THE STUDY OF REMOVAL EFFICIENCY OF BLENDED *ALOE VERA* AND POLY-ALUMINUM CHLORIDE AS COAGULANT IN TEXTILE WASTEWATER TREATMENT

Sileshi Zerihun Haileyesus

A Thesis Submitted to Department of Applied Chemistry

School of Applied Natural Science

Presented in partial fulfilment of the Requirements of the Degree of Master of Science in Applied Chemistry (Industrial Chemistry)

Office of Graduate Studies

Adama Science and Technology University

June, 2024

Adama, Ethiopia

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Advisor: Dr. Defaru Negera (PhD)

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DECLARATION

I hereby declare that this Master's Thesis entitled "**Investigation of Removal Efficiency of Blended *Aloe vera* and Poly-aluminum Chloride as Coagulant in Textile Wastewater treatment**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other University. All sources of material that are used for this thesis have been duly acknowledged through citation.

Sileshi Zerihun Haileyesus __________________ ________________________

Name of student Signature Date

RECOMMENDATION

I, the Advisor of this Thesis, hereby certify that I have read the revised Version of the Thesis entitled "**Investigation of Removal Efficiency of Blended *Aloe vera* and Poly-aluminum Chloride as Coagulant in Textile Wastewater treatment**" prepared under my guidance by Sileshi Zerihun Haileyesus, submitted in partial fulfilment of the degree of Masters of Science in Applied Chemistry. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedure.

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Advisor Name	Signature	Date

APPROVAL PAGE

I, the Advisor of the Thesis entitled "**Investigation of Removal Efficiency of Blended *Aloe vera* and Poly-aluminum Chloride as Coagulant in Textile Wastewater treatment**" and developed by Sileshi Zerihun Haileyesus, hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the Thesis.

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APPROVAL OF BOARD OF REVIEWERS

We, the undersigned member of the Board of Reviewers of the Thesis by Sileshi Zerihun Haileyesus have read and evaluated the thesis entitled "**Investigation of Removal Efficiency of Blended *Aloe vera* and Poly-aluminum Chloride as Coagulant in Textile Wastewater treatment**" and examined the candidate during open defense. This is, therefore to certify that the Thesis is accepted for partial fulfilment of the Requirements of the Degree of Master of Science in Applied Chemistry (Industrial Chemistry)

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LIST OF ABBREVIATIONS

AIP	Adama Industrial Park
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EEPA	Ethiopian Environmental Protection Authority
EPA	Environmental Protection Authority
FTIR	Fourier transforms infrared spectroscopy
mg/L	Milligram per liter
NTU	Nephelometric Turbidity Unit
Pt-Co	Platinum Cobalt Unit
pH	potential of Hydrogen
PAC	Poly aluminum chloride
TSS	Total Suspended solids
TS	Total solids
WTP	Water Treatment Plants
ZLD	Zero Liquid Discharge

ABSTRACT

Ethiopia has various textile industries in existence. Textile wastewater production in the country has expanded, causing environmental and health hazards. Coagulation, a treatment approach, employs synthetic or semi-natural coagulants. However, these have limitations, such as pH sensitivity, inefficiency, low-temperature water inefficiency, and poor health consequences. Therefore; the objective of this study was to study the effectiveness of Polyaluminum Chloride and Aloe vera as a blended coagulant for the treatment of textile wastewater discharged from Adama Industrial Park. Peeled Aloe vera powder (250 g) was mixed with a 1:1 ratio of polyaluminum Chloride (PAC). The coagulation experiments were carried out using Jar-test apparatus in order to study the effect of blended coagulant as well as optimum condition of coagulation by varying some operational parameters such as dose of blended coagulant (100 to 350 ppm of 10% stock solution), pH (4-10), and mixing time (10-60), while the amount of de-colorant was kept constant at 250 ppm (5% stock solution). Color, Turbidity, TSS, COD, BOD, and pH were selected as dependent variable of the experiment to show material effectiveness and measured following APHA 2000 standard procedure. The optimum conditions for the efficient use of blended PAC and Aloe vera as a coagulant were 300ppm of coagulant dose, pH 6, and 40 minutes of mixing time. At this optimum condition the removal efficiency with rapid mixing of 150rpm for 3 minutes and slow mixing of 50 rpm for 40 minutes and 20 minutes of the settling time for Color, Turbidity, TSS, COD, and BOD, was 95.2%, 99.7%, 99.6%, 85.2%, and 83.2% respectively from textile Wastewater. Hence, the uses of blended Polyaluminum Chloride and Aloe Vera as coagulant in the presence of 250ppm decolorant is found to be effective for removal of aforementioned parameters.

Keywords: *coagulation, blended coagulant, Textile Wastewater and Aloe vera*

CHAPTER ONE

1. INTRODUCTION

1. Background of Study

The textile industry is a significant water consumer and polluter, with contaminants such as suspended solids, heavy metals, coloring agents, acidity, and other chemicals found in textile wastewater. These pollutants can harm people and the environment, particularly through the food chain (Vashi, 2013). The Ethiopian government is focusing on the textile sub-sector, which has shown promise in industrial development. However, textile wastewater is one of the dirtiest industries due to its high color, salinity, and non-biodegradable chemical content. To maintain and advance the textile industry's competence, there is a continuous search for cheap, efficient, locally available, and environmentally friendly ways to treat textile wastewater (Ghebremechael et al., 2004).

Coagulation is one of the effective textile wastewater treatment techniques. This technique is affirmed to remove, dissolved, and suspended matter as well as color from dyes which are responsible for turbidity as well as, organic matters which contribute to BOD and COD content of wastewater. The method needs adding of chemicals such as salts of aluminum and polyelectrolytes coagulant in to textile wastewater (John et al., 2005). These chemical coagulants are acknowledged for their effectiveness on treatment of the wastewater. However, the use of such chemical coagulants is not free from some limitations. The limitations include detrimental effects on human health and toxicity to aquatic life, production of large sludge volume and non-biodegradable, ineffectiveness in low temperature, change pH value of the treated water. Besides, such chemical coagulants incur high procurement costs both for import and sludge disposal. In recent years, there has been a move on the part of researchers to identify and apply blended natural materials instead of only chemical coagulants (Sunita et. al., (2014).

Coagulation occurs in several steps and intended to overcome the forces that stabilize the suspended particles, allowing particle collusion and growth of floc. The first step in the coagulation process is destabilization of particle charge in the water. Coagulant of opposite charges added to neutralize the negative charge on the dispersed non settable solids. Once the charge is neutralizing, the smaller particles are capable of sticking together to form a slightly larger particle. Rapid mixing ensures proper dispersion of the coagulant throughout the water and promotes particle collisions necessary for good coagulation and slower mixing increases particles collisions and promote the formation of larger flocs (Metcalf and Eddy, 2003).

Natural macromolecular coagulants are promising and have attracted the attention of many researchers because of their abundant source, low price, non-toxicity, multi-functional and biodegradability (Hemapriya et al.2015). A natural derived coagulant offers several advantages over conventional coagulants such as aluminum sulphate: for example, the activity is maintained over a wide range of influent pH values means no pH correction required, natural alkalinity of the raw water is unchanged following coagulation means no addition of alkalinity required and sludge production is greatly reduced and is essentially organic in nature with no aluminum residuals means sludge volumes are reduced by a factor of up to 5. Among the natural coagulants Aleo vera is one of the plants that acts as a coagulant in wastewater clarification due to the presence of a soluble, high molecular weight cationic protein which can reduce the COD, turbidity, color of untreated water (Ghebremichael, 2005). This paper concentrates on removal efficiency and assesses its effect on the treatment of textile waste water by combined the natural coagulant (Aloe Vera) and synthetic coagulant (PAC).

Thus, as a solution can be minimized to the problem that has been stated in the above by using the combined *Aloe Vera* and PAC can be used as an alternative to replace synthetic aluminum to reduce the TSS, turbidity, Color, COD, heavy metals and heat of the water and make it more suitable and safer to be consumed by textile industry and the coagulation/flocculation technique followed by sedimentation is used worldwide in the treatment of residual waste waters. This treatment consists in the quick dispersion of the coagulating agent in the water to be treated, followed by intense agitation, which is commonly defined as quick mixing. Coagulants are added to effluents to destabilize the colloidal material and aggregate the small particles to form greater species, which are more easily removed as flocs (Metcalf and Eddy, 2003). In this work, the potential removal efficiency of combined Aloe vera and PAC for textile wastewater treatment was evaluated, its limits analyzed, and the optimum use and dosage assessment was evaluated.

1.2. Statement of Problem

Environmental pollution poses significant challenges for human beings. In Ethiopia, like in many developing countries, water quality is adversely affected by industrial pollution. Among the industries contributing to water pollution, the textile sector stands out due to its multi-component wastewater production processes. Textile dyeing and finishing processes, in particular, are notorious for generating colored wastewaters heavily contaminated with dyes, dissolved solids, textile auxiliaries, and chemicals. Wastewater discharge is a common environmental issue faced by all textile industries (Roussy, 2005).

While various methods have been developed to treat textile wastewater, most of them are either expensive or harmful to the environment and human health (Venceslau et al., 1994). To address these challenges, it becomes essential to explore alternative, cost-effective, and eco-friendly materials capable of effectively removing color, turbidity, total suspended solids (TSS), chemical oxygen demand (COD), and biological oxygen demand (BOD) from textile effluents. This study aims to develop a novel coagulant using a blend of Aloe vera and Poly-Aluminum Chloride.

1.3. Objective of the Study

1.3.1. General objective

The main objective of this study is to evaluate removal efficiency of blended *Aloe vera* and Poly-aluminum chloride as coagulant in textile wastewater treatment discharged from Adama Industrial Park

1.3.2. Specific objectives

The specific objectives of this research are:

- ✓ To characterize the prepared coagulant of blended *Aloe vera* and Poly-Aluminum Chloride using FTIR, SEM, XRD
- ✓ To characterize the major quality parameters (Color, TSS, pH, Turbidity, COD and BOD) of raw and treated (using Blended coagulant vs. conventional Coagulant) textile wastewater
- ✓ Determine the effect of operating parameters, namely coagulant dose, contact time, and pH on the performance of coagulation process of the textile wastewater
- ✓ To determine the optimum values of those aforementioned operating parameters.

1.4. Scope of the Study

This study generally objected at assessing the effectiveness of blended *Aloe vera* and Poly-aluminum chloride coagulant in textile wastewater treatment as a blended coagulant in treating textile wastewater. Thus, this study does not concern methods and processes which may be applicable for textile wastewater treatment other than coagulation. Besides, this research does not attempt to examine every parameter of textile wastewater. Instead, it is delaminated on parameters namely pH, Color, Turbidity, TSS, COD and BOD. Furthermore, although there are different factors which can be studied in relation to coagulation process, this study pays attention on the major factors like coagulant dose, pH, and mixing time.

1.5. Significance of the Study

This study is to introduce the application of blended *Aloe vera* and Poly-aluminum chloride as a coagulant which is semi-natural material. This semi-natural coagulant has numerous advantages like safe for human health, environmentally friendly behavior, cost effective, produce lesser volume and biodegradable sludge, and unchanged pH value of treated water. The significance of the study is fully recognized in solving the environmental problems of the textile sector by suggesting a coagulation process using natural coagulant. Therefore, this research is beneficial in Ethiopia to have effective textile wastewater treatment method, by using blended *Aloe vera* and Poly-aluminum Chloride, which has fundamental importance for maintaining people's health, protecting the quality of the environment and ultimately to reduce the costs of wastewater treatment chemicals.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Wastewater in Textile industry

The degradation of surface and groundwater quality caused by industrial and urban discharges has long been known. Throughout the world, rivers and streams are common recipients of industrial waste. The decrease in water quality has a negative impact on humans as well as aquatic ecosystems, either directly or indirectly (Ugochukwu, 2004). When untreated or partially treated effluent enters a body of water, it either dissolves or remains trapped on the river bed, polluting the water. Industries are induced to believe that they cannot avoid significant amounts of wastewater created during important industrial activities, and as a result, they lack initiative in pollution control (Hayelom, 2019).

