SUSTAINABLE TREATMENT OF PAINT INDUSTRY WASTEWATER AND RESOURCE RECOVERY

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In The Name of ALLAH Who Is Most Beneficent and Merciful

Table of Contents

Table of Contents II

List of Figures VI

List of Tables VIII

List of Acronyms IX

DEDICATION X

ACKNOWLEDGEMENTS XI

ABSTRACT 1

CHAPTER 1 2

INTRODUCTION 2

1.1 Scope 2

1.2 Background 2

1.3 Research Gap 3

1.4 Problem Statement 4

1.5 Objectives 4

1.6 Significance 4

CHAPTER 2 6

LITERATURE REVIEW 6

2.1 Introduction 6

2.2 Background 6

2.2.1 Paint Industry Wastewater 6

2.2.2 Pollutants in Paint Industry Wastewater 7

2.2.3 Environmental Impacts of Untreated Wastewater 7

2.3 Conventional Wastewater Treatment Methods for Paint Industry 7

2.3.1 Limitations of Conventional Methods 8
2.3.2 Cost Effectiveness of Conventional Methods 9
2.3.3 Chemical Dependency 9
2.4 Classification of Coagulants 9
2.4.1 Synthetic Coagulants 9
2.4.2 Green Coagulants 10
2.5 Green Coagulants as a Sustainable Alternative 10
2.5.1 Calotropis Procera for Wastewater Treatment 11
2.5.2 Azaadirachta Indica for Wastewater Treatment 11
2.6 Wastewater Sludge and Applications 12
2.7 Apparatus and Instruments 12
2.7.1 Jar Test Apparatus 12
2.7.2 Hardness Test Apparatus 13
2.7.3 TSS Apparatus 13
2.7.4 Spectrophotometer 14
2.7.5 EC Meter 14
2.7.6 TDS Meter 15
2.7.7 Turbidity Meter 15
2.7.8 pH and Temperature Meter 16
CHAPTER 3 17
METHODOLOGY 17
3.1 Introduction 17
3.2 Methodology Diagram 17
3.3 Effluent Collection 17
3.4 Preparation of Coagulants 18

3.4.1 Preparation of Sodom Apple (Sodom Apple) coagulant 18

3.4.2 Preparation of the Neem Leaf powder (NLP) 19

3.4.3 Preparation of Neem Leaf solution (NLS) 20

3.4.4 Wastewater Characterization before Treatment 20

3.5 Coagulation and Flocculation 21

3.6 Sludge characterization 21

3.7 Biochar production 22

3.8 Evaluation of the biochar for agricultural use 22

CHAPTER 4 23

RESULTS AND DISCUSSION 23

4.1 Effect of Coagulant Dosage on Treatment of wastewater 23

4.1.1 Treatment of PIW with AAK coagulant 23

4.1.2 Effect of Unfiltered Coagulant on Turbidity of PIW 24

4.1.3 Effect of Filtered coagulant on the turbidity of PIW 26

4.1.4 Treatment of PIW using Alum 28

4.2 Effect of pH on Treatment of wastewater 30

4.2.1 Treatment of PIW at varying pH using Alum 30

4.2.2 Treatment of PIW at pH 5 using NLS 33

4.2.3 Treatment of PIW at pH 6.5 using NLS 35

4.2.4 Treatment of PIW at pH 7 using NLS 37

4.2.5 Treatment of PIW at pH 8 using NLS 39

4.2.6 Treatment of PIW at pH 9 using NLS 41

4.3 Resource recovery 42

4.3 Wastewater characterization after treatment 43

CHAPTER 5 45

CONCLUSIONS AND RECOMMENDATIONS 45
5.1 Introduction 45
5.2 Conclusions 45
5.3 Recommendations 46
A.1 SDG's Achievements 47
REFERENCES 49

List of Figures

Figure 1. The process chain of Industrial Wastewater Treatment 8
Figure 2. AAK plant 11
Figure 3. Jar test apparatus 12
Figure 4. Hardness test apparatus 13
Figure 5. Lab apparatus for measuring TSS 13
Figure 6. Spectrophotometer 14
Figure 7. EC meter 14
Figure 8. TDS meter 15
Figure 9. Turbidity Meter 15
Figure 10. pH and temperature meter 16
Figure 11. Stages of wastewater treatment process 17
Figure 12. PIW sample 18
Figure 13. Latex of *Calotropis Procera* (Sodom apple) 19
Figure 14. Neem leaves powder 19
Figure 15. NLS 20
Figure 16. Sludge obtained from PIW 22
Figure 17. Coagulant dosage effect on turbidity 24
Figure 18. Coagulant dosage effect on turbidity 25
Figure 19. Coagulant Filtration Process 27
Figure 20. Coagulant dosage effect on turbidity 27
Figure 21. Settling of TSS in PIW after coagulation 28
Figure 22. Effect of Alum dosage on turbidity 29
Figure 23. Settlement of samples with different pH 31
Figure 24. Alum dose effect on turbidity at different pH levels 32
Figure 25. Settlement of samples treated with NLS 33
Figure 26. Effect of NLS dose on turbidity at pH 5 34
Figure 27. Effect of NLS dose on turbidity at pH 6.5 36
Figure 28. Settlement of samples treated with NLS at pH 7 37
Figure 29. Effect of NLS dose on turbidity at pH 7 38

Figure 30. Effect of NLS dose on turbidity at pH 8 40
Figure 31. Effect of NLS dose on turbidity at pH 9 42
Figure 32. Before addition of Bio-Sludge 43
Figure 33. After two weeks growth of Moringa 43
Figure 34: Treated PIW 44

List of Tables

Table 1. Natural coagulants from different sources 10
Table 2. Initial characterization of paint industry wastewater 21
Table 3. Coagulant dosage effect on turbidity 23
Table 4. Coagulant dosage effect on turbidity 25
Table 5. Coagulant dosage effect on turbidity 26
Table 6. Alum dose effect on removal efficiency at Natural pH 29
Table 7. Effect of Alum dose on turbidity at varying pH levels 31
Table 8. Effect of NLS dose on turbidity at pH 5 34
Table 9. Effect of NLS dose on turbidity at pH 6.5 35
Table 10. Effect of NLS dose on turbidity at pH 7 38
Table 11. Effect of NLS dose on turbidity at pH 8 39
Table 12. Effect of NLS dose on turbidity at pH 9 41
Table 13. Final characterization of paint industry wastewater 44

List of Acronyms

PIW	Paint Industry wastewater
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
EC	Electrical Conductivity
NLS	Neem Leaves Solution
NLP	Neem Leaves Powder
UN	United Nations
SDGs	Sustainable Development Goals

DEDICATION

We are honored to dedicate our work to our parents, who have been our unwavering source of love, support, and inspiration. We express our heartfelt appreciation. Their sacrifices, guidance, and belief in our abilities have been instrumental in shaping our lives and empowering us to pursue our dreams.

