.73%	22.2	31
20/80%	9	17.1333	1.32665	7.74%	15.7	19.7
10/90%	9	25.2333	2.99625	11.87%	20	29.6
0/100%	9	24.2444	2.79513	11.53%	20.4	28.9
Total	99	64.2869	43.1393	67.10%	15.7	150

ANOVA Table

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	181219	10	18121.9	1376.21	0.0000
Within groups	1158.79	88	13.168		
Total (Corr.)	182378	98			

Multiple Range Tests

Multiple Range Tests			
Method: 95.0 percent LSD			
	Count	Mean	Homogeneous Groups
20/80%	9	17.1333	X
0/100%	9	24.2444	X
10/90%	9	25.2333	XX
30/70%	9	28.2	X
40/60%	9	33.2778	X
50/50%	9	48.7333	X
60/40%	9	69.6222	X
70/30%	9	88.8889	X
80/20%	9	100.933	X
90/10%	9	126.111	X
100/0%	9	144.778	X

Appendix 7: Effective dose of the blend of FMos/Alum

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
100/0 %	9	250.11	6.51	2.60%	239	258	19
90/10 %	9	207.56	6.60	3.18%	200	219	19
80/20 %	9	156.00	3.39	2.17%	150	160	10
70/30 %	9	89.78	4.52	5.03%	82	96.5	14.5
60/40 %	9	71.46	3.92	5.48%	65.9	76.3	10.4
50/50 %	9	53.96	4.09	7.58%	48.3	60	11.7
40/60 %	9	34.18	3.60	10.53%	30	40.2	10.2
30/70 %	9	25.17	3.26	12.95%	20.7	29.3	8.6
20/80 %	9	26.72	3.17	11.87%	22.2	31.4	9.2
10/90 %	9	28.03	2.69	9.61%	24.6	32	7.4
0/100 %	9	24.12	3.79	15.70%	17.7	28.6	10.9
Total	99	87.9162	77.3164	87.94%	17.7	258	240.3

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	584186	10	58418.6	3133.51	0.0000
Within groups	1640.6	88	18.6432		
Total (Corr.)	585827	98			

Multiple Range Tests

Method: 95.0 percent LSD			
	Count	Mean	Homogeneous Groups

0/100%	9	24.1222	X
30/70%	9	25.1667	X
20/80%	9	26.7222	X
10/90%	9	28.0333	X
40/60%	9	34.1778	X
50/50%	9	53.9556	X
60/40%	9	71.4556	X
70/30%	9	89.7778	X
80/20%	9	156	X
90/10%	9	207.556	X
100/0%	9	250.111	X

Appendix 8: Effective dose of the blend of BMo/Alum

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
100/0%	9	811.00	5.81	0.72%	802	819	17
90/10%	9	529.44	6.80	1.28%	520	539	19
80/20%	9	448.67	7.11	1.58%	440	460	20
70/30%	9	297.33	5.81	1.95%	288	305	17
60/40%	9	268.67	3.67	1.37%	263	275	12
50/50%	9	189.89	4.68	2.46%	183	196	13
40/60%	9	145.67	4.53	3.11%	140	153	13
30/70%	9	122.33	4.21	3.44%	118	129	11
20/80%	9	88.64	5.21	5.88%	82	96.3	14.3
10/90%	9	63.47	3.09	4.87%	58.7	68	9.3
0/100%	9	24.01	2.62	10.91%	20.4	28	7.6
Total	99	271.74	229.32	84.39%	20.4	819	798.6

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	5.15E+06	10	515131	20134.1	0.0000
Within groups	2251.48	88	25.585		
Total (Corr.)	5.15E+06	98			

Multiple Range Tests

Method: 95.0 percent LSD			
	Count	Mean	Homogeneous Groups

0/100%	9	24.0111	X
10/90%	9	63.4667	X
20/80%	9	88.6444	X
30/70%	9	122.333	X
40/60%	9	145.667	X
50/50%	9	189.889	X
60/40%	9	268.667	X
70/30%	9	297.333	X
80/20%	9	448.667	X
90/10%	9	529.444	X
100/0%	9	811	X