The textile and apparel industry are one of the world's largest and oldest industry. The textile industry's dyes and chemicals have been discovered to differ based on the materials generated. The textile industry is particularly water-intensive; it needs fresh water for a variety of activities during the production process. In terms of the amount and complexity of waste water discharge, the textile industry is one of the most polluting sources. The waste water created by the textile industry is often warm, alkaline, strong smelling, and coloured by colouring chemicals. In general, textile companies produce 200–350 L of wastewater for 1 kilogram of completed product (Gozálvez et al., 2008), resulting in an average pollution of 100 kg COD per ton of fabric (Vandana, 2007).

Different types of dyes, synthetic chemicals used in manufacturing processes, and colors with complex compositions make up the wastewater produced by the textile sector. Additionally, because of its high solubility in water, it has a significant negative environmental impact when released into water sources. Additionally, typical textile wastewater is known to have a range of pH solutions, high temperatures, high COD and BOD demands, high suspended solids (SS), and is also distinguished by a high amount of color given by remaining colors (Hayelom, 2019).

2.2. The Production process in Textile Industry and Source of wastewater

2.2.1. Production process in textile industry (textile processing)

The textile industry is made up of a diverse group of companies that manufacture and/or process goods related to textiles (such as fibres, yarn, and fabric) in preparation for further processing into apparel, home goods, and industrial items. During the numerous phases involved in textile production, textile industry facilities, in various ways, gather and organize fibres; change fibres into yarn, thread, or webbing; transform the yarn into fabric or associated commodities; and dye and finish these commodities (Ghosh et al.,2000).

Textile wet processing

The wet processing of textiles is an important step in the production of textiles because it gives the fabric its wonderful and useful qualities, which add the most value. Wet processing of textiles requires the use of a significant amount of water as a solvent. At the last stage, this water which is polluted with unfixed dyes, chemicals, and auxiliaries is discharged as effluent. Because they constitute a chemical mix, textile effluents are challenging to handle (Saxena et al., 2017).

Table 1: Wet textile processing and wastewater generation

Process	Wastewater contaminants
Desizing	BOD from water-soluble sizes; synthetic sizes, lubricants
Scouring	NaOH disinfectant and insecticide residue, detergents and fats
Bleaching	Hydrogen peroxide, Sodium silicate, organic stabilizer
Mercerizing	High pH chemicals, NaOH
Dying	Heavy metals, salts, surfactants, BOD, Color agent
Printing	Suspended solids, urea, solvent, color, metals, BOD
Finishing	BOD, COD, suspended solids, spent solvents

Adopted and modified from (Babu et al., 2007)

Sizing and Desizing

Sizing is done to give the fabric's face a smooth, uniform, and clean appearance by eliminating the loose, hairy threads from its surface. The yarn is coated throughout the size process to make it easier to weave, knit, and tuft. Chemicals, including polyvinyl alcohol, carboxymethyl cellulose, and polycyclic acids, are used to conduct sizing. The amount of sizing material in the effluent released from an average mill that generates roughly 60,000 meters of fabric is estimated to be around 750 kilograms (kg). Processes including dyeing, printing, and finishing are hampered by the presence of sizing components in the yarn. For instance, the presence of starch might prevent color from dispersing into the fibres (Council, 1995).

Desizing is the process of removing the sizing ingredients that have been applied to the cloth to improve the yarn's strength. Without being desized, fabric is stiff and difficult to handle during the following procedures. Starch is detached or changed into a water-soluble state during the desizing process, either by hydrolysis or by oxidation (Batra, 2017). Approximately half of the entire wastewater volume, which has high levels of biological oxygen demand (BOD), is a result of the desizing process. The issue can be solved by using enzymes that can convert starch into straightforward ethanol rather than complicated anhydroglucose. It is also possible to use an oxidizing agent, such as hydrogen peroxide (H_2O_2), to completely dissolve starch into carbon dioxide (CO_2) and water (H_2O) (Babu et al., 2007).

Table 2: Ecological friendly unconventional chemicals for textile wet processing

Purpose	Convectional chemicals	Alternative chemical
Sizing	Starch	Water-soluble polyvinyl alcohol
Desizing	Hydrochloric acid	Amylase
Scouring of cotton	Sodium hydroxide	Pecrinase
Bleaching	Hypochloride	Hydrogen peroxide

Oxidation of vat and sulfur dyes	Potassium dichromate	Hydrogen peroxide
Thickener	Kerosene	Water-based polyacrylate copolymer
Hydrotropic agent	Urea	Dicyanamide
Water repellent	C_8 fluorocarbons	C_6 fluorocarbons
Wetting agent	Alkyl phenol ethoxylates	Fatty alcohol phenol ethoxylates
Neutralization	Acetic acid	Formic acid
Mercerization	Sodium hydroxide	Liquid ammonia
Reducing agent	Sodium sulfide	Glucose, acetyl acetone
Dyeing	The powder form of sulfur dyes	Per-reduced dyes

(Adopted and modified from (Arputharaj et al., 2016))

Scouring

Scouring is a chemical washing procedure used on cotton fabric to remove any more dust or dirt as well as any natural wax and non-fibrous impurities (such as seed pieces) from the fibres. An alkali solution is used to boil the cloth, creating soap with free fatty acids. In this process, hot alkali, detergent, or soap solutions, such as glycerol, ethers, and scouring solvents, separate cotton wax and other non-cellulosic components of cotton (Madhu et al., 2017). Sodium hydroxide (NaOH), detergents, insecticide residues, pectin, fats, oils, and wax, spin finishes, knitting lubricants, spent solvents, and scouring can all be used to add significant organic loads to textile effluents. Scouring can be done in batch or continuous processes. These effluents have a pH of 10 to 11, which is quite alkaline (Keerthi et al., 2012).

Bleaching

By reducing the cotton's remaining residual impurities and natural color, bleaching enhances the whiteness of the fabric. The yarn's inherent coloring gives the cloth a creamy look. To obtain white yarn that will enable the creation of light and bright hues, the yarn must first be dyed by bleaching (Madhu et al., 2017). One of the earliest industrial bleaching agents was hypochlorite. Today, absorbable organ-halides are further employed as bleaching agents. Using absorbable organically bound halogen (AOx), the formation of very harmful chlorinated organic by-products during the bleaching process can be reduced. Additionally, peracetic acid (CH_3CO_3H) is a risk-free substitute for hypochlorite. Using CH_3CO_3H results in higher brightness ratings with less fiber damage. Recently, one-step preparatory desizing, scouring, and bleaching treatments have reduced the quantity and toxicity of the effluent (Slokar, 1998).

Mercerization

Mercerizing is a process that gives cotton fabric and threads a glossy sheen and increases their tensile strength. Cotton and other cellulosic materials are subject to the procedure. Fabric is treated with a sodium hydroxide solution during mercerizing to cause the fibres to swell. Strength and dye affinity are therefore enhanced. After bleaching, cotton fabric and fibres are mercerized in their grey condition to add sheen, boost strength, and improve colour absorption. During the mercerization process, cotton textiles are exposed to a strong (18–24%) caustic soda solution for 1–3 minutes before being washed clean. When cotton is handled with this solution, longitudinal shrinkage might happen. In order to prevent shrinking, the fibres or textiles are maintained under stress during this operation. The fabric and fibres obtain the required characteristics of luster, improved strength, dye intake potential, and amplified absorbency. Membrane techniques may be used for the recovery of NaOH present in the wash water. The use of zinc chloride ($ZnCl_2$) is another way to increase the fabric's weight, accelerate dye intake, and permit the easy recovery of NaOH. This practice does not need neutralization, and thus, it is environment-friendly (Karim et al., 2006).

Dyeing

The process of dying involves giving textile items like fibres and yarns color. Typically, dyeing is carried out in a customized solution that contains dyes and a specific chemical. Following dyeing, the chemical link between the dye and fibre molecules is no longer disrupted. The two main elements that influence this process are temperature and time. Chemical pigments (dyes) are added to fibres or cloth during the dyeing process to create colors. Synthetic dyes, which mainly come from coal tar and petroleum industry by-products, are most frequently employed in the textile industry. In synthetic dyes, auxochromes, an electron-withdrawn or electron donating substituent, are in charge of the exaggeration of the color, while chromospheres, the atoms, are responsible for the color. To improve dye adsorption onto the fibres, a variety of chemicals, including formaldehyde, heavy metals, surfactants, salts, and sulphide, may be added. These compounds are major pollutants in the dyeing process effluent (Sarayu et al., 2012).

Water is used in the dyeing process to transport colours in steam form and warm the treatment baths. For wet processes, the dyeing of cotton fibre requires enormous amounts of water. For instance, to dye 1 kilogram of cotton using reactive dyes, 0.6 to 0.8 kg of sodium chloride (NaCl), 30 to 60 grams of dyestuff, and 70 to 150 litres of water are needed (Jotshana et al.,2021). Following the dying process, a range of colorful dye baths with high salt and organic component concentrations are discharged. Dye baths are typically quite polluted. For instance, 20 to 30 percent of the reactive dyes in wastewater created during reactive dyeing are hydrolyzed reactive dyes that are not attached to the textile materials. The various hues of the dyeing process' effluents can be attributed to these leftover dyes. Recycling organic materials or coloring agents is not possible. As a result, their addition to effluents causes the effluents' high BOD and Chemical Oxygen Demand (Babu et al., 2007).

Printing

The term "localized dyeing" refers to a branch of dyeing that includes printing. In printing, certain portions of the cloth that make up the design are dyed. Printing and dyeing both entail necessary chemical processes. Color is applied as a thick paste of the dye in printing, whereas color is utilized as a solution in dyeing. The most popular chemically reactive dye used in printing, urea, has a significant pollution burden. Recently, screen-free printing methods have developed that are more environmentally friendly than these other methods, such as electrostatic printing and ink jet printing (Babu et al., 2007).

Finishing

All bleached, dyed, printed, and certain grey textiles go through a series of steps called finishing before being sold. The goal of textile finishing is to make products suitable for their intended use or purpose and/or to increase the fabric's usability. Applying one or more finishing techniques to fabric may result in a significant increase in value. Both natural and synthetic fibre textiles require a variety of finishing activities to be processed. Finishing entails applying a variety of finishing chemicals made for cross-linking, softening, and waterproofing in order to generate certain qualities in the refined fabric. The use of biocides finishing chemicals gives finished textile fabrics specific antimicrobial properties and protects finished goods from microbial deterioration (USEPA 1997). Biocides are mostly inorganic or organ synthetic compounds that are used to sterilize, sanitize, or disinfect objects in order to maintain them or guard against microbial deterioration. The fundamental connection between textile biocides and toxicity in dye house effluent Similar to that, color carriers also make textile effluents more hazardous than other effluents (Arslan, 2007).

2.2.2. Source of wastewater

Water used for cleaning, preparation, dyeing, finishing, non-contact cooling, and other processes are often the major sources of effluent. Depending on the mill, processes, tools, and materials produced, the industry's water usage varies greatly. Each textile manufacturing process uses a significant quantity of water, which eventually turns into wastewater (Teshale et al., 2021).

The pretreatment, dyeing, printing, and finishing of textile materials are among the major production phases' most important producers of wastewater. Desizing is the primary source of wastewater in the business during the pretreatment stage (National safety council, 1995). All the sizes used during weaving are taken out of the cloth during desizing and discharged into the wastewater. Scouring removes dirt, oil, and waxes from natural fibers in the garment and flushes them into the wastewater stream. Desizing and scouring are frequently coupled, and the combined effects of these two processes may account for 50% of the BOD in the wastewater after wet processing. The peroxide bleaching wastewater is not a significant issue. (De Forion et al 2005). The majority of the overall effluent is produced by the dyeing process. Wastewater is produced during the dye preparation, wasted dye bath cleaning, and washing operations. Wastewater from dyeing has a high salt, alkalinity, and color content. Organic contaminants caused by finishing procedures, such as resin, softener, and other auxiliaries residue, are produced. (Legrine et al., 1993). A textile mill's effluent is often produced at high pH, temperature, detergents, oil, suspended and dissolved particles, dispersants, leveling agents, hazardous and non-biodegradable materials, color, and alkalinity levels. (Muralimoham et al., 2004).