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ABSTRACT

This study presents a comprehensive investigation into the development of a sustainable wastewater treatment solution for the paint industry, focusing on the utilization of natural coagulants *Azadirachta Indica* and *Calotropis Procera* locally known as Neem and Sodom Apple/AAK respectively. The research addresses the limitations of conventional chemical treatments by demonstrating the efficacy of natural coagulants in treating paint industry wastewater, considering both economic feasibility and environmental safety. The study evaluates the effectiveness of Neem and AAK in reducing turbidity of paint industry wastewater and compares their performance with traditional chemical coagulants such as Alum. Furthermore, the research explores the environmental implications of chemical sludge produced in conventional treatment methods and proposes an innovative approach for sludge recovery by utilizing it as a fertilizer for plants. The coagulation-flocculation process is conducted using a Jar test apparatus, facilitating controlled experimentation and optimization of treatment parameters. Through experimental analysis and quality assessment, this research demonstrates the potential of natural coagulants in providing a sustainable and environmentally friendly solution for paint industry wastewater treatment, contributing to the reduction of environmental impact and promoting circular economy principles in industrial wastewater management.

CHAPTER 1

INTRODUCTION

1.1 Scope

This study aims to evaluate the feasibility of utilizing natural coagulants as a sustainable alternative to synthetic coagulants in the coagulation-flocculation process. The investigation focuses on *Calotropis procera* (Sodom apple) and *Azadirachta indica* (Neem), readily available and low-cost plant materials prevalent in Pakistan. The research expects the use of natural coagulants to not only reduce treatment system costs but also mitigate the potential harmful effects associated with synthetic coagulants, contributing to a safer and more sustainable water treatment approach. Furthermore, the potential for converting the generated sludge into bio char will be explored, promoting a closed-loop system and maximizing resource utilization.

1.2 Background

The paint manufacturing industry plays a vital role in enhancing our visual world, providing color and vibrancy to buildings, vehicles, furniture, and clothing. However, these production processes generate significant volumes of wastewater laden with pollutants such as chemicals, suspended solids, heavy metals, and organic matter. This wastewater poses a severe threat to the environment, particularly to aquatic ecosystems. Effective treatment measures are crucial to meet the United Nations Sustainable Development Goals (SDGs).

Nicholas (2018) estimated that paint-manufacturing industries globally utilize a staggering 75-85 million gallons of water daily, with only a meager 4% being recycled. A concerning 70% of this wastewater is discharged untreated into natural water bodies, while another 25% evaporates, potentially concentrating pollutants in the environment. This untreated wastewater exacerbates water pollution, leading to eutrophication, fish kills, and potential risks to human health.

Coagulation-flocculation is a critical technique for treating industrial wastewater, including that generated by the paint industry. This process utilizes coagulants to destabilize colloidal particles and flocculants to promote the formation of larger flocs, facilitating the removal of pollutants. While synthetic coagulants have been traditionally employed, the drive for sustainable solutions has shifted focus towards natural alternatives derived from plant or animal sources. These natural coagulants offer not only comparable efficacy in pollutant removal but also possess advantages in terms of cost-effectiveness and environmental friendliness compared to their synthetic counterparts.

Furthermore, biochar, a charcoal-like material obtained from the pyrolysis of organic matter, presents a promising avenue for addressing environmental concerns. Biochar possesses excellent adsorption properties, making it a valuable tool for pollutant removal from wastewater. Its applications extend beyond wastewater treatment, as it can also enhance soil fertility and mitigate greenhouse gas emissions.

Motivated by these considerations, this research investigates the utilization of two natural coagulants, Calotropis procera (Sodom apple) and Azadirachta indica (neem), for the treatment of wastewater generated by the paint industry. The overarching goal is to develop a sustainable and economically viable wastewater treatment process that not only mitigates environmental impacts but also contributes to the broader objective of achieving sustainability in industrial practices.

1.3 Research Gap

There exists a notable research gap in the application of *Calotropis Procera* (Sodom Apple) and *Azadirachta Indica* (Neem) as coagulants in the context of paint industry wastewater treatment. Despite their inherent advantages, including sustainability, cost-effectiveness, and non-toxicity, these natural coagulants have not received widespread utilization. Furthermore, an additional research gap pertains to the inefficient management of sludge generated from wastewater treatment, resulting in its wastage. These gaps signify opportunities for further investigation and innovation in the field of paint industry wastewater treatment and sludge utilization.

1.4 Problem Statement

The treatment of wastewater generated by the paint industry poses several challenges, including high costs, energy intensity, and reliance on synthetic coagulants with significant environmental and health impacts. Disposing of the sludge produced during these operations can also be costly and challenging. To address these issues, this study aims to develop a wastewater treatment system for the paint industry that is affordable, sustainable, and environmentally friendly. This will be achieved through the utilization of locally available natural coagulants such *Calotropis procera* (Sodom apple) and *Azadirachta indica* (Neem) and using the sludge produced as fertilizer for plants.

1.5 Objectives

The objectives of this research are to determine the low cost and sustainable coagulants for the treatment of paint industry wastewater in Pakistan with the following specific goals:

- To evaluate *Calotropis Procera* (Sodom Apple) and *Azadirachta Indica* (Neem) as natural coagulants for paint industry wastewater.
- To utilize sludge for biochar production that may serve as a fertilizer.
- To develop a sustainable and cost-effective wastewater treatment approach for the paint industry using natural coagulants.

1.6 Significance

The significance of the proposed project lies in the following:

- **Sustainability**. The suggested wastewater treatment process uses natural coagulants and produces biochar, making it more sustainable than traditional approaches. Natural coagulants come from plant or animal sources and are frequently eco-friendlier than synthetic coagulants. Biochar is a substance that resembles charcoal that may be created from sludge and is useful for several things, including amending soil.