Appendix 9: Effective dose of blended DMos/ PAC

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	
100/0%	9	144.778	3.34581	2.31%	140	150	de
90/10%	9	120.667	3.16228	2.62%	115	125	c
80/20%	9	109.122	32.0835	29.40%	93	194	b
70/30%	9	93.57	3.65	3.90%	89	100	a
60/40%	9	110.333	3.67423	3.33%	104	115	b
50/50%	9	123	3.39116	2.76%	118	128	c
40/60%	9	138.111	4.04489	2.93%	132	144	d
30/70%	9	149.556	4.44722	2.97%	142	156	ef
20/80%	9	151.111	4.22624	2.80%	146	159	ef
10/90%	9	159	3.20156	2.01%	154	164	fg
0/100%	9	161.111	2.61937	1.63%	157	165	g
Total	99	132.76	23.7744	17.91%	89	194	

ANOVA Table

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	46112.1	10	4611.21	43.73	0.0000
Within groups	9279.78	88	105.452		
Total (Corr.)	55391.8	98			

Multiple Range Tests

Method: 95.0 percent LSD			
	Count	Mean	Homogeneous Groups
70/30%	9	93.5667	X

80/20%	9	109.122	X
60/40%	9	110.333	X
90/10%	9	120.667	X
50/50%	9	123	X
40/60%	9	138.111	X
100/0%	9	144.778	XX
30/70%	9	149.556	XX
20/80%	9	151.111	XX
10/90%	9	159	XX
0/100%	9	161.111	X

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	146411	10	14641.1	773.98	0.0000
Within groups	1664.67	88	18.9167		
Total (Corr.)	148076	98			

Multiple Range Tests

Method: 95.0 percent LSD			
	Count	Mean	Homogeneous Groups
70/30%	9	110.444	X
60/40%	9	113.444	X
50/50%	9	124.111	X
80/20%	9	127.222	X
40/60%	9	132.889	X
30/70%	9	143.667	X
20/80%	9	150	X
10/90%	9	155	X
0/100%	9	160	X
90/10%	9	189.889	X
100/0%	9	250.667	X

Appendix 10: Optimal dosage of combined BMo/PAC

Summary Statistics

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
100/0%	9	810.889	5.55528	0.69%	802	818	16
90/10%	9	536	7.68115	1.43%	525	548	23
80/20%	9	389.889	5.90433	1.51%	380	398	18
70/30%	9	339.111	4.85913	1.43%	332	348	16
60/40%	9	294.778	3.11359	1.06%	290	300	10
50/50%	9	220.778	4.2947	1.95%	215	228	13
40/60%	9	206.889	4.67559	2.26%	200	214	14
30/70%	9	193.444	4.92725	2.55%	187	201	14
20/80%	9	181.222	4.84195	2.67%	173	188	15
10/90%	9	174.111	2.80377	1.61%	171	178	7
0/100%	9	161.222	3.49205	2.17%	156	166	10
Total	99	318.939	191.218	59.95%	156	818	662

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	3.58E+06	10	358119	14803.25	0.0000
Within groups	2128.89	88	24.1919		
Total (Corr.)	3.58E+06	98			

Multiple Range Tests

Method: 95.0 percent LSD			
	Count	Mean	Homogeneous Groups
0/100%	9	161.222	X
10/90%	9	174.111	X
20/80%	9	181.222	X
30/70%	9	193.444	X
40/60%	9	206.889	X
50/50%	9	220.778	X
60/40%	9	294.778	X
70/30%	9	339.111	X
80/20%	9	389.889	X
90/10%	9	536	X
100/0%	9	810.889	X

Appendix 11: Physicochemical Parameters of optimized individual and blended coagulants

Biological Oxygen Demand
Initial BOD

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	360.444	7.26483	2.02%	350	370	20
Col_2	9	360	7	1.94%	348	368	20
Col_3	9	360.889	7.68838	2.13%	350	372	22
Col_4	9	361.556	9.26163	2.56%	348	374	26
Col_5	9	360.667	6.32456	1.75%	352	370	18
Total	45	360.711	7.23823	2.01%	348	374	26