2.3. Characteristics of Textile Wastewater

Different textile effluents have different characteristics that rely on the type of raw materials used, the chemicals used, and the type of cloth produced (Ejeomo et al., 2013). High levels of pollutants that harm the environment and human health are present in the textile wastewater, including suspended and dissolved particles, biological oxygen demand, chemical oxygen demand, heavy metals, odor, and color (Ghaly et al., 2004). Several BOD/COD ratios have been found to be around 1:4 which implies the presence of non-biodegradable materials. A textile industry's effluent is typically characterized by dangerous swings in a variety of parameters, including COD, BOD, pH, color, and saltiness. (Mekibib, 2011). The many organic-based substances, chemicals, and colors employed in the dry and wet processing phases will determine the wastewater's composition. (Venceslau et al., 1993).

2.4. Environmental Impact of Textile Wastewater

Textile industries are thought to hold the top ranking in terms of wastewater volume produced and composition. There are significant issues with the incorrect and careless dumping of textile effluents in natural rivers as well as land (Mekibib, 2011). The organic and inorganic chemical constituents found in textile effluent are harmful to water purity and the development of all plants and animals. Every stage of the textile industry's life cycle has seen environmental effects as a result of its chemical-intensive nature as applied to various operations (Vinod et al., 2012).

Recent research has indicated that the widespread use of organic dyes with complex and highly diverse chemical structures is the primary cause of environmental issues connected to textile related activities (Carliell, 1993). In addition to giving water an unpleasant hue, dyes can irritate the skin and lungs and induce migraines, congenital abnormalities, nausea, and hemorrhages. They could prevent sunlight from penetrating through water's surface, which would stop photosynthesis. Additionally, dyes cause the receiving water's biochemical oxygen demand to rise, which slows down the re-oxygenation process and prevents the growth of photoautotrophic organisms (De

Florio et al., 2003). Additionally, the aquatic flora and wildlife are impacted by the dye that is released with the effluent into receiving waters. Some colors are carcinogenic, while others produce poisonous substances such aromatic amines after being transformed or degraded (Mekibib, 2011).

Additionally, dyes build up in sediments at various locations, particularly near where wastewater is discharged, which affects the biological balance in the aquatic system. These contaminants damage the ground water system due to soil leaching (Patel, 2013). Color is the first pollutant that can be identified in dyeing effluents; hence it must be eliminated before discharge into the receiving environment. Similar to inorganic compounds, textile effluents include an excess number of soluble salts that render the water unfit for usage. Even in small amounts, it has been discovered that these compounds are harmful to aquatic life (Ministry of Finance and Economic Development, 2010).

Due to their interaction with greasy slime and disruption of the oxygen transfer process at the air-water interface, the suspended material concentrations in effluents have a significant impact on the environment (Farah et al., 2013). Additionally, the release of organic pollutants like COD or BOD into the receiving stream may cause the dissolved oxygen to be depleted, which will result in anaerobic conditions. Hydrogen sulfides and other strong-smelling compounds can be formed in anaerobic environments. As a result, the biological activity in the receiving stream will be disturbed. Additionally, the textile mills produce wastewater that contains harmful heavy metals including cadmium, chrome, lead, nickel, and zinc, among others (Mekibib, 2011).

Heavy metals are present in water used for irrigation that contains textile waste, which accumulates in various plant sections and causes a variety of health problems in both humans and animals via the food chain (Ghaly et al., 2004). The accumulation of heavy metals in the effluent increases the potential that they may enter the food chain (Pala, 2011). In both cases, the inorganic heavy metals are taken in immediately by the freshwater and marine life or are incorporated into the groundwater, meaning that the heavily consumed marine foods and contaminated groundwater may cause diseases like cancer, tumors, brain and liver diseases, psychiatric illnesses, and sexual diseases (Ejeomo et al., 2013). In conclusion, textile wastewater has negative environmental effects. Due to many factors, Ethiopia is predicted to have a high level of this consequence. In place of using waste treatment, there is a tendency to dump industrial effluent directly into aquatic bodies or land (Achi et al., 2011).

2.5. Textile Wastewater Disposal Standards

There are several methods for treating textile wastewater, but the majority of them are too expensive for enterprises of all sizes to adopt. Many physico-chemical technologies also don't offer a long-term solution to the issue since they just change the forms or phases of the contaminants (Rahel et al., 2007). Around the world, a variety of environmental protection agencies have put restrictions in place to safeguard the environment and public health from pollution caused by the textile industry. These organizations establish guidelines for the release of effluents into the environment (Ghaly et al., 2004). The challenges of disposal have been observed to vary by area. Monitoring these discharge restrictions on a regular basis is vital to maintaining a safe and healthy ecosystem. In order to safeguard depleted natural water resources, industries must instantly monitor textile effluents on a continuous basis and take the required actions to properly remove the wastewater before dumping it into water bodies (Ejeomo et al., 2013).

2.6. Textile Wastewater Treatment Methods

Due to the variety of raw materials, chemicals, processes, and technical improvements employed in those activities, the textile industry's impact on the environment is complex and dynamic (UNEP, Textile Industry and Environment). Different contaminants have varying amounts in textile wastewater, depending on the wastewater treatment methods used and the volume of water used in the manufacture (Pala, 2001). Therefore, it is crucial to implement an efficient treatment strategy. There are several ways to remediate textile wastewater. Different plants will have unique combinations of techniques that are effective depending on the size, kind, and amount of therapy needed. The three main treatment methods used to treat wastewater from the textile industry are biological, physical, and chemical methods (Debbie, 2013). Regarding the complexity of textile wastewater, a number of parameters, including dye type, wastewater composition, chemical dose and cost, operating expenses, environmental destiny, and handling costs of created waste products, influence each treatment option's technical and financial viability (Van Der Zee, 2002).

2.6.1. Biological methods

Different biological therapeutic modalities exist. Activated sludge, aerobic and anaerobic processes, sequencing batch reactors, oxidation ponding, and trickling filters are a few examples (Pala, 2001). The developed activated sludge system and conventional processes make up the majority of biological processes. After initial settling, the wastewater in the activated sludge process enters a tank. Aggregates of the microorganism found in activated sludge are suspended in the wastewater. Compressed air maintains the suspension of the sludge and wastewater and also provides the oxygen required for biological activity. A part of the sludge from the continual removal and settlement of the aerated waste is added back to the influent. Typically, approaches include oxidizing organic waste utilizing a natural process involving bacteria and other microorganisms to remove contaminants from wastewater. Biological approaches are routinely utilized to remove organic and color from dyeing and textile effluent because they are often inexpensive and easy to use (Arshad et al., 2013). Because many industrial dyestuffs are poisonous to the organisms being utilized and produce the issues of sludge thickening, rising sludge, and pin flock, biological treatment techniques are typically ineffective for treating dyestuff effluent. (Arshad et al, 2013). Because of the toxicity of the wastewater and the requirement for an aeration system, biological treatment of dyeing wastewater is less expensive than other procedures but less effective for color removal (Sapci, 2003)

2.6.2. Physical methods

Reverse osmosis, membrane filtration, and adsorption are examples of physical methods. Adsorption is a useful technique for reducing the number of dissolved dyes in the effluent, which removes color. Without pretreatment, suspended particles quickly block the filter, making it unable to adsorb on activated carbon. Therefore, only a biological treatment or a flocculation-decantation therapy in conjunction with this process is practical. Activated carbon is expensive, but the combination allows for a decrease in organic and suspended particles as well as a small lightening of color. Pollutant removal from wastewater may be accomplished through membrane filtering. But the initial investment cost is quite high, and the expense of replacing the membrane on a regular basis is surprisingly significant. The removal of macromolecules and particles is possible using ultrafiltration (Verma et al., 2012).

2.6.3. Chemical methods

Coagulation, flocculation, oxidation, and other processes are included in the process. Although successful, the majority of chemical treatment approaches have been studied with an emphasis on color removal since they are costly or may result in additional secondary pollutants. The greatest immediate solution for undeveloped areas lacking good wastewater treatment infrastructure is to adopt straightforward, reasonably priced point-of-use technology like coagulation. The process of coagulation is crucial to the treatment of industrial effluent. Chemical oxidation forces the breakdown of refractory organic pollutants by using potent oxidizing agents like chlorine, hydrogen peroxide, and others. Due to its simplicity, chemical oxidation is the most commonly used technique for color removal by chemicals. Hydrogen peroxide is the primary oxidizing agent. Chlorinated hydrocarbons, phenol, insecticides, and aromatic hydrocarbons can all be degraded by ozone oxidation. One of the main benefits of Ozonation is that it reduces the amount of sludge and effluent (Verma et al., 2012). Table 3: presents the pros and cons among the major textile wastewater treatment methods.

Table 3: Pros and cons of textile wastewater treatment methods

Process	**Advantages**	**Disadvantage**
Biodegradation	Rates of elimination by Oxidizing substance about 90%	Low Biodegradability of dyes
Coagulation-Flocculation	Elimination of in soluble dyes	Production of sludge blocking filter
Adsorption on Activated Carbon	Suspended solids and organic substance well reduced	Cost of activated carbon
Ozone treatment	Good decolonization	No reduction of COD
Electrochemical process	Capacity of adaptation to different volumes and pollution loads	Iron hydroxide sludge

Reverse Osmosis	Removal of all mineral salts, Hydrolyzes reactive dyes and chemical auxiliaries	High pressure
Nano-filtration	Separation of Organic compounds of low molecular weight	Require high cost
Ultra-filtration-microfiltration	Low pressure	Insufficient quality of he treated wastewater

2.6.4. Coagulation process

In industrial wastewater different compounds are present like suspended, colloidal and dissolved solids. Suspended solids have a diameter larger than 10^{-6} mm, colloidal solids between 10^{-9} mm and 10^{-6} mm and dissolved solids smaller than 10^{-9}mm. This material must be removed prior to discharge (Metcalf and Eddy, 2003). Because of the nature of the colloidal suspension these particleswill not sediment or be separated with conventional physical methods (such as filtration or settling) unless they are agglomerated through coagulation. Coagulation is the one of the most popular unit operations in water and wastewater treatment. This process is physic-chemical operations used to facilitate the separate of suspended and colloidal solids from the wastewater. Coagulation is frequently applied to process in the primary purification of industrial wastewater and in some cases in secondary and tertiary treatment. It is the main component of wastewater treatment units and the applications include wastewater treatment, recycling and removal of pollutants. Coagulation process is the destabilization of colloidal particles brought about by the addition of a chemical reagent known as a coagulant. Flocculation is the agglomeration of destabilized particles into microfloc, and later into bulky floccules which can be settled called floc. In commonly, the coagulation-flocculation process consists in destabilizing colloids, aggregating and binding them together into flocculates; the resulting flocs can finally be removed either by settling or flotation. Coagulation, flocculation and clarification, followed by filtration, which are the key steps in wastewater treatment systems (Karoliny, 2018). The coagulation process includes dosing of a coagulant in water and it results in the destabilization of water. It occurs in several steps intended to overcome the forces that stabilizes the suspended particles, allowing particle collusion and growth of floc.

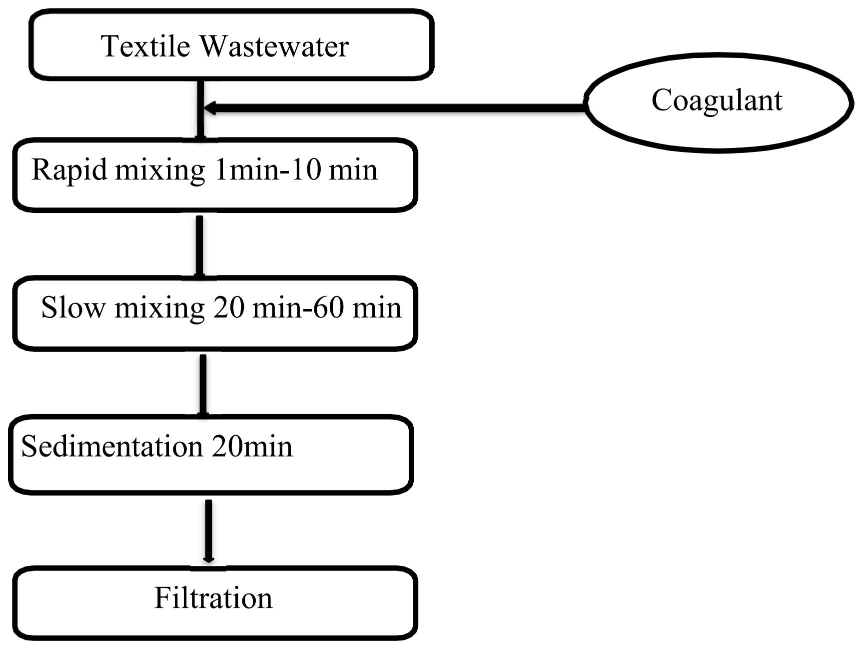

Figure 1. Steps of coagulation process

The first step in the coagulation process is destabilizing the particle charges in the water. Coagulant of opposite charges added to neutralize the negative charge on the dispersed non settable solids. Once the charge is neutralizing, the smaller particles are capable of sticking together to form a slightly larger particle. Rapid and slow mixing after coagulant dosing is a design parameter. Rapid mixing ensures the coagulant is properly dispersed in the water and promotes particle collision that is needed to achieve good coagulation. Slower mixing helped in promoting floc formation by enhancing particle collisions which led to larger flocs (Metcalf and Eddy, 2003). Depending on the type of colloidal suspension that should undergo coagulation different destabilization mechanisms can be employed such as: Repression of the double layer, neutralization of colloid charge by adsorption of counter ions on the surface of the colloid, bridging of colloidal particles via polymer addition and Entrapment of colloidal particles by sweeping floc.