- **Cost-effectiveness**. Because natural coagulants are frequently less expensive than synthetic coagulants, the suggested wastewater treatment technique is likewise more affordable than traditional methods. Additionally, biochar can be made into a profitable byproduct that can be sold to contribute to the expense of treating wastewater.
- **Reusability**. Sludge waste generated during the proposed wastewater treatment procedure may be converted into useful products like biochar. It is possible to use biochar as a biofuel, fertilizer, and soil improvement. This lessens the demand for landfills and promotes resource conservation. Additionally, the treated water can be reused for many purposes like irrigation, industry etc., which will reduce the need for water.
- **Reduced environmental impact**. By eliminating contaminants from wastewater and creating a useful byproduct that can be utilized for agriculture, the proposed wastewater treatment process can assist in lessening the environmental impact of the paint industry.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review serves diverse purposes including description, understanding, explanation, existing testing and method, tools and techniques used (Rivard, 2024). The purpose of this literature review is to give a comprehensive study of present research and development in Chemical Treatment of Industrial wastewater especially paint industry wastewater. The effectiveness and usage of green coagulants including Calotropis Procera and Azadirachta Indica in the treatment of wastewater is reviewed here. The apparatus and tools which are used for different testing purposes are also reviewed in literature.

2.2 Background

Water contamination is one of the world's most serious problem. Water pollution not only harms the environment but also health, economic and social problems in any society. Any industrial wastewater containing dangerous and corrosive chemicals may have a negative impact on wastewater management systems(Irshad et al., 2023).

2.2.1 Paint Industry Wastewater

In chemical industries paint manufacturing industry is among the industries that generates large volumes of wastewater. The mostly wastewater produced during batch wash-off (Ejimofor et al., 2022). Wastewater generally produced due to varying degree of chemicals used, the wastewater contains appreciable amounts of chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS) and total dissolved solids (TDS) are also found the paint industry effluents. Wastewater also affects the health of residents. Due to legal restrictions and environmental protection in industrial areas, wastewater must be treated before being discharged (Aboulhassan et al., 2014).

2.2.2 Pollutants in Paint Industry Wastewater

Latex paints generally contain organic and inorganic pigments and dyes, extenders, cellulosic and non-cellulosic thickeners, latex, emulsifiers, defoaming agents, preservatives, solvents and coupling agents (Aboulhassan et al., 2014). It contains microbial organisms, inorganic and organic matter. Microbial contamination occurs during the production and storage of the coating. Changes in various physical and chemical conditions, such as temperature and high humidity, increase the potential for microbial organisms in the coating. For this reason, wastewater generated during production can cause serious diseases. The wastewater generated during cleaning of the coating material may be contaminated with bacteria as well as organic compounds and pigments (Dursun & Sengul, 2006).

2.2.3 Environmental Impacts of Untreated Wastewater

Untreated wastewater containing many dyes is thought to be harmful to organisms living in freshwater ecosystems. Direct discharge of wastewater into water can cause ecological and environmental problems. Pollutants in wastewater can limit the photosynthetic process of aquatic plants by preventing sunlight from entering or poisoning the fauna (Hrouzková & Szarka, 2021). The paint has a beautiful appearance and anti-corrosion properties. For this reason, the paint industry is one of the sectors with rapid international demand (Iloamaeke et al., 2023).

Therefore, the treatment of industrial wastewater is very important and new technologies are needed to remove existing colors and pollutants and reduce COD and BOD, so that this will not be discharged untreated into the environment (El-Sawy et al., 2013).

2.3 Conventional Wastewater Treatment Methods for Paint Industry

Common applications include coagulation, adsorption (El-Sawy et al., 2013), flocculation, filtration, electrochemical processes (Nair K et al., 2021), advanced oxidation processes, and biological processes such as composting (Balik & Aydin, 2016). Currently, a combination of different treatments is also used for the safe disposal or recycling of treated wastewater (Barbosa et al., 2018).

The treatment of industrial wastewater can be divided into four stages: preliminary treatment, primary treatment, secondary treatment and tertiary treatment as shown in figure 1. In the first stage, neutralization and equilibrium occur. Primary treatment includes simple techniques such as sedimentation, chemical coagulation, flocculation, magnetic separation and flotation. In the second stage, physicochemical isolation or biological oxidation is used to reduce organic compounds. Tertiary treatment is used to improve wastewater treatment. A review of some treatment methods also revealed the use of different molecularly imprinted polymers in removing heavy metal ions in daily cosmetics (Sharma & Kandasubramanian, 2020).

Figure 1. The process chain of Industrial Wastewater Treatment

2.3.1 Limitations of Conventional Methods

The main aspects of any method are cost, requirement of user and efficiency of system. In the current situation, advanced water purification technologies are urgently needed to ensure water quality, reduce toxic chemicals and pollutants, and improve production processes. Today's wastewater treatment is done by combining simple physicochemical processes with electrochemical oxidation, or advanced technologies. However, future research should focus on improving the process and reducing costs. At the same time, the main concern of the end user is the disposal of the generated sludge, especially considering the circular economy and the reduction of all costs. However, in processes such as electrochemical oxidation, there is much work to be done in the future, such as the creation of new materials with higher performance or their combination with other processes, where having a connection can increase the efficiency and therefore the applicability of the process combinations (Hrouzková & Szarka, 2021).

2.3.2 Cost Effectiveness of Conventional Methods

Traditional methods such as coagulation and flocculation are reliable in industrial wastewater treatment, but cost effectiveness depends on factors such as coating, regulations and sludge disposal options. Although physicochemical methods can effectively remove solids and organic matter, the cost of chemicals and sludge disposal can be high (Viktoryová et al., 2022). Biological treatment, although effective in some diseases, can combat different products of colored wastewater, needs to be replaced and can reduce its effectiveness. In general, conventional methods are sufficient, but a cost-effective analysis that takes all these factors into account is essential in wastewater treatment in the coating industry.

2.3.3 Chemical Dependency

The conventional processes and methods rely on chemicals, and produces toxic sludge that requires further treatment. Color combination is also difficult from a biological process perspective. While effective, consider factors such as initial investment and ongoing maintenance when evaluating traditional methods (Nair K et al., 2021). Explore other methods such as AOP or membrane technology, which may provide good results in reducing sludge or improving purification, but will have higher costs.

2.4 Classification of Coagulants

Coagulants used in wastewater treatment are generally divided into two groups: synthetic coagulants and natural coagulants (Ugwu et al., 2017). They entered the coagulation system to destabilize colloidal particles, increasing their aggregation and forming large flocs. Other types of coagulants include coagulants and coagulants, which improve floc formation by increasing their density (Choy et al., 2016).