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	11.9111	4	2.97778	0.05	0.9947
Within groups	2293.33	40	57.3333		
Total (Corr.)	2305.24	44			

Final BOD reduction of individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	32.6667	4.69042	14.36%	26	40	14
Col_2	9	65.5556	6.69162	10.21%	56	76	20
Col_3	9	78.4444	6.06447	7.73%	72	90	18
Col_4	9	88.6667	4.69042	5.29%	82	96	14
Col_5	9	140	5.47723	3.91%	132	148	16
Total	45	81.0667	35.7812	44.14%	26	148	122

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value

Between groups	55088.4	4	13772.1	442.67	0
Within groups	1244.44	40	31.1111		
Total (Corr.)	56332.8	44			

Final BOD reductions of combined coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	28.6667	3.16228	11.03%	24	34	10
Col_2	9	31.3333	4	12.77%	26	38	12
Col_3	9	34	3.74166	11.00%	30	40	10
Col_4	9	55.5556	3.12694	5.63%	50	60	10
Total	36	37.3889	11.322	30.28%	24	60	36

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	4088.33	3	1362.78	109.51	0
Within groups	398.222	32	12.4444		
Total (Corr.)	4486.56	35			

Chemical Oxygen Demand

Initial COD

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	598.667	8.83176	1.48%	586	612	26
Col_2	9	602.222	8.80025	1.46%	586	614	28
Col_3	9	599.333	9.05539	1.51%	584	612	28
Col_4	9	596.444	9.15302	1.53%	586	612	26
Col_5	9	597.111	13.7518	2.30%	580	614	34
Total	45	598.756	9.84691	1.64%	580	614	34

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	183.644	4	45.9111	0.45	0.7719
Within groups	4082.67	40	102.067		
Total (Corr.)	4266.31	44			

Final COD Reductions of individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	129.778	5.86894	4.52%	120	138	18
Col_2	9	180.889	6.41179	3.54%	172	190	18
Col_3	9	214.444	6.91215	3.22%	204	226	22
Col_4	9	232	7.14143	3.08%	220	242	22
Col_5	9	295.778	9.45751	3.20%	282	314	32
Total	45	210.578	56.0837	26.63%	120	314	194

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	136287	4	34071.7	645.84	0.0000
Within groups	2110.22	40	52.7556		
Total (Corr.)	138397	44			

Final COD reductions of blended coagulants

Summary Statistics					
	Count	Average	Standard deviation	Coeff. of variation	Minimum
Col_1	9	113.778	4.05518	3.56%	108
Col_2	9	127.556	5.98145	4.69%	120
Col_3	9	118	5.47723	4.64%	110
Col_4	9	168	4.89898	2.92%	160

Total	36	131.833	22.3242	16.93%	108

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	16593.2	3	5531.07	208.28	0
Within groups	849.778	32	26.5556		
Total (Corr.)	17443	35			

Color

Initial color of the wastewater

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	862.778	27.2845	3.16%	825	895	70
Col_2	9	891.667	14.4444	1.98%	870	920	50
Col_3	9	873.333	47.0372	5.39%	825	980	155
Col_4	9	881.111	19.49	2.21%	850	910	60
Total	36	877.222	30.8092	3.51%	825	980	155

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	4027.78	3	1342.59	1.47	0.2408
Within groups	29194.4	32	912.326		
Total (Corr.)	33222.2	35			

Final color reductions by individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Alum	9	30.3333	3.88104	12.79%	25	36.5	11.5
PAC	9	235	13.6931	5.83%	215	255	40
Defatted	9	44.0556	2.93092	6.65%	40	48.5	8.5
fatted	9	170	12.5	7.35%	150	185	35
bark.	9	730.556	35.8333	4.90%	690	800	110
Total	45	241.989	259.56	107.26%	25	800	775