The addition of certain chemicals into the raw water causes particles to destabilize and allows agglomeration and floc formation to occur. The general terms used for this purpose are:

- ✓ Coagulants, which assist the destabilization of particles (particularly colloidal sizes).
- ✓ Flocculants (also known as flocculent aids or coagulant aids), which assist joining and enmeshing of the particles together.

In textile wastewater treatment coagulation-flocculation are treatment methods that can be employed to reduce color effluent and also to reduce the total load of pollutants. The main advantage of these methods is cost effective, simple to operate and energy saving treatment alternative. The inherent disadvantage to this process is the generation of large quantities of chemical sludge and its classification as hazardous waste, necessitating the need for secured land filling of hazardous solid wastes (Metcalf and Eddy, 2003). For this reason, alternative natural materials have been considered for environmental applications. In this study the term was used coagulation, in line with the common trend, to represent the whole process starting from adding of coagulant in wastewater up to their settlement.

2.6.5. Types of Coagulants

A viable pre-treatment technology for reducing the pollution problems is the physic-chemical treatment using coagulants and this has been successfully applied to different wastewaters The coagulants used play a major role in the treatment of wastewater and disposal of sludge. Selecting a coagulant for treatment of water and wastewaters is a function of several factors which include the nature of the suspended particles, raw water and wastewater condition, design of treatment facility, cost of coagulant chemicals, zeta potential (the amount of repulsive forces which ensure that particles stay in water environment), and Van der Waal's forces (weak inter-molecular forces that influence particle formation) (Sunita and Sonal, 2014). For any treatment process to be effective, attention must be paid to required effluent quality, sludge handling disposal cost (chemical coagulants generate sludge), and overall dosage cost of coagulant. There are two types of chemicals coagulants used in coagulation process. These include; primary coagulants and coagulant aids (Metcalf, Eddy, 2003). Primary coagulants are involved in neutralize the electrical charges of particles in the water which causes the particles to clump together. Coagulant aids add density to slow-settling flocs and add toughness to the flocs so that they will not break up during the mixing and settling processes (Mohammad et al., 2017). Primary coagulants are always used in the coagulation/flocculation process. Coagulant aids, in contrast, are not always required and are generally used to reduce flocculation time. Coagulants used in wastewater treatment can be classified into inorganic coagulants (e.g. Aluminum sulphate (Alum), Poly-aluminum chloride, ferrous sulphate, and ferric chloride), synthetic organic polymers (e.g. polyacrylamide derivatives and polyethylene amine) and naturally occurring coagulants (e.g. Chitosan, Moringa and cactus etc. (Sahu and Chaudhari, 2013). As indicated above the type of coagulant used is one determining factor for effective wastewater treatment. In this relation, application the aforementioned most common type of chemical coagulants has some advantages and disadvantages. Alum is common name for Aluminum Sulphate also known as Sulphate of alumina, and the most widely used coagulants in water and wastewater treatment all over the world because of effectiveness. However, numerous recent studies have raised doubts about introducing aluminum into environment. Also, some studies have reported that this salt is characterized in poisoning factor for encephalopathy, and impact of aluminum on human health; it is strongly evidenced aluminum-based coagulants linked in the development of neurodegenerative ill-ness and with Alzheimer's disease. Several studies have pointed out the introduction of naturally prepared coagulants produced or extracted from microorganisms, animals, or plants. Moringa seed, Nirmali, Okra, Beans, cactus, Rice and Maize are the type of coagulants which have been identified from plant. On the other hand, chitosan is affirmed to be good coagulant which has animal origin (Hassan, et al, 2008). Other studies also indicated the presence of four types of plants which have been extensively used as coagulants viz. Moringa seed, Nirmali seeds, Tannin and Cactus has been used for successfully removed pollutant from industrial wastewater. In coagulation cactus has been recognized to remove industrial pollutant namely from textile, dairy, brewery, and tannery (Gobinath et.al, 2013).

2.6.7. Application of Aleo vera as Coagulant

Aloe Vera may be an exceptionally compelling and imperative home-grown plant in numerous other plants, it gives so numerous restorative exercises and pharmacological impacts for human creatures. Aloe Vera also is utilized for restorative application completely different framework of our societies (Himes et al 2011). Aloe Vera could be a tough, lasting, tropical, drought-resistant, juicy plant. The aloe Vera has delivered the gigantic conventional part in endemic framework of rules of pharmaceutical such as the Siddha, Unani, Ayurveda and Homeopathy. Aloe Vera may be a standard, dry spell debate, sticky plant. The aloe title is starts from the Arabic "Alloeh" or Hebrew "Halal" implies heightening Sparkly master. It has conveyed a considerable routine portion in inborn course of action of pharmaceutical system like. Aloe barbadensis process administrator could be a semi tropical plant is one of the 250 sorts of Aloe Vera. Aloe Vera (/ˈæloʊiː/ or /ˈæloʊ/) could be a juicy plant species of the class Aloe. An evergreen lasting, it begins from the Middle Eastern Promontory but develops wild in tropical climates around the world and is developed for rural and therapeutic employments. The species is additionally utilized for enriching purposes and develops effectively inside as a pruned plant (Ayurveda et al., (2010).

The main factor behind the possibility of using Aleo vera as material for waste water treatment is its biochemical composition without any toxic effects. It was reported by many studies that Aloe vera is composed of low protein and lipid contents and polysaccharide is considered as the mainingredient. Interestingly, Aloe vera species are known by the polysaccharose production. The presence of minerals, such as Ca^{2+} and K^{+}, is necessary for the gelatinous properties of mucilage. It was reported that calcium ion exists in the Aloe vera as calcium-oxalate and this has strong effect in molecular conformation of the mucilage increasing its water holding capacity. Moreover, the rate of mucilage viscosity was observed to be enough to show industrially desired consistency to liquid formulations, especially in suspension preparations, suggesting the possible use of this product as natural thickeners. The high flocculation/coagulation capacity of Aloe vera may related to its polysaccharide structure that composed of various carbohydrates, such as l-arainose, d-galactose, l-rhamnose, d-xylose and galacturonic acid. In this context, it was reported that galacturonic acid is significantly implicated as the main active coagulant agent, based on its polymeric structure. This polymeric structure provides a bridge for particles to adsorb. Moreover, the functional groups of Aloe vera polysaccharides included carboxyl (-COOH), hydroxyl (–OH) and amino or amine (–NH_2) groups, as well as hydrogen bonds. These functional groups considered as preferred groups for the coagulation-flocculation process (Rebah and Siddeeg, 2017).

Figure 2. Photographic representation Aloe vera

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study site description

The *Aloe vera* cladode used in this study was collected from local market and the wastewater were collected from Adama Industrial Park.

3.2. Chemicals and reagents

The chemicals and reagents used in this study were analytical grade. Hydrochloric acid (36%), Sodium Hydroxide (1M), potassium Bromide, nitric acid, Calcium Chloride, Iron Chloride, Magnesium Sulphate, Sulphuric acid (supplied by High Quality laboratory Chemicals pvt.. Ltd, Mumbai India), Polyaluminium chloride (Henan Aierfuke Chemicals Co., Ltd. Gujarat, India), Decolorant ENVI Color4103 (Arvind Envisol pvt. Ltd. Gujarat, India.), reagents used for COD (Hach, Loveland, USA).

3.3. Apparatus and Instruments

The equipment and tools used throughout the experiment were Jar test apparatus (PSI, Patel Sci. Inst. pvt. Ltd., Gujarat, India), BOD Incubator (PSI, Patel Sci. Inst. pvt. Ltd., Gujarat, India), Oven (PSI, Patel Sci. Inst. pvt. Ltd., Gujarat, India), Magnetic stirrer (2MLH, REMI Mumbai, India), weight balance (CY 223, ACZel PVT. LTD, 220±0.001gm, Mumbai, India), pH meter (HANNA, HI76312, Smithfield, USA), Turbidimeter (HANNA, HI98703, Smithfield USA), COD reactor, Spectrophotometer (DR3900, HACH, Loveland, USA), polyethylene bottle (Tarsons PvtL, Kolkata India), FTIR (FT/IR-6600 type A, Jasco Inc., Easton, America) Aquarium air-pump (AP-408A, VENUS AUQUA, India), SEM, and XRD

3.4. Sample Collection

The wastewater sample was collected by the grab sampling technique from Equalization Tank A of the Adama Industrial Park, Zero Liquid Discharge Treatment Plant. Clean plastic containers (polyethylene terephthalate (PET)) was used for sample collection after cleaning with detergent, soaked in 10% concentrated nitric acid, and rinsed with deionized water. Whereas about 500g of Aloe vera cladode was collected near the industrial park and brought to the Zero Liquid Discharge (ZLD) Laboratory for further preparation.

Figure 3. Sampling unit in Adama Industrial Park ZLD plant (Equalization tank A)

3.5. Preparation of bended Coagulant

The collected *Aloe vera* cladode sample was washed with tap water, and the outer part of the Aloe *vera* peel was fed using a knife. The inner part of the *Aloe vera* was divided, and about 250 g was sliced and dried at 60°C for 24 hours in a hot air oven and milled using a mixer-grinder into a powder or dry amorphous form later used for coagulation purposes. The of peeled *Aloe vera* was crushed in a blender, homogenized with PAC (Polyaluminum Chloride) in a ratio of 1:1, and used as a coagulant on a sample of wastewater collected to select the form of blended PAC and *Aloe vera* for further investigation. It was conducted in an optimized condition following the procedure (Saurabh et al., 2019) and the result was shown in appendix D**.**

3.6. Batch Coagulation Experiment

The coagulation experiment used the jar test apparatus, which consists of a batch test and a series of six beakers together with six spindle steel paddles, as shown in Figure 6 below. Before operating the jar test, the wastewater samples were mixed homogenously, and their initial pH was adjusted to the point where the experiment was done by adding either 1M strong acid (HCl) or 1M strong base (NaOH). Then the wastewater sample of 1L was poured into each beaker, followed by the addition of the different coagulant doses (blended PAC and *Aloe vera*) ranging from 100 ppm to 350 ppm from the 10% stock solution. The beakers were then dosing Decolorant (ENVI Color4103) at 250 ppm from the 10% stock solution and agitating at various mixing times with constant speed consisting of rapid mixing at 150 rpm for 3 minutes and slow mixing at 50 rpm for 10 to 60 with 10-minute intervals to determine the optimum blended coagulant dose (Beyene et al., 2017).