2.4.1 Synthetic Coagulants

The most commonly used synthetic coagulants are Iron and aluminum salts and organic polymers in water purification. They are chosen for their cost-effectiveness and versatility in removing particles from water (Teh et al., 2016). These chemicals neutralize particles in the water, causing them to clump together and precipitate. This process helps purify the water. However, it also has some disadvantages, such as changing the pH of the water and creating a lot of sludge containing iron residues (Iwuozor, 2019). Medicine consumption must be carefully controlled to avoid harming the environment and human health. Additionally, due to its corrosive nature, special equipment is needed. Some aluminum-based coagulants may leave toxic residues, raising concerns about long-term risks such as Alzheimer's disease (Dotto et al., 2019). Proper disposal procedures and sanitation are important when these chemicals are used in water treatment.

2.4.2 Green Coagulants

Natural (green) coagulants are frequently used in wastewater treatment to create and remove sludge. Their advantage is that they control pH very well because they do not consume alkalinity. Unlike iron-based coagulants, they do not add iron to the wastewater produced and produce less sludge, thus reducing the cost of sludge treatment. Organic coagulants come from many sources, including plants, animals, and bacteria, as shown in table 1 (Ugwu et al., 2017).

Table 1. Natural coagulants from different sources

Natural Coagulant	
Plant-based	**Non-plant based**
• **Seeds**: watermelon, tamarind, bean, moringa oleifera, pawpaw, mustard	• **Shell:** chitosan, chitin, insects
• **Leaves**: acorn, hibiscus, oak	• **Gelatin:** animal proteins
• **Bark (tannins)**: acacia, schinopsis, castanea	• **Alginate:** brown seaweed
• **Peels:** cassava, orange, banana	
• **Pads (mucilage):** Cactus, aloe vera, okra	
• **Starch:** tuber (potato, cassava), grain (wheat, corn, rice)	

2.5 Green Coagulants as a Sustainable Alternative

The application of green coagulant means sustainable development of the industry without harming the quality of water, human health and the environment. Green coagulants work better than inorganic coagulants (alum) under certain pH conditions. The advantages of using green coagulants are many, not limited to their positive effects on the environment and ecosystem, because they have low toxicity and high biodegradability, ensuring the safety of human consumption, health and water in water; They do not produce second-hand pollution and are environmentally friendly (Choy et al., 2016).

2.5.1 Calotropis Procera for Wastewater Treatment

Calotropis Procera, a plant known as the "apple of Sodom" as shown in figure 2, has become a promising green coagulant in wastewater treatment due to its bioactive compounds that can flocculate suspended particles. This environmentally friendly feature has the potential to reduce medical costs compared to conventional medicine. Studies have shown that it can purify many types of wastewater resources, including river and textile wastewater, by reducing turbidity and pollutants (Giwa et al., 2017). However, optimization of Calotropis Procera application in the paint industry wastewater treatment is still pending.

Figure 2. AAK plant

2.5.2 Azaadirachta Indica for Wastewater Treatment

Azadirachta indica commonly known as “Neem” is an environmentally friendly coagulant for wastewater treatment. Its leaves contain antibiotics such as Neem and azadirachtin that fight against harmful bacteria, while studies have shown that the leaves or bark can act as adsorbents for some pollutants such as dyes and heavy metals (Anandh et al., 2023). However, for widespread use, research is needed to determine dosage and process design to increase the effectiveness of Neem in different wastewater types.

2.6 Wastewater Sludge and Applications

Paint wastewater is hazardous to ecological and human health but after treatment of wastewater the produced sludge also pose threats if disposed without further care and treatment. Although the sludge is a waste but recent studies have shown that the sludge produced from wastewater like paint industry wastewater can be reutilized for many purposes like biochar production (Gabhane et al., 2020), for use in agriculture and fertilizer companies, for biogas production having enough methane (Ejimofor et al., 2020), further processing with the construction materials for light weight concrete production (Avci et al., 2017), remediation of soils and again for the treatment of wastewater (Agegnehu et al., 2017). There are further studies in pipeline for many other useful conversions of wastewater sludge and making the waste into wealth (Ejimofor et al., 2020).

2.7 Apparatus and Instruments

2.7.1 Jar Test Apparatus

This is a device used to simulate the flocculation process in water treatment. It consists of multiple beakers with paddles that stir the water at controlled speeds as shown in figure 3. By adding different flocculants (chemicals that help particles clump together) and observing the settling behavior, operators can determine the most effective treatment method for a specific water sample.

Figure 3. Jar test apparatus

2.7.2 Hardness Test Apparatus

This instrument measures the concentration of dissolved calcium and magnesium ions in water, which contribute to water hardness as shown in figure 4.

Figure 4. Hardness test apparatus

2.7.3 TSS Apparatus

TSS stands for Total Suspended Solids. This apparatus measures the number of solid particles suspended in a liquid as shown in figure 5. There are two main methods: the gravimetric method where the liquid is filtered, the solids dried and weighed, and the volumetric method where the volume of settled solids is measured.

Figure 5. Lab apparatus for measuring TSS

2.7.4 Spectrophotometer

This is a versatile instrument that measures the interaction of light with a sample. It shines light through the sample and detects how much light is absorbed or transmitted at different wavelengths. In water analysis, spectrophotometers can be used to measure various parameters like chlorine residual, specific organic compounds, or nutrient levels as shown in figure 6.

Figure 6. Spectrophotometer

2.7.5 EC Meter

EC stands for Electrical Conductivity. This meter measures the ability of water to conduct electricity, which is indirectly proportional to the total dissolved ions present. Higher EC indicates higher salinity or mineral content as shown in figure 7.

Figure 7. EC meter

2.7.6 TDS Meter

TDS stands for Total Dissolved Solids. This meter measures the total amount of dissolved solids in water, including both organic and inorganic matter as shown in figure 8.

Figure 8. TDS meter

2.7.7 Turbidity Meter

This meter measures the clarity of water by quantifying the amount of light scattered by suspended particles. Higher turbidity indicates more particles in the water, which can impact its aesthetic quality, hinder disinfection processes, and provide a habitat for microorganisms as shown in figure 9.

Figure 9. Turbidity Meter

2.7.8 pH and Temperature Meter

pH and Temperature Meter: This instrument measures two important water quality parameters: pH (acidity or alkalinity) and temperature as shown in figure 10. Both factors can influence the chemical and biological properties of water.