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2.95E+06	4	737785	2233.77	0
Within groups	13211.4	40	330.286		
Total (Corr.)	2.96E+06	44			

Final Color Reductions by combined coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	14.444	2.97909	17.19%	12.5	21.5	9
Col_2	9	27.6667	3.92906	14.20%	20	32.5	12.5
Col_3	9	40.1667	4.61655	11.49%	34.5	48.5	14
Col_4	9	167.778	13.4887	8.04%	150	190	40
Total	36	63.2361	62.1797	98.33%	12.5	190	177.5

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	133501	3	44500.2	782.18	0
Within groups	1820.56	32	56.8924		
Total (Corr.)	135321	35			

Total Dissolved Solids

Initial

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	1820	51.4782	2.83%	1740	1890	150
Col_2	9	1781.11	35.8624	2.01%	1720	1820	100
Col_3	9	1817.78	41.1636	2.26%	1760	1890	130

Col_4	9	1775.56	32.059	1.81%	1730	1820	90
Col_5	9	1795.56	34.3188	1.91%	1740	1840	100
Total	45	1798	42.0281	2.34%	1720	1890	170

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	15031.1	4	3757.78	2.4	0.0661
Within groups	62688.9	40	1567.22		
Total (Corr.)	77720	44			

Final TDS reductions of Individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	770	39.6863	5.15%	710	820	110
Col_2	9	1281.11	41.6667	3.25%	1200	1330	130
Col_3	9	253.333	31.6228	12.48%	210	300	90
Col_4	9	381.111	60.7134	15.93%	280	460	180
Col_5	9	831.111	32.5747	3.92%	780	880	100
Total	45	640.667	379.967	59.31%	210	1330	1120

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	6.28E+06	4	1.57E+06	857.04	0
Within groups	73266.7	40	1831.67		
Total (Corr.)	6.35E+06	44			

Final TDS reductions of combined coagulants

Summary Statistics					
	Count	Average	Standard deviation	Coeff. of variation	Minimum
Col_1	9	267.778	28.6259	10.69%	220
Col_2	9	355.556	40.9607	11.52%	300
Col_3	9	286.667	32.7872	11.44%	240
Col_4	9	447.778	41.4662	9.26%	380
Total	36	339.444	79.5683	23.44%	220

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	179256	3	59751.9	45.17	0
Within groups	42333.3	32	1322.92		
Total (Corr.)	221589	35			

Electrical Conductivity

Initial EC

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	2477.78	42.3609	1.71%	2420	2540	120
Col_2	9	2486.67	32.0156	1.29%	2430	2530	100
Col_3	9	2467.78	38.0058	1.54%	2400	2520	120
Col_4	9	2497.78	38.0058	1.52%	2450	2560	110
Col_5	9	2476.67	41.833	1.69%	2410	2540	130
Total	45	2481.33	38.2337	1.54%	2400	2560	160

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	4653.33	4	1163.33	0.78	0.5449
Within groups	59666.7	40	1491.67		
Total (Corr.)	64320	44			

Final EC reduction by individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	701.111	56.8868	8.11%	600	780	180
Col_2	9	1914.44	47.1993	2.47%	1850	1990	140
Col_3	9	435.556	34.6811	7.96%	400	500	100
Col_4	9	724.444	28.7711	3.97%	690	780	90
Col_5	9	1285.56	51.0174	3.97%	1210	1360	150
Total	45	1012.22	537.007	53.05%	400	1990	1590

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1.26E+07	4	3.15E+06	1560.8	0.0000
Within groups	80777.8	40	2019.44		
Total (Corr.)	1.27E+07	44			

Final EC reduction by combined coagulants

Summary Statistics					
	Count	Average	Standard deviation	Coeff. of variation	Minimum
Col_1	9	495.556	39.0868	7.89%	440
Col_2	9	691.111	39.5109	5.72%	630
Col_3	9	512.222	33.4581	6.53%	460
Col_4	9	650	48.734	7.50%	600
Total	36	587.222	94.3432	16.07%	440