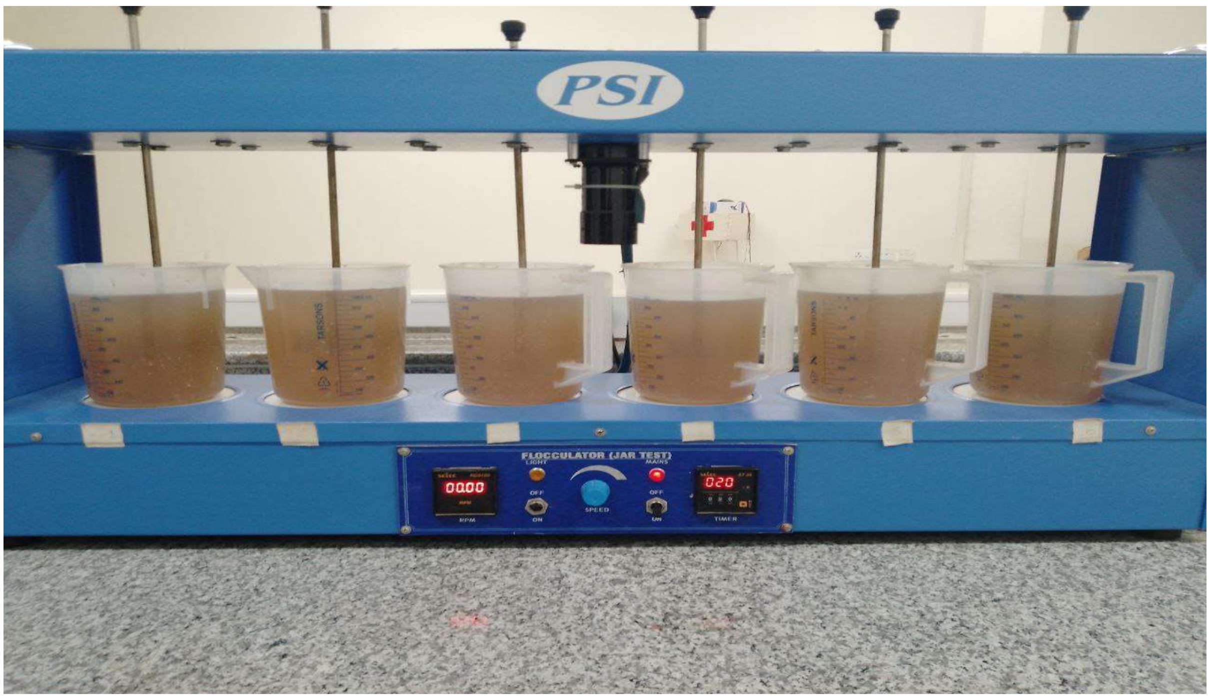

Figure 4. A photo illustration of the Jar test apparatus's experimental setup

The rapid mixing disperses the blended coagulant uniformly throughout the beakers whereas the slow mixing promotes the formation floc by enhancing collisions of particle that led to larger flocs. The suspension was allowed to settle for 20 minutes after the agitation was stopped, and then the supernatant was filtered. Then after, the TSS, turbidity, color, COD, BOD, and pH of the supernatant samples extracted from each beaker were examined.

Following determination of the optimized amount of blended coagulant, the batch experiment was conducted by varying some operating parameters that have a prime effect on the coagulation of textile wastewater, such as blended coagulant dose (amount ranging from 100 to 300 ppm from 10% stock solution), pH (values ranging from 4 to 10), and mixing time (ranging from 10 to 60 minutes in units of 10), while other parameters were kept constant in order to identify the optimal dosage, pH, and mixing time required to obtain the best blended coagulant performance in the coagulation process. The optimal value of each parameter was obtained by varying the required parameter in the specified ranges while keeping other parameters constant. pH was adjusted by adding either 1M strong acid (HCl) or 1M strong base (NaOH). The details of the treatment combinations are indicated in Figure 7 below:

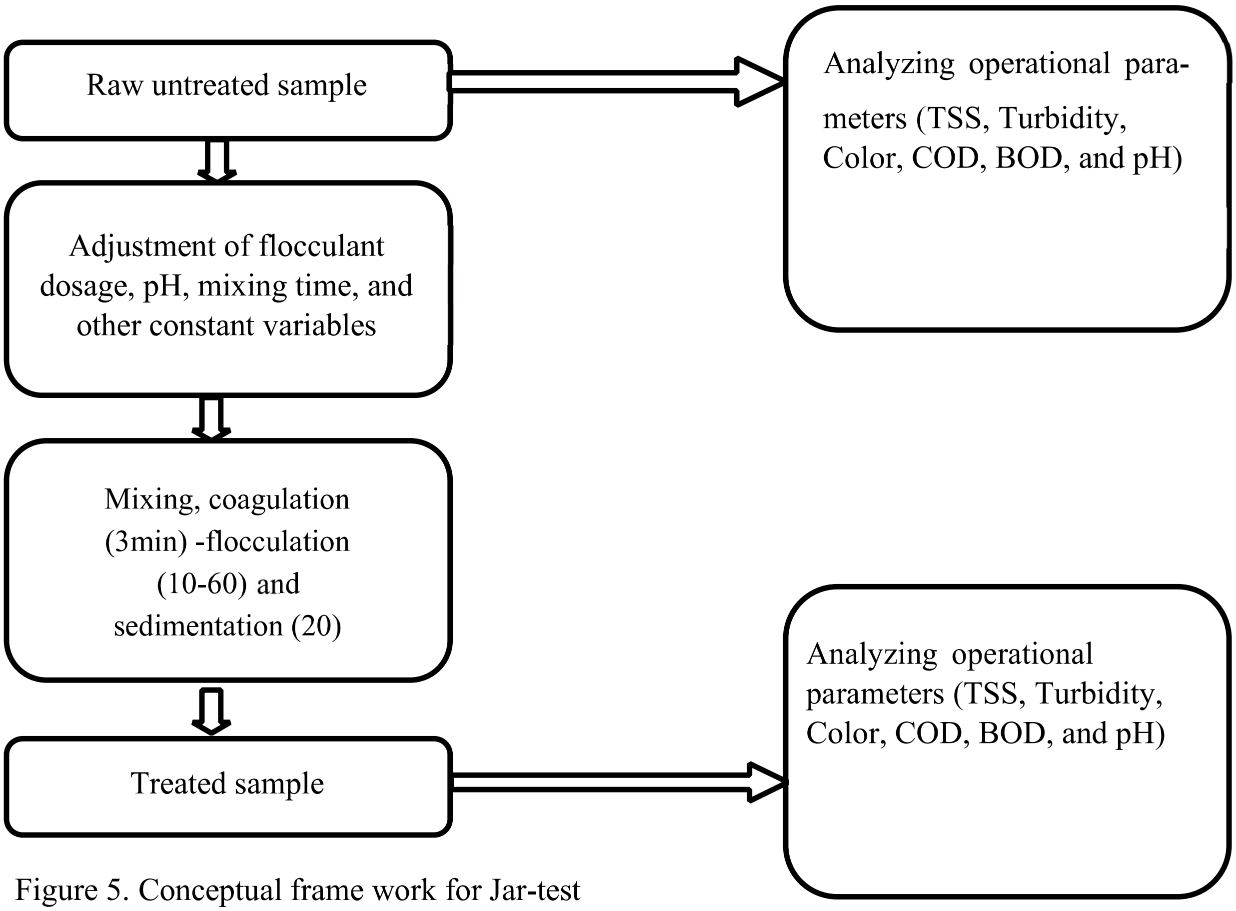

Figure 5. Conceptual frame work for Jar-test

3.7. Analysis of Different Quality Parameters

Standard procedures of Adama Industrial Park, ZLD Laboratory were used to measure Color, Turbidity, TSS, COD, BOD and pH (APHA., 2000).

Color Measurement

A HACH spectrophotometer (DR3900) were used for the Color measurements in Pt-Co unit. The blank (deionized water) was wiped and place it into the cell holder and the display was then showed 0 Pt-Co and, the prepared 10ml wastewater sample was wiped in to cell holder and touch read, display was then showed by Pt-Co unit. Appendix B of C shows HACH spectrophotometer (DR 3900) used for color measurement.

Turbidity Measurement

A HANNA turbidimeter (HI98703) were used for the turbidity measurements in NTU unit. The prepared 10ml wastewater sample was wiped and placed into the cell holder and run the analysis, the result was appeared in NTU unit. HANNA Turbidimeter (HI98703) used for turbidity measurement was shown in appendix B of D.

Total Suspended Solid Analysis

A HACH spectrophotometer (DR3900) were used for the TSS measurements in mg/L unit. The blank (deionized water) was wiped and place it into the cell holder and the display was then showed 0 mg/L and, the prepared 10ml wastewater sample was wiped in to cell holder and touch read, display was then showed by mg/L unit. Appendix B of C shows HACH spectrophotometer (DR 3900) used for TSS measurement.

pH Measurement

The pH of the sample's measurements was carried out using PH meter (HI5521). Before starting the analysis calibration of PH meter using Buffer solutions of 4.0, 7.0 and 10.0 pH meter (HI5521) used for pH measurement was shown in appendix B of F

COD Measurement

100 mL of sample were inserted in to blender and blended until homogenized. DRB200 Reactor was set the power to on. Pre heated to 150 °C. The cap from vials was removed for the selected range. Clean pipet was used to add 2.00 mL of sample to the vial. Also, clean pipet was used to add 2.00 mL of deionized water to the vial. Vials were rinsed with water and wiped with a clean paper towel. After being gently mixed, the vials were immersed in the pre-heater reactor. The lid was closed. After 2 hours of heating, a reactor power shut off. The vials are removed and cooled to room temperature. The vial consisting of blank (deionized water) was wiped and placed into the cell holder, and the display then showed 0 mg/L. The vial's sample was wiped into the cell holder and touched; the display then showed in mg/L unit. Appendix B of C shows HACH spectrophotometer (model: DR3900, HACH, USA) used for COD measurement.

3.8. Data Analysis

The data collected from the above experiment were analyzed using Microsoft Excel program and Originlab software. The results are presented using tables and graphs. The percentage removal efficiency of the parameters was calculated using following formula.

$$\text{Removal efficiency (\%)} = \frac{Co-Ce}{Co} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 1}$$

Where, Co= Initial concentration (Before treatment)

Ce= Final concentrations (After treatment)

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. Physico-chemical analysis of untreated Wastewater

The analysis of the untreated textile wastewater of Adama Industrial Park revealed 463 mg/L, 437 NTU, 3091 Pt-Co 7.59, 852 mg/L, and 478 mg/L of TSS, turbidity, color, pH, COD, and BOD, respectively, as presented in Table 4, indicating a high level of contaminants. These results align with prior research, which found comparable outcomes of textile wastewater for pH levels between 6 and 10, TSS concentrations from 150 to 1100 mg/l, COD ranging from 410 to 865 mg/l, and BOD levels between 236 and 436 mg/l, as reported by (Aslam et al. 2004).

Table 4: Characteristics of raw textile wastewater emanated from Adama Industrial Park (AIP) and sampled from the Equalization Tank A

Parameters	Unit	Result
pH		7.59
Color	pt-co	3091
Turbidity	NTU	437
TSS	mg/L	463
COD	mg/L	852
BOD	mg/L	478

4.2. Analysis of Functional group

FTIR is implied in this research to study the functional groups present in the blended Aloe vera and poly aluminum chloride. As show the FTIR spectrum of blended Aloe vera and PAC in Figure 6, the strong and broad band spectrum observed at 3223 cm^{-1} was due to the stretching of amine (N-H) group and the bound hydroxyl (O-H) stretching vibration. Furthermore, the carbonyl function (C=O) and CH_3 primary aromatic amines were detected at 1628 cm^{-1} and 1416 cm^{-1}, respectively. These peaks confirm the presence of NH groups in amides and the carboxyl group (COOH) which are responsible for water TSS and turbidity removal. The bands at 1084 cm^{-1} indicate the presence of C-O stretching. The peaks at 975 cm^{-1} and 461 cm^{-1} indicate the presence of aromatic CH out-of-plane deformation. From the above analysis, the blended of aloe vera and poly aluminum chloride can be concluded during the coagulation process conducted with blended

Aloe vera, its functional groups (the carboxyl group) act as adsorption sites for the suspended and colloidal solids. In addition, the amide groups in blended Aloe vera form intermolecular bonds between the suspended solids and the coagulant, thus increasing the efficiency of the coagulation process. This result agrees with the study done by (Madera et al., 2018). The principal IR absorption for certain functional groups used as reference representation in Appendix C (Olivares et al., 2012).