Figure 10. pH and temperature meter

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology portion of this research project is focused on the coagulation and flocculation process for the treatment of paint industry wastewater using natural coagulants as shown in figure 11. Afterwards the produced sludge will be used for bio-char production.

3.2 Methodology Diagram

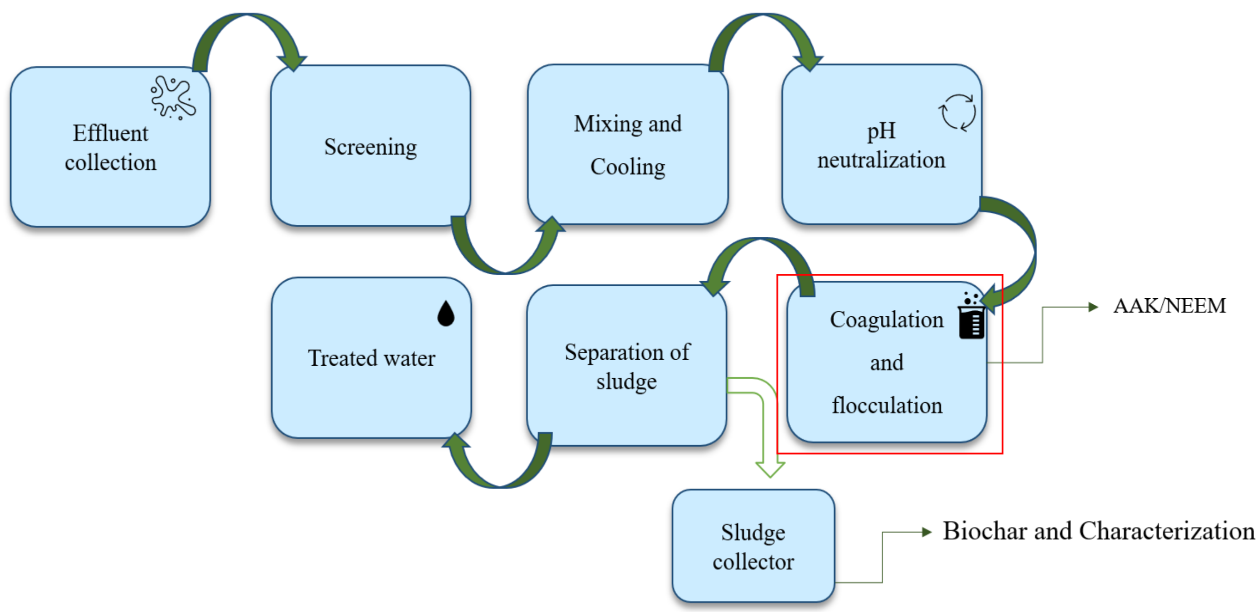

Figure 11. Stages of wastewater treatment process

3.3 Effluent Collection

A 20-liter sample was obtained from 3MS Paints Industry Rawalpindi, serving as a comprehensive representation of the characteristics of wastewater from the paint industry. Particular attention was given to ensuring the absence of any gas above the sample, and thorough checks were conducted to confirm the retention of physical, chemical, and biological parameters without any alteration as shown in figure 12.

Figure 12. PIW sample

3.4 Preparation of Coagulants

Before start of experimentation, the coagulants should be prepared to improve the effectiveness and efficiency of working for treatment of industrial wastewater.

3.4.1 Preparation of Sodom Apple (Sodom Apple) coagulant

The project commenced with an extensive literature review to establish the theoretical framework. Subsequently, the *Calotropis Procera* coagulant was sourced Sodom apple weed plant located in Rahim Yar Khan. A quantity of 500 ml of Sodom apple latex was collected from the leaves of the Sodom apple tree as shown in figure 13. Afterwards in laboratory the coagulant is passed from fine cloth and screens to remove any visual particles and make the coagulant evenly fine. This was stored at 4 °C temperature.

Figure 13. Latex of *Calotropis Procera* (Sodom apple)

3.4.2 Preparation of the Neem Leaf powder (NLP)

After exploring the efficacy of Sodom Apple as a natural coagulant, the study investigated Azadirachta Indica, commonly known as Neem, as an alternative option. Neem leaves were collected and thoroughly washed with clean water to remove any impurities. Subsequently, the leaves were dried in sunlight for seven days. Following the drying process, a blender was utilized to grind the leaves into a fine powder form suitable for use as a coagulant, as depicted in Figure 14.

Figure 14. Neem leaves powder

3.4.3 Preparation of Neem Leaf solution (NLS)

Neem leaves sourced from Risalpur Cantonment were acquired and subjected to a cleansing process to eliminate any impurities. Subsequently, 30 grams of Neem leaves were introduced into 600 ml of distilled water and subjected to a 24-hour heating process at 60 degrees Celsius in the oven. Following this, the solution was carefully filtered to obtain the Neem leaf extract, depicted in Figure 15.

Figure 15. NLS

3.4.4 Wastewater Characterization before Treatment

After acquiring the wastewater from paint industry, experiments were conducted including Turbidity, TSS, TDS, COD, Hardness, EC, and pH to analyze the characterization of wastewater. The characterization of PIW before the treatment process is shown in table 2.

Table 2. Initial characterization of paint industry wastewater

Parameter	Unit	Values
Turbidity	FAU	16890
TSS	mg/L	2100
COD	mg/L	694
Hardness	mg/L	433
TDS	mg/L	838
EC	S/m	3.8
pH	-	6.5

3.5 Coagulation and Flocculation

Paint industry wastewater sample will be prepared by adjusting the pH to the desired value. Natural coagulant will be added to the wastewater sample and mixed rapidly for a brief period (e.g., 2 minutes). The mixing speed reduced, and the process continued to mix for a longer period (e.g., 20 minutes) to allow the flocs to form, allow the flocs to settle for a period (e.g., 30 minutes).

3.6 Sludge characterization

Coagulation and flocculation process produces sludge, which will be collected then determine the physical and chemical properties of the sludge as shown in figure 16, such as moisture content, ash content, pH, electrical conductivity, and nutrient content.

Following the coagulation-flocculation process, the generated sludge will be collected and undergo a comprehensive characterization to determine its physical and chemical properties. These include moisture content, ash content, pH, electrical conductivity, and nutrient content. The sludge produced after treatment of PIW is shown in figure-16.