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	258856	3	86285.2	52.43	0
Within groups	52666.7	32	1645.83		
Total (Corr.)	311522	35			

Total Suspended solids

Initial

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	577.778	30.3223	5.25%	530	610	80
Col_2	9	571.556	22.4227	3.92%	542	602	60
Col_3	9	550.667	19.5895	3.56%	526	580	54
Col_4	9	564.444	43.9065	7.78%	500	640	140
Col_5	9	556.111	16.729	3.01%	530	580	50
Total	45	564.111	28.7988	5.11%	500	640	140

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	4383.56	4	1095.89	1.37	0.2632
Within groups	32108.9	40	802.722		
Total (Corr.)	36492.4	44			

Final TSS reduction by individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	19.4444	3.74537	19.26%	15	25	10
Col_2	9	48.7778	4.89331	10.03%	40	56	16
Col_3	9	27.1111	3.14024	11.58%	22	32	10
Col_4	9	34.8889	3.72305	10.67%	30	40	10
Col_5	9	256.111	12.1906	4.76%	230	270	40
Total	45	77.2667	91.1728	118.00%	15	270	255

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	364066	4	91016.6	2163.91	0.0000
Within groups	1682.44	40	42.0611		
Total (Corr.)	365749	44			

Final TSS reduction by combined coagulants

Summary Statistics					
	Count	Average	Standard deviation	Coeff. of variation	Minimum
Col_1	9	5.77778	2.10819	36.49%	3
Col_2	9	17	4.58258	26.96%	10
Col_3	9	11.1111	3.1798	28.62%	7
Col_4	9	28.7778	6.13958	21.33%	20
Total	36	15.6667	9.5857	61.19%	3

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2630	3	876.667	47.87	0
Within groups	586	32	18.3125		
Total (Corr.)	3216	35			

Turbidity

Initial

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Col_1	9	1805.33	4.24264	0.24%	1800	1812	12
Col_2	9	1800.22	7.10243	0.39%	1790	1812	22
Col_3	9	1800.89	6.79052	0.38%	1790	1810	20
Col_4	9	1800	8.30662	0.46%	1790	1812	22
Col_5	9	1802.44	8.5894	0.48%	1792	1814	22
Total	45	1801.78	7.12514	0.40%	1790	1814	24

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	175.111	4	43.7778	0.85	0.5018
Within groups	2058.67	40	51.4667		
Total (Corr.)	2233.78	44			

Final Turbidity reduction by individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	R
Col_1	9	24.4111	3.59807	14.74%	19.8	29.6	9
Col_2	9	160	3.39116	2.12%	154	165	1
Col_3	9	144.222	3.80058	2.64%	138	150	1
Col_4	9	251	5.02494	2.00%	243	258	1
Col_5	9	811	5.80948	0.72%	802	819	1
Total	45	278.127	279.175	100.38%	19.8	819	7

ANOVA Table						
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	
Between groups	3.43E+06	4	857128	43779.91	0	
Within groups	783.124	40	19.5781			
Total (Corr.)	3.43E+06	44				

Appendix 11: Microbial load Reduction

Microbial load reductions of individual coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Initial CFUs	9	264.889	7.84991	2.96%	254.6	275.4	20.8
Alum	9	24.4444	2.4037	9.83%	21	28	7
PAC	9	60.4444	6.61648	10.95%	50	71	21
DMos	9	6.55556	1.74005	26.54%	4	9	5
FMos	9	15.8889	1.90029	11.96%	13	19	6
BMo	9	27.2222	4.49382	16.51%	21	34	13
Total	54	66.5741	91.203	137.00%	4	275.4	271.4

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Initial CFUs	9	264.889	7.84991	2.96%	254.6	275.4	20.8
Alum	9	24.4444	2.4037	9.83%	21	28	7
PAC	9	60.4444	6.61648	10.95%	50	71	21
DMos	9	6.55556	1.74005	26.54%	4	9	5
FMos	9	15.8889	1.90029	11.96%	13	19	6
BMo	9	27.2222	4.49382	16.51%	21	34	13
Total	54	66.5741	91.203	137.00%	4	275.4	271.4