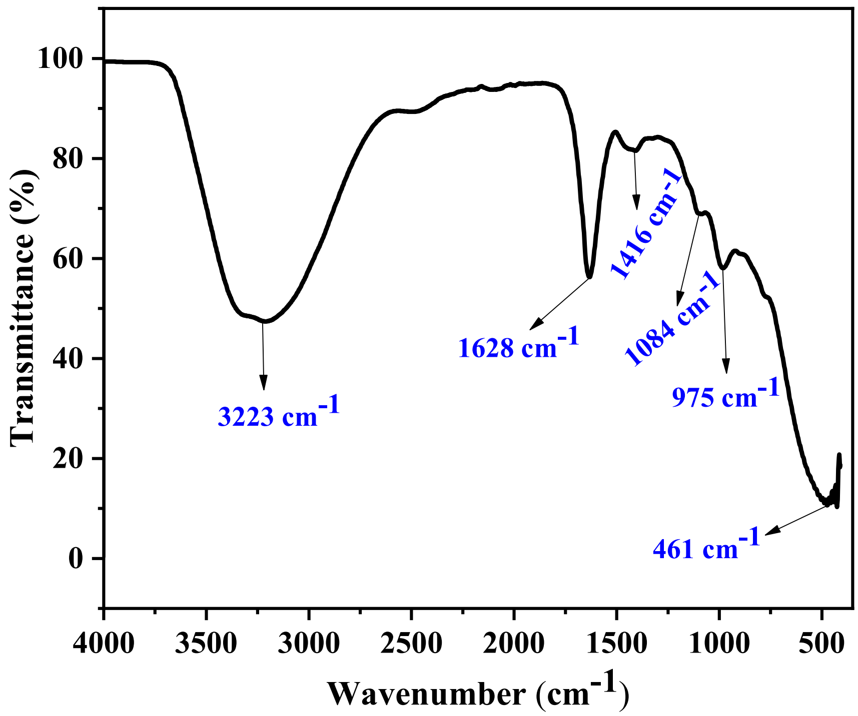

Figure 6. FTIR spectra of blended Aloe vera and poly aluminum chloride coagulant.

4.3. Analysis of crystalline structure

The phase purity and crystalline structure of the powdered coagulant was evaluated by an X-ray diffractometer. The spectra of blended Aloe vera and poly aluminum chloride were obtained in the range of 10 – 80 degrees. Figure 7, shows the XRD pattern of blended Aloe vera and poly aluminum chloride powder. The peaks between 15 and 56 degrees could be representative of various substances such as lipids, proteins, carbohydrates, and ash. A prominent sharp peak exhibited at 27.18° in the XRD spectrum corresponded to its crystalline structure (Colan et al., 2017). The specific nature of this coagulant allows contaminants to enter the coagulant surface.

According to the obtained results, it was noticed that the different coagulation agents present in the blended Aloe vera and poly aluminum chloride facilitate the removal of suspended solids and negatively charged colloidal particles, thus promoting the turbidity reduction and, as consequence, water quality improvement.

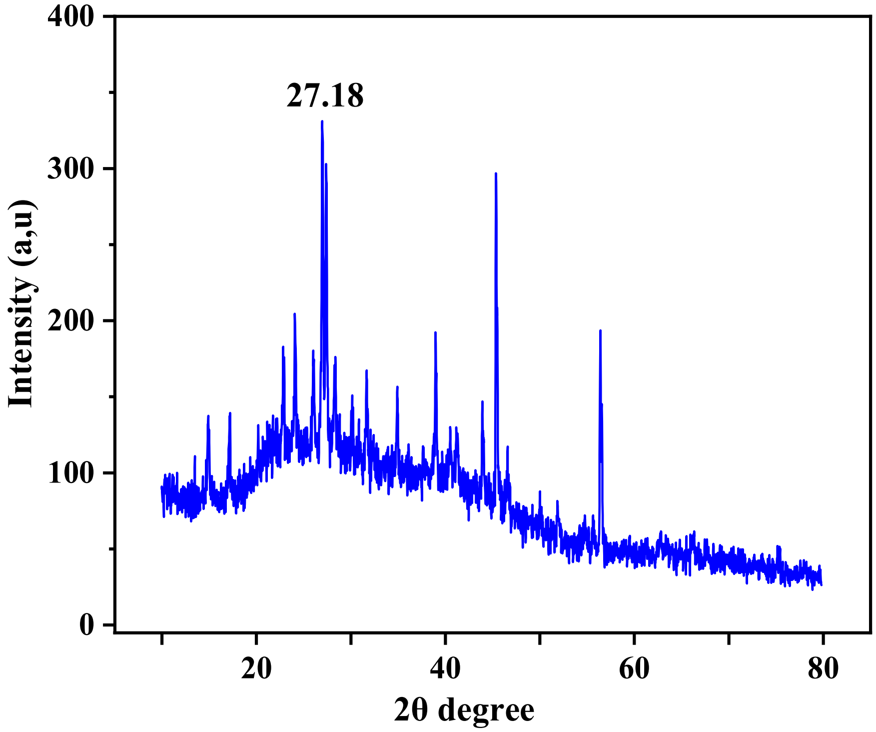

Figure 7. X–ray diffractogram for blended Aloe vera and poly aluminum chloride coagulant

4.4. Morphology Analysis

The SEM images of the blended Aloe vera and poly aluminum chloride coagulant as shown in Figure 8, were studied to examine its morphology and microstructure. The surface micrograph of blended coagulant revealed a villus structure bearing porous matrix. It can be assumed that the villus plays an essential role in the decolorization, as the spaces between porous matrices may facilitate the adsorption of dye.

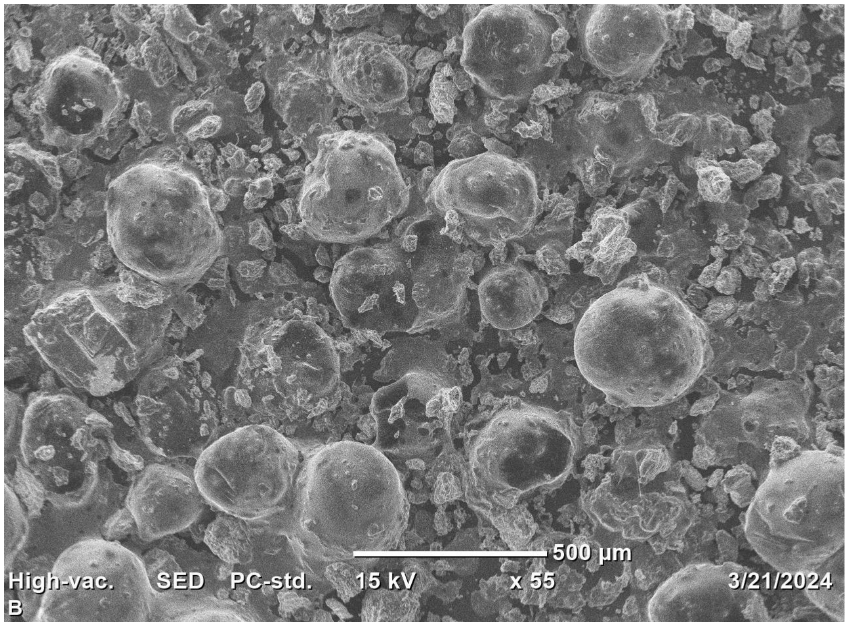

Figure 8. SEM images of the blended Aloe vera and poly aluminum chloride coagulant

4.5. Effects of Operating Parameters on Coagulation Experiment

The effects of blended coagulant dose, pH, and mixing time are important factors in order to investigate the performance of Blended PAC and Aloe Vera blended coagulant in coagulation process. In these experiments their effects primary on TSS, Turbidity, Color, COD and BOD level in textile wastewater are considered, which can be used as the indicator on the coagulant capacity of blended PAC and Aloe vera. The analysis results obtained were presented below

4.5.1. Effect of Coagulant dose

Coagulant dosage is one of the most essential parameters that have been evaluated to define the optimum conditions for bended Coagulant performance in the coagulation process (Himanshu et al., 2012). Specially, inadequate dose or overdosing would result in poor process performance. As a result, determining the appropriate dose is critical in order to reduce dosing costs and sludge formation while simultaneously achieving optimal performance in the treatment process.

Effect of Bended coagulant dose at constant pH and mixing time

The effect of coagulant dose at constant decolorant 250 ppm, while pH at 7.59 and mixing time at 20 min were kept constant, as shown in Table 5 below, the results showed that increasing coagulant doses from 100 to 300ppm led to an increased percentage removal of measured parameters. This suggests that the coagulant plays a crucial role in enhancing the effectiveness of the impurity removal. However, it is important to note that beyond a certain point (Above 350ppm), further increases in coagulant dose may not significantly improve the removal efficiency. The lowest percent removal of color (76.5%), turbidity (76.4%), TSS (54.6%), BOD (58.6%), and COD (52.2%) were observed when amount of dosage was at 100ppm this is because the amount of coagulant to make coagulate is inadequate.

The highest percentage removals of color, turbidity, TSS, COD and BOD were 89.8%, 96.8%, 95%, 82.6 and 84.1%, respectively, and observed at a coagulant dose of 300ppm. These high percentage removals indicate that 300ppm of coagulant is the optimal dose for achieving maximum effectiveness in removing color, turbidity, TSS, COD and BOD. Here, similar results were obtained by (Hayelom, 2019) while using a blended coagulant of cactus and alum, thus confirming the effect of coagulant on the aforementioned operational parameters.

It is crucial to carefully determine the appropriate coagulant dosage to avoid unnecessary waste and ensure cost-effectiveness in water treatment processes. In addition to this pH result of the experiment showed that unlike only chemical coagulants, change in blended coagulant dose did not have significant effect on the pH of treated effluent. Besides, pH scale of the treated effluent has fulfilled the permissive limit standard which set by EPA of Ethiopia (refer Appendix A). Thus, there is no need of pH adjustment for treated textile wastewater after coagulation process using blended PAC and Aloe vera coagulant. This in turn avoids additional cost which is commonly incurred to adjust pH while using the chemical coagulant. Overall, the observed results confirmed the effectiveness of blended PAC and Aloe vera act as coagulant in textile wastewater treatment as mentioned on Appendix D of II.

Table 5: Quality parameter removal capacity at various coagulant doses while other operation parameter kept constant (pH is 7.59, and mixing time is 20 min)

Sample/Treatment	1	2	3	4	5	6
Blended Coagulant (ppm)	100	150	200	250	300	350
Parameters						
pH	7.52	7.49	7.46	7.41	7.38	7.24
Color (pt-co)	725	618	523	439	376	545

Turbidity (NTU)	103	48	36	25	14	19
TSS (mg/L)	210	96	71	49	23	32
COD (mg/L)	407	310	226	184	148	194
BOD (mg/L)	198	174	137	84.6	76	92

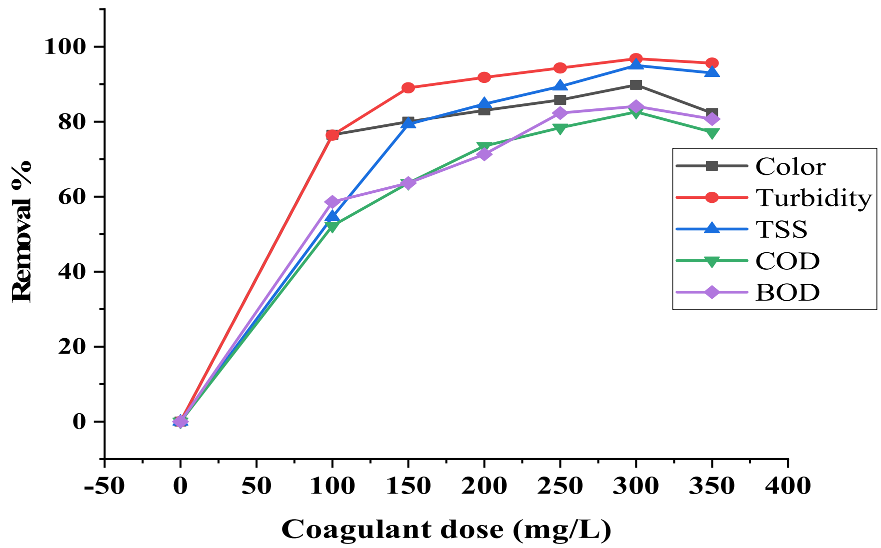

Figure 9. Effect of blended coagulant dosage on turbidity, and TSS, color, BOD and COD percentage removal

4.5.2 Effect of pH

The effect of variation in pH was analyzed at optimum dose of 300ppm, decolorant 250 ppm and constant mixing times of 20 minutes were presented in Table 6 The results revealed that the percentage removal of color (95%) turbidity (98.9%), TSS (98.3%), COD (78.4%) and BOD (67.8%) was reached maximum at neutral condition (at pH 6) whereas the percent removal has gradually declined as pH increase beyond 8 and decrease below 4. Similar results are also obtained in another study (Amine et. al., 2022). This may be due to at pH 6-point particles surface charge were reduced or neutralized as well as destabilized the suspension due to presence of blended PAC and Aloe vera which is favorable condition to coagulate, it to collect those destabilized suspension. The observed minimum percent removal of color (76.4%), turbidity (94%), TSS (91.1%), COD (76.6%) and BOD (64.6%) of the blended coagulant at pH of 10 may be due to as the pH becomes basic condition the solubility of PAC decrease that may contribute to decline charge neutralization roles of the coagulant to destabilize the particles. Moreover, at higher pH positive charges of Blended PAC and Aloe vera surface decreased significantly (Gobinath et al., 2013). Overall, at pH around 7 the result showed that flocs produced by blended coagulate were rapid and caused large size of flocs formation which was important for easiness of the settlement. Therefore, the Blended PAC and Aloe vera coagulant is effective for the treatment of textile wastewater at near neutral condition pH 6 Overall, the observed results regard to effect of pH was mentioned on Appendix D of III.