Figure 16. Sludge obtained from PIW

3.7 Biochar production

Sludge will be dried in an oven at a temperature of 105°C for 24 hours the dried sludge will be pyrolyzed in a pyrolysis reactor at a temperature of 500-700°C for 2-3 hours then collected biochar will be allowed to cool.

3.8 Evaluation of the biochar for agricultural use

Pot experiments will be conducted to evaluate the impact of the biochar on plant growth and yield.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Effect of Coagulant Dosage on Treatment of wastewater

In this series of experiments, the PIW is treated with the varying dosages to evaluate the efficiency of coagulant in the treatment of PIW.

4.1.1 Treatment of PIW with AAK coagulant

Lab experiments were conducted on PIW to determine the efficiency of coagulant. Three samples, each containing 250 ml of wastewater, were prepared. Varying concentrations of Sodom apple coagulant (5 ml, 10 ml, and 15 ml) were added to each sample Coagulation was conducted at 200 rpm for 20 minutes, followed by flocculation at 30 rpm for 7 minutes on Jar test apparatus. Settlement was allowed for 30 minutes at room.

Experiment objectives

The experiment was conducted with the primary aim of evaluating the efficacy of coagulant (**AAK**) in treating PIW as shown in table 3.

Outcomes

Turbidity of wastewater increased due to high concentration of coagulant as shown in figure 17.

Table 3. Coagulant dosage effect on turbidity

AAK dosage (ml)	Ini. pH	Final pH	Ini. turbidity (FAU)	Final turbidity (FAU)
0	6.5	6.5	16890	14345
5	6.5	7.3	16890	19684
10	6.5	7.1	16890	23655
15	6.5	6.9	16890	26936

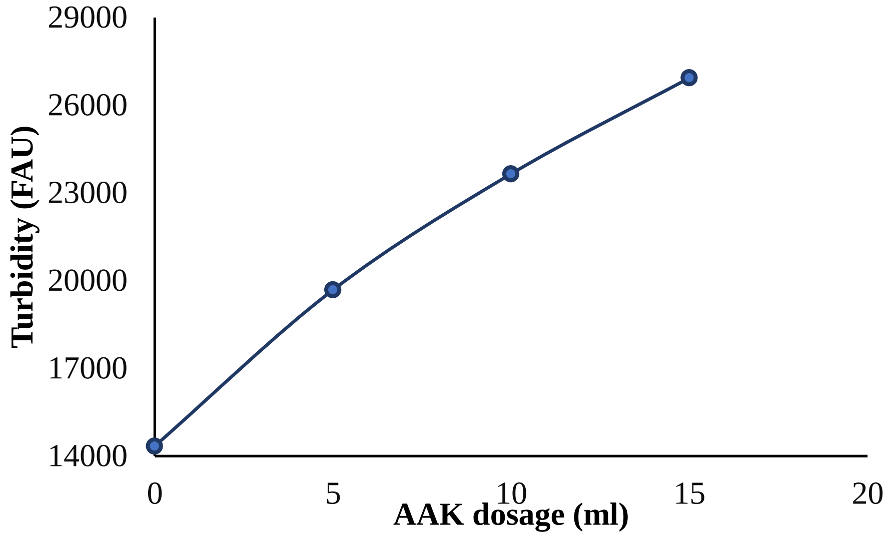

Figure 17. Coagulant dosage effect on turbidity

Conclusions

In this initial experiment, the AAK coagulant was tested on PIW. The coagulant displayed higher turbidity, bearing a resemblance to the color of milkish. Interestingly, an increase in the concentration of the AAK coagulant corresponded with a rise in wastewater turbidity. This suggests that excessive coagulant concentration may exacerbate water cloudiness.

4.1.2 Effect of Unfiltered Coagulant on Turbidity of PIW

The focus shifted to more suitable coagulant concentration. Four samples of 250 ml of PIW were prepared, with Sodom apple coagulant doses ranging from 1 ml to 2.5 ml, alongside a controlled sample. Coagulation was conducted for 15 minutes, followed by flocculation for 4 minutes. Settlement was allowed for 30 minutes at room temperature.

Experiment Objectives

The primary objective of this experiment was to evaluate the effectiveness of the AAK coagulant in treating PIW by optimizing its concentration. Subsequently, the research direction shifted towards identifying an optimal coagulant concentration for enhanced efficiency**.** The results of this experiment are shown in Table 4.

Table 4. Coagulant dosage effect on turbidity

AAK dosage (ml)	Ini. pH	Final pH	Ini. turbidity (FAU)	Final turbidity (FAU)
0	6.5	6.5	16890	14350
1	6.5	7.56	16890	17635
2	6.5	7.48	16890	18994
2.5	6.5	7.57	16890	19200

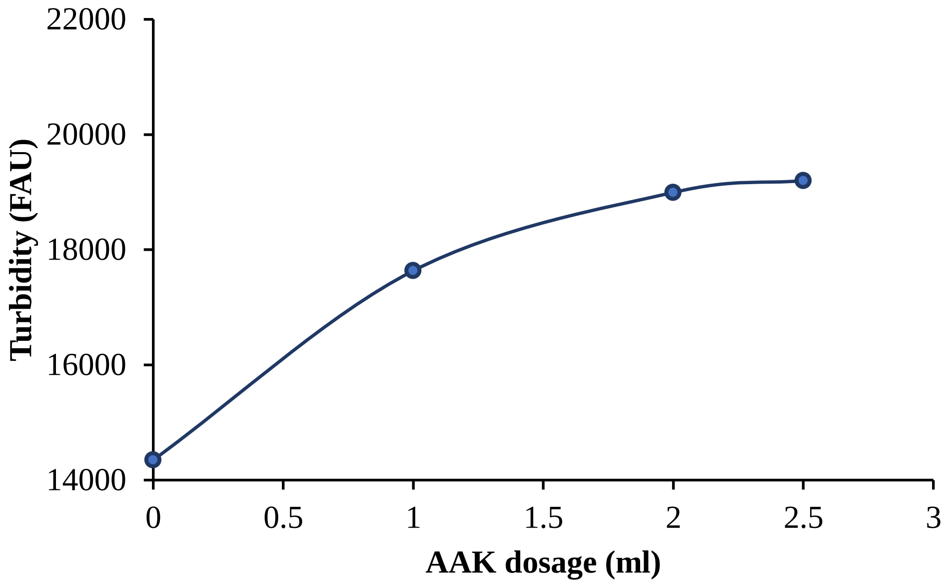

Figure 18. Coagulant dosage effect on turbidity

Outcomes

- The values of turbidity were high due to unfiltered coagulant and its milkish color as shown in figure 18.