ANOVA Table					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	439749	5	87949.8	3823.63	0
Within groups	1104.08	48	23.0017		
Total (Corr.)	440853	53			

Multiple Range Tests					
Method: 95.0 percent LSD					
	Count	Mean	Homogeneous Groups		
DMos	9	6.55556	X		
FMos	9	15.8889	X		
Alum	9	24.4444	X		
BMo	9	27.2222	X		

PAC	9	60.4444	X		
Initial CFUs	9	264.889	X		

Microbial load Reduction of combined coagulants

Summary Statistics							
	Count	Average	Standard deviation	Coeff. of variation	Minimum	Maximum	Range
Initial CFUs	9	264.75	6.40312	2.42%	257.5	273.5	16
DMOS/Alum	9	2.22222	1.09291	49.18%	1	4	3
FMos/Alum	9	16.2222	1.98606	12.24%	13	19	6
DMos/PAC	9	8	1.73205	21.65%	6	11	5
Fmos/PAC	9	21	2.73861	13.04%	17	26	9
Total	45	62.4389	102.559	164.26%	1	273.5	272.5

ANOVA Table

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	462353	4	115588	10203.97	0
Within groups	453.111	40	11.3278		
Total (Corr.)	462806	44			

Method: 95.0 percent LSD					
	Count	Mean	Homogeneous Groups		
DMOS/Alum	9	2.22222	X		
DMos/PAC	9	8	X		
FMos/Alum_1	9	16.2222	X		
FMos/Alum	9	21	X		
Initial CFUs	9	264.75	X		

Parameters	WHO Drinking water Standards	NEMA Drinking water Standards	USEPA Drinking water Standards
Ph	6.5 -8.5	6.5-8.5	6.5-8.5
Biological Oxygen Demand	<30mg/L	30mg/L	30mg/L
Chemical Oxygen Demand	250mg/L	50mg/L	50 mg/L
Turbidity	5 NTU	5 NTU	5NTU
Total Suspended Solids	30mg/L	30mg/L	30mg/L
Total Dissolved solids	1000 mg/L	1200mg/L	500mg/L
Electrical Conductivity	400-1200µs/cm	1000 µs/cm	1000µs/cm
Color	< 15 TCU	<15 Hazen Units	15 Color Units
Total Coliforms	Nil (CFU/100ml)	Nil (CFU/100ml)	Nil (CFU/100ml)

Parameters	WHO effluent discharge Standards	NEMA effluent discharge Standards	USEPA effluent dischar Standards
pH	6.5 -8.5	6.0-9.0	6.0-9.0
Biological Oxygen Demand	50 mg/L	30mg/L	50mg/L
Chemical Oxygen Demand	<120 mg/L	50mg/L	250mg/L
Turbidity	50 NTU	5 NTU	75 NTU

Total Suspended Solids		30mg/L	50mg/L
Total Dissolved solids	1000 mg/L	1200mg/L	1500 mg/L
Electrical Conductivity	<2700µs/cm		750ms/cm
Color	< 15 TCU	15 Hazen Units	30 Color Units
Total Coliforms	10^3 (CFU/100ml)	30 (counts/100ml)	400 (MPN/100ml)

Appendix 12: Similarity Report

University of Eldoret

Certificate of Plagiarism Check for Synopsis

Author Name	NYAMBURA JANEROSE WAMBUI SENV/EBH /M/008/18
Course of Study	Type here...
Name of Guide	Type here...
Department	Type here...
Acceptable Maximum Limit	Type here...
Submitted By	titustoo@uoeld.ac.ke
Paper Title	EFFICACY OF TREATING WASTEWATER FROM WASTEPAPER RECYCLING MILL USING A BLEND OF Moringa oleifera Lam AND SYNTHETIC COAGULANTS
Similarity	4%
Paper ID	978959
Submission Date	2023-09-21 21:13:26

Signature of Student

Signature of Guide

Head of the Department

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