Table 6: Percentage removal of major quality parameters at various pH values, optimized flocculant dose and constant mixing time

Sample/Treatment	1	2	3	4	5	6
pH	4	6	7	8	9	10
Parameters						
pH	4.51	6.16	7.39	7.59	8.71	9.85
Color (pt-co)	164	159	160	215	436	731
Turbidity (NTU)	9	5	8	15	18	26
TSS (mg/L)	16	8	13	24	33	41
COD (mg/L)	192	184	189	195	199	199
BOD (mg/L)	158.7	154	154	160	162	159

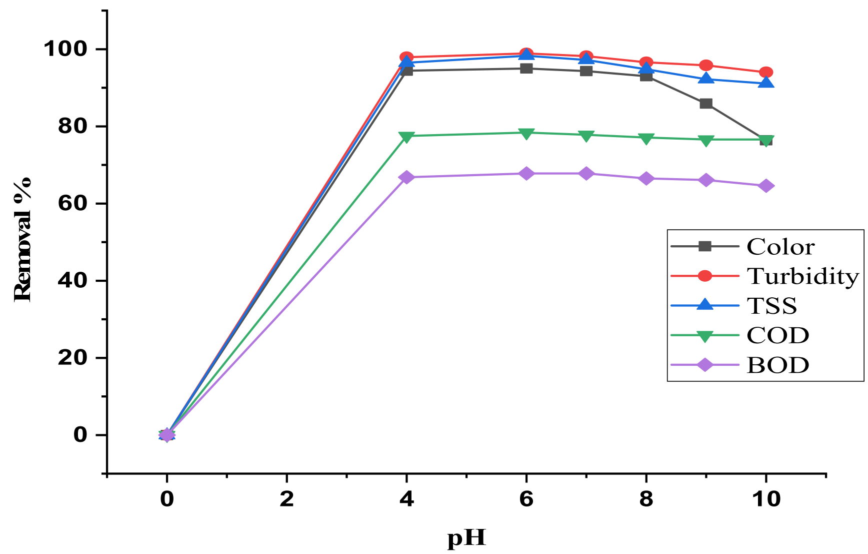

Figure 10. Effect of pH on color, turbidity, and TSS and COD percentage removal

Finally, the result of the experiment demonstrated that at pH 6 there is highest percentage removal of Color, Turbidity, TSS, COD, and BOD. Therefore, blended PAC and Aloe vera is effective for the treatment of textile wastewater in near neutral condition. Similar results were obtained other researchers (Hayelom, 2019) while using a blended coagulant of cactus and alum

4.5.3. Effect of Mixing Time

The effect of mixing time on removal of Color, Turbidity, TSS, COD, and BOD was tested at optimum 300ppm blended coagulant dose and at pH 6, which consists of rapid mixing 150 rpm for 3 minute and slow mixing time from 10 to 60 minutes with 20 minutes of settling time. When the mixing time is long (more than 50 minutes), it leads to an increase in flocs breakage and limits the size of the floc formed. It is a great importance to optimize the mixing time so as to increase removal performance of the coagulation. The minimum percentage removal was observed at mixing time was observed at mixing time 10 minutes (Color (94.6%), TSS (95.8), Turbidity (97.7), COD (76.6) and BOD (79.9)) and maximum percentage removal was observed at 40 minutes (Color (94.9%), TSS (98.5), Turbidity (99.1), COD (77.1) and (80.5)) that is the way the optimum point of mixing time was achieved. At less mixing time minutes the blended coagulant and impurity in wastewater do not efficiently collide, which prevents the precipitation of suspended solids in wastewater. On the other hand, if mixing time was longer than 40 minutes, it would lead to an increase in flocs breakage and limit the size of the floc formed (Asman et al., 2017). Overall, the observed results regard to effect of mixing time was mentioned on Appendix D of IV.

Table 7: Percentage removal of operational parameters and others at various mixing time

Sample/Treatment	1	2	3	4	5	6
Mixing Time	10	20	30	40	50	60
Parameters						
pH	6.78	6.79	6.78	6.78	6.79	6.78
Color (pt-co)	165	164	159	159	161	161
Turbidity (NTU)	10	7	5	4	5	9
TSS (mg/L)	19	12	9	7	8	14
COD (mg/L)	199	197	196	195	199	202
BOD (mg/L)	96	95	93.5	93	96	98

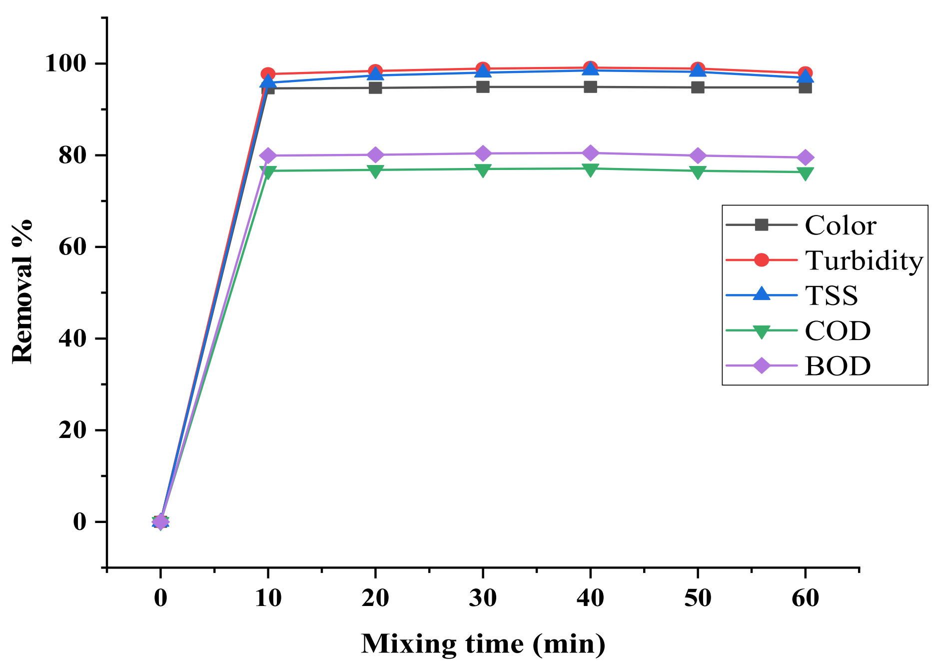

Figure 11. Effect of mixing time on color, turbidity, and TSS and COD percentage removal

4.6. The Optimum Operational Parameters

The optimum condition for removal of Color, Turbidity, TSS, COD, BOD, and pH using blended coagulant in coagulation process were at 6.0, 300ppm blended coagulant dose, and 40 minutes for mixing time. Therefore, these optimum experimental conditions are needed to achieve the best performance of the blended coagulant. This result were maximum removal efficiencies in which these results are above the limit value set by the EEPA. Since there is no clear standard which are set for color, turbidity, and TSS it made difficult to compare the result of the experiment. The results of these are summarized under Table 8. Appendix A also present emission limits set by EEPA for textile industry.

Table 8: Comparisons between treatment result with other scholars finding

Coagulant	Removal efficiency (%)					Reference
	Color	Turbidity	TSS	COD	BOD	
Alum	85.4	89.4	87	62	59	Radin et.al, 2014
Moringa	75	81	83.4	58	57	Karoliny et.al ,2018
Ferric Sulfate	92	96	94	64.4	67.4	Radin et.al, 2014
Blended PAC and Aloe vera	95.2	99.7	99.6	85.2	83.5	This study

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The removal of TSS, Color, Turbidity, COD, and BOD from textile wastewater has been done using blended PAC and Aloe vera as coagulant. This study indicated that it is critical to treat textile wastewater before disposal to protect the safety of our environment. Coagulation, as used in this research, is a strong treatment strategy for contaminants in textile wastewaters. As a result, many sorts of experiments were conducted to address each of the study specific objectives. The initial character of the textile wastewater sample showed TSS-463 mg/L, Color-3091(pt-co), Turbidity-437 NTU, COD-852 mg/L, and BOD-478 mg/L. This shows that the textile wastewater was highly polluted, high suspended solid, highly colored.

The coagulation experiment proved blended coagulant dose, pH, and mixing time to be important operating parameters for the removal of Color, Turbidity, TSS, COD, and BOD from textile wastewater using blended Polyaluminum Chloride and Aloe vera as a coagulant and their optimum conditions were 300 ppm of coagulant dose, pH 6, and 40 minutes of mixing time. At these optimal conditions, the removal efficiency of Color, Turbidity, TSS, COD, and BOD, was 95.2%, 99.7%, 99.6%, 85.2%, and 83.2% respectively. This removal efficiency was almost similar with conventional/ control chemicals as mentioned on Appendix D (I). The FTIR study also confirmed the presence of various functional groups that are responsible for the coagulation process. In general, blended PAC and Aloe Vera is an effective coagulant with the capacity to significantly reduce the level of operating parameters in textile industry effluent. As a result, the encouragement and growth of coagulants provide several benefits for developing nations such as Ethiopia, including being cost effective and friendly to the environment.

Finally, from this study, we can conclude that the removal efficiency of the blended Polyaluminum Chloride and Aloe vera was very good in the treatment of textile waste water for TSS, Color, Turbidity, COD, and BOD.

5.2. Recommendations

Based on findings, the researcher suggests that blended Polyaluminum Chloride and Aloe vera can be used as a coagulant for the treatment of textile industrial wastewater in Ethiopia. Because, for one thing it is possible to produce Aloe vera locally and another thing its application as conjunct to PAC should be encouraged since it is environmentally friendly. To that purpose, the following points must be addressed:

- ✓ It is recommended to use blended Polyaluminum Chloride and Aloe vera as a coagulant since it has a high potential for removing TSS, Color, Turbidity COD and BOD from textile industry effluent.
- ✓ Additional research should be undertaken to determine other operational variables that may impact the efficiency of blended Polyaluminum Chloride and Aloe vera as a coagulant in the treatment of textile wastewater.
- ✓ More study should be done the industrial scale application of blended coagulant for textile wastewater treatment.