Conclusions

The experimental findings indicate that, contrary to expectations, turbidity does not exhibit a significant decrease; rather, it increases with rising coagulant concentration. The coagulant employed, being unfiltered and possessing a color resembling that of milkish, appears to contribute to an elevation in wastewater turbidity rather than a reduction.

4.1.3 Effect of Filtered coagulant on the turbidity of PIW

This time the coagulant is filtered and four samples were prepared, with varied Sodom apple coagulant doses ranging from 0.5 ml to 1.5 ml, alongside a controlled sample as shown in figure 19. Coagulation was conducted at 250 rpm for 10 minutes, followed by flocculation at 50 rpm for 4 minutes. Settlement was allowed for 30 minutes at room temperature.

Experiment Objectives

The objective of this experiment is to evaluate the effectiveness of the AAK coagulant in reducing the turbidity of PIW. For this iteration, the coagulant was subjected to filtration prior to experimentation, resulting in a reduction of its inherent turbidity. The results of this experiment are shown in Table 5.

Table 5. Coagulant dosage effect on turbidity

AKK dosage (ml)	Ini. pH	Final pH	Initial turbidity (FAU)	Final turbidity (FAU)
0	6.5	6.5	16890	14223
0.5	6.5	6.45	16890	16990
1	6.5	6.48	16890	17435
1.5	6.5	6.61	16890	18559

Figure 19. Coagulant Filtration Process

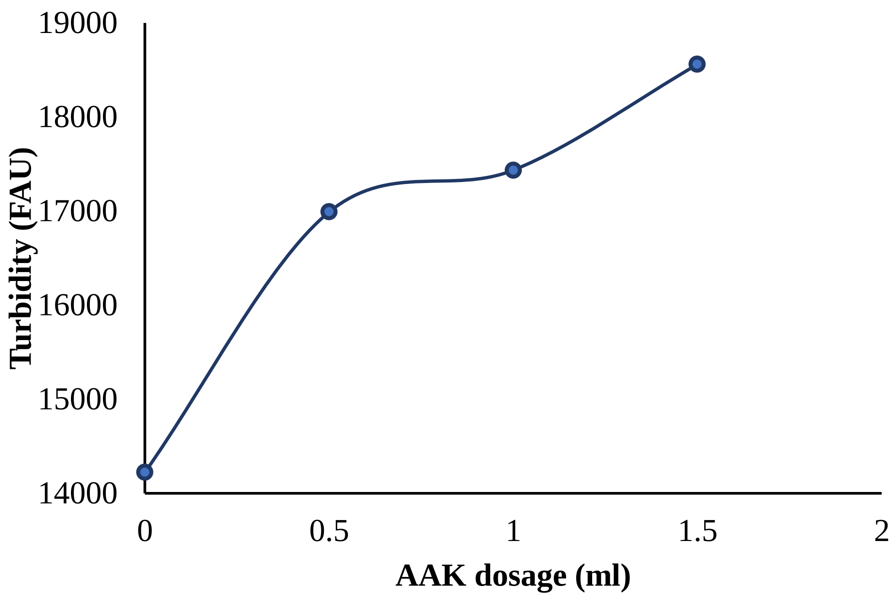

Figure 20. Coagulant dosage effect on turbidity

Outcomes

- The values of turbidity are not reduced as expected as shown in figure 20.

Conclusions

In summary, the experiment utilized filtered coagulant, resulting in lower turbidity values compared to those observed with unfiltered coagulant. However, the effectiveness of Sodom apple coagulant in reducing PIW turbidity was found to be limited. This can be attributed to the inherent turbidity of the coagulant, stemming from its milky coloration.

4.1.4 Treatment of PIW using Alum

Before testing natural coagulants, a Jar Test Apparatus was utilized to assess the treatability of the wastewater through coagulation-flocculation methods. This experiment involved incrementally varying the dosage from 0 to 1 gram in 200 ml wastewater samples, with a total of 11 samples prepared. Coagulation was conducted for 10 minutes at 200 rpm, followed by a 4-minute flocculation at 50 rpm. Subsequently, the samples were allowed to settle for 30 minutes, as depicted in Figure 21. The initial turbidity of the untreated wastewater was measured at 16890 FAU, with a pH of 6.5

Experiment Objectives

The objective of this experiment was to evaluate the efficacy of Aluminum Potassium Sulphate, also known potash alum as a coagulant for treating paint industry wastewater as shown in table 6.

Outcomes

- Turbidity values decreased proportionally with increasing concentrations of alum as shown in figure 22.

Figure 21. Settling of TSS in PIW after coagulation

Table 6. Alum dose effect on removal efficiency at Natural pH

Sample	Alum dosage (g)	pH	Ini. turbidity (FAU)	Final turbidity (FAU)	Removal efficiency (%)
Control	0	6.5	16890	14566	13.75
A	0.1	6.5	16890	1435	91.5
B	0.2	6.5	16890	982	94.2
C	0.3	6.5	16890	641	96.2
D	0.4	6.5	16890	340	97.9
E	0.5	6.5	16890	180	98.9
F	0.6	6.5	16890	150	99.1
G	0.7	6.5	16890	138	99.2
H	0.8	6.5	16890	121	99.3
I	0.9	6.5	16890	105	99.4
J	1	6.5	16890	86	99.5