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Appendices

Appendix A: Textile Wastewater Disposal Standards (Environmental Protection Authority)

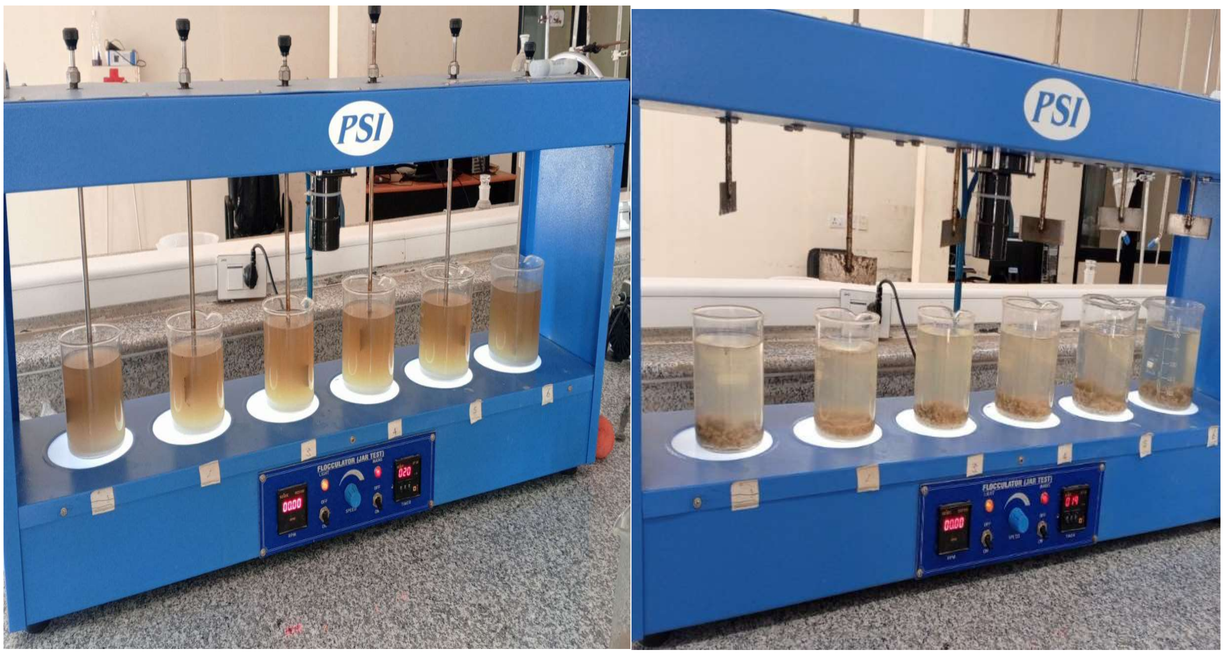
The manufacture and finishing of textiles

Limit Values for Discharges to Water

Parameter	Limit Values
Temperature	40^0C
pH	6–9
BOD_5 at 20^0C	50 mg/L
Total nitrogen (as N)	40 mg/L
COD (mgO_2/l)	150 mg/L
Total phosphorus (as P)	10 mg/L
Suspended solids	30 mg/L
Total ammonia (as N)	20 mg/L
Oils, fats & grease	20 mg/L
Phenols	1 mg/L
Mercury (as Hg)	0.001 mg/L
Nickel (as Ni)	2 mg/L
Cobalt (as Co)	1 mg/L
Lead (as Pb)	0.5 mg/L
Antimony (as Sb)	2 mg/L
Tin (as Sn)	5 mg/L
Chromium (as Cr VI) Chromium (as total Cr)	0.1 mg/L 1 mg/l
Arsenic (as As)	0.25 mg/L
Cadmium (as Cd)	1 mg/L
Zinc (as Zn)	5 mg/L

Copper (as Cu)	2 mg/L
Mineral oils (Interceptors)	20 mg/L

Appendix B: Photographic Representation of laboratory work



A. Photographic representation of before and after treatment of Textile Wastewater

B) Photographic representation of me while doing Jar-test

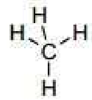
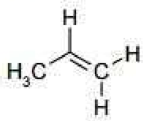
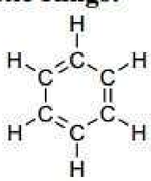
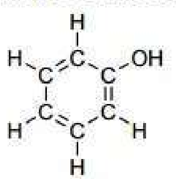
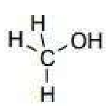
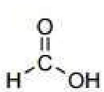
C) HACH spectrophotometer (model DR 3900)

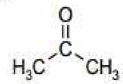
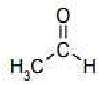
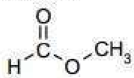
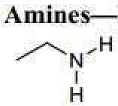
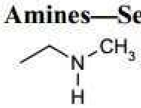
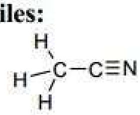
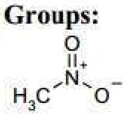
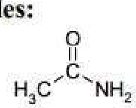
D) HANNA turbidimeter (HI98703)

E) Hot Air Oven

F) pH meter model (HANNA HI5521) Appendix

C: Principal IR Absorptions for Certain Functional Groups

Functional Group Names **&** **Example compounds**	**Absorption Ranges(cm^{-1})** [Look for a single absorption in these regions, unless stated otherwise.]	**Type of Vibration** **causing IR absorption**
Alkanes:  Methane	**3000-2800** (Note: The absorptions can be seen as several distinct peaks in this region.)	H-C-H Asymmetric & Symmetric Stretch
	1500-1440	H-C-H Bend
Alkenes:  1-Propene	**3100-3000**	C=C-H Asymmetric Stretch
	1675-1600	C-C=C Symmetric Stretch
Alkynes: $HC\equiv C-CH_3$ Propyne	**3300-3200**	$\equiv C-H$ Stretch
	2200-2100	$C\equiv C$ Stretch
Aromatic Rings:  Benzene	**3100-3000**	C=C-H Asymmetric Stretch
	1600-1580	C-C=C Symmetric Stretch
	1500-1450	C-C=C Asymmetric Stretch
Phenols & Alcohols:  Phenol  Methanol (Alcohol)	**3600-3100** (Note: Phenols <u>MUST</u> have Aromatic Ring Absorptions too.)	Hydrogen-bonded O-H Stretch (This peak usually appears much broader than the other IR absorptions.
Carboxylic Acids:  Formic Acid	**3400-2400** *(This peak always covers the entire region with a **VERY BROAD** peak.)*	Hydrogen-bonded O-H Stretch *[Note: This peak can obscure other peaks in this region.]*
	1730-1650	C=O Stretch

Ketones:  Acetone	**1750-1625**	C=O Stretch
Aldehydes:  Ethanal	**1750-1625**	C=O Stretch
	2850-2800	C-H Stretch off C=O
	2750-2700	C-H Stretch off C=O
Esters:  Methyl Formate	**1755-1650**	C=O Stretch
	(1300-1000)	(C-O Stretch)
Ethers:  Diethyl Ether (aka-Ethyl Ether)	**(1300-1000)**	(C-O Stretch)
Amines—Primary:  Ethylamine	**3500-3100 (TWO PEAKS!)**	N-H Stretch
	1640-1560	N-H Bend
Amines—Secondary:  N-Methylethylamine	**3500-3100 (ONE PEAK!)**	N-H Stretch
	1550-1450	N-H Bend
Nitriles:  Methanenitrile	**2300-2200**	$C\equiv N$ Stretch
Nitro Groups:  Nitromethane (Note: Both peaks are <200 cm-1 apart.)	**1600-1500**	N=O Stretch
	1400-1300	N=O Bend
Amides:  Methanamide	**3500-3100**	N-H Stretch (similar to amines)
	1670-1600	C=O Stretch
	1640-1550	N-H Bend

(Olivares et.al., 2012)

Appendix D

I) Control

This experiment was conducted by using conventional chemicals used in Adama Industrial Park to treat textile effluent for the entire estimation of color removal, PAC, and polyacrylamide.

Sample/Treatment	1	2	3	4	5	6
PAC (ppm)	100	150	200	250	300	350
Polyacrylamide (ppm)	0.5	1	1.5	2	2.5	3
Parameters						
pH	7.52	7.49	7.46	7.41	7.38	7.29
Color (pt-co)	601	456	423	356	312	227
Color removal (%)	80.5	85.2	86.2	88.5	90	92.7
Turbidity (NTU)	102	49	18	9	4	7
Turbidity removal (%)	76.7	88.8	95.9	98	99	98.3
TSS (mg/L)	156	75	29	17	8	12
TSS removal (%)	66.3	83.8	93.7	96.3	98.3	97.4
COD (mg/L)	324	241	201	167	122	92
COD removal (%)	62	71.7	76.6	80.3	85.7	89.2
BOD (mg/L)	187	136	105	88	71	54
BOD removal (%)	60.8	71.5	78	81.6	85.1	88.7

II) Blended Coagulant dose effect

Varying the blended coagulant while the pH was 7.59, Decolor 250 ppm (5% stock solution) was added to each 1L beaker, and the mixing time of 20 min was maintained constant to determine the optimum dose while varying the dose 100 to 350 ppm (here our stock solution is 10%). For all phases, the optimum value was picked depending on the highest removal efficiency of color (pt-co), turbidity (NTU), TSS (mg/L), COD (mg/L), and BOD (mg/L).

Sample/Treatment	1	2	3	4	5	6
Blended Coagulant (ppm)	100	150	200	250	300	350
Parameters						
pH	7.52	7.49	7.46	7.41	7.38	7.24
Color (pt-co)	725	618	523	439	314	545
Color removal (%)	76.5	80	83	85.8	89.8	82.3
Turbidity (NTU)	103	48	36	25	14	19
Turbidity removal (%)	76.4	89	91.8	94.3	96.8	95.6
TSS (mg/L)	210	96	71	49	23	32
TSS removal (%)	54.6	79.3	84.7	89.4	95	93
COD (mg/L)	407	310	226	184	148	194
COD removal (%)	52.2	63.6	73.5	78.4	82.6	77.2
BOD (mg/L)	198	174	137	84.6	76	92
BOD removal (%)	58.6	63.6	71.3	82.3	84.1	80.7

III) Effect of pH

Varying pH (4 to 10) while blended Coagulant was held constant at 300 ppm (10% stock solution), Decolor 250 ppm (5% stock solution) was added to each 1L beaker, and mixing time = 20 min was maintained constant to determine the optimum pH value. For all phases, the optimum value was picked depending on the highest removal efficiency of color (pt-co), turbidity (NTU), TSS (mg/L), COD (mg/L), and BOD (mg/L).

Sample/Treatment	1	2	3	4	5	6
pH	4	6	7	8	9	10
Parameters						
pH	4.51	6.16	7.39	7.59	8.71	9.85
Color (pt-co)	171	159	174	215	436	731
Color removal (%)	94.4	95	94.3	93	85.9	76.4
Turbidity (NTU)	9	5	8	15	18	26
Turbidity removal (%)	97.9	98.9	98.2	96.6	95.8	94
TSS (mg/L)	16	8	13	24	33	41
TSS removal (%)	96.5	98.3	97.2	94.8	92.2	91.1
COD (mg/L)	192	184	189	195	199	199
COD removal (%)	77.5	78.4	77.8	77.1	76.6	76.6
BOD (mg/L)	158.7	154	154	160	162	169
BOD removal (%)	66.8	67.8	67.8	66.5	66.1	64.6

IV) Mixing time effect

Varying the mixing time from 10 min to 60 min while the pH = 6, Decolor 250 ppm (5% stock solution), blended Coagulant dose 300 ppm (Here our stock solution is 10%) was added to each 1L beaker to determine the optimum mixing time. For all phases, the optimum value was picked depending on the highest removal efficiency of color (pt-co), turbidity (NTU), TSS (mg/L), COD (mg/L), and BOD (mg/L).

Sample/Treatment	1	2	3	4	5	6
Mixing Time	10	20	30	40	50	60
Parameters						
pH	6.78	6.79	6.78	6.78	6.79	6.78

Color (pt-co)	165	164	159	159	161	161
Color removal (%)	94.6	94.7	94.9	94.9	94.8	94.8
Turbidity (NTU)	10	7	5	4	5	9
Turbidity removal (%)	97.7	98.4	98.9	99.1	98.9	97.9
TSS (mg/L)	19	12	9	7	8	14
TSS removal (%)	95.8	97.4	98	98.5	98.2	96.9
COD (mg/L)	199	197	196	195	199	202
COD removal (%)	76.6	76.8	77	77.1	76.6	76.3
BOD (mg/L)	96	95	93.5	93	96	98
BOD removal (%)	79.9	80.1	80.4	80.5	79.9	79.5

Appendix E

Poly Aluminum Chloride Structure

The structure of Poly Aluminum Chloride is composed of aluminum cations (Al^{3+}) surrounded by hydroxyl ions (OH^-) and chloride ions (Cl^-). The combination of these ions results in a highly charged polymer with a net positive charge.