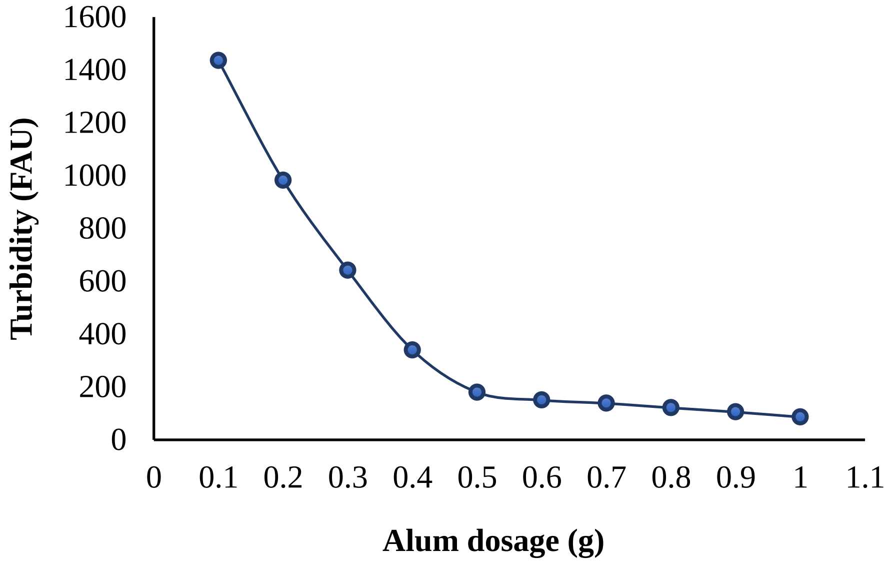

Figure 22. Effect of Alum dosage on turbidity

Conclusions

The use of alum in treating paint industry wastewater was investigated in this experiment. The preliminary use of alum before natural coagulants (NEEM and AAK) was deemed necessary to assess the viability of treating this water through coagulation/flocculation processes. Based on the experimental results, it can be concluded that the coagulation/flocculation process utilizing a Jar test apparatus is effective for treating the acquired paint industry wastewater. Alum exhibited a significant 99.5% reduction in turbidity when employed at a dosage of 5 grams per liter.

4.2 Effect of pH on Treatment of wastewater

In this series of experiments, the efficiency of wastewater treatment at different pH values is performed. This is done to evaluate the maximum efficiency at most favorable pH value for the treatment of PIW using natural coagulants.

4.2.1 Treatment of PIW at varying pH using Alum

Five samples of 200 mL of wastewater were prepared, each with varying pH values ranging from pH 5 to pH 12. A constant dosage of 2.5g/liter of Alum is used. To adjust the pH of the wastewater to the desired values, 1 molar solutions of NaOH and H_2SO_4 were meticulously prepared and added. The same method of coagulation-flocculation is performed using jar test apparatus. In this experiment, the coagulation time is set for 10 minutes at 200 rpm followed by flocculation for 4 minutes at 50 rpm and settling time is 30 minutes as shown in figure 23.

Experiment Objectives

This experiment investigates the correlation between pH levels and the turbidity of wastewater, utilizing a constant dosage of alum as a coagulant.

Outcomes:

- Decrease in turbidity observed in basic condition as shown in table7.
- Consistent decrease in turbidity values as pH is adjusted from 5 to 12.
- Lowest turbidity observed at pH 12 as shown in figure 24.

Figure 23. Settlement of samples with different pH

Table 7. Effect of Alum dose on turbidity at varying pH levels

Sample	Alum dosage (g)	pH	Ini. turbidity (FAU)	Final turbidity (FAU)	Removal efficiency (%)
A	0.5	5	16890	387	97.71
B	0.5	7	16890	221	98.69
C	0.5	9	16890	192	98.86
D	0.5	11	16890	118	99.30
E	0.5	12.4	16890	61	99.64

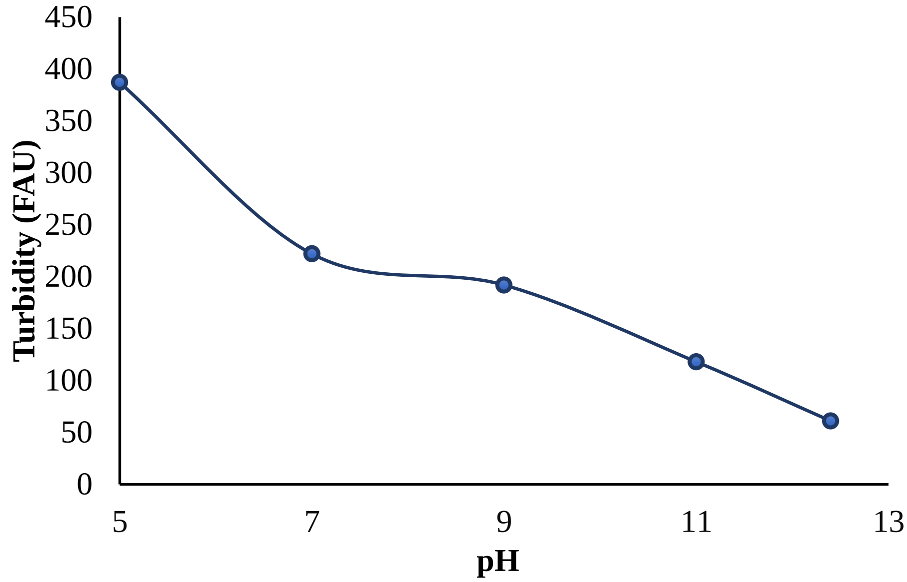

Figure 24. Alum dose effect on turbidity at different pH levels

Conclusions

Throughout this experiment, a consistent dosage of alum at 0.5g per 200 ml was maintained. Various samples of wastewater were prepared with pH levels ranging from pH 5 to pH 12.4. Analysis of the experimental data reveals that, at a constant alum dosage, turbidity decreases as the pH values increases, indicating a correlation between increased pH (more basic conditions) and improved coagulant efficacy. This suggests that the coagulant performs optimally in a basic medium

4.2.2 Treatment of PIW at pH 5 using NLS

In this experiment, a NEEM Extract solution is employed for wastewater treatment. The pH of the wastewater is adjusted to 5 by adding 20ml of a 1 molar solution of H_2SO_4. Subsequently, the coagulation-flocculation process is applied to six 200 mL samples of wastewater, all with a pH of 5. The experimental procedure involves a coagulation duration of 5 minutes at 200 rpm, followed by a flocculation period of 10 minutes at 50 rpm. The samples are then allowed to settle for 30 minutes as shown in figure 25.

Experiment objectives

This study aims to evaluate the efficacy of Neem coagulant in reducing the turbidity of paint industry wastewater, with a specific focus on varying pH conditions. The initial pH of the wastewater is set to 5, and the experiment seeks to identify the optimal pH level and coagulant dosage for achieving maximum turbidity reduction.

Outcomes

- Turbidity values decreased significantly at pH 5 as shown in figure 26.
- NEEM leaf solution functioned as a coagulant.
- Highest turbidity reduction of 97.84% achieved at 0.3 ml in 200 ml of wastewater with NEEM leaf solution as shown in table 8.

Figure 25. Settlement of samples treated with NLS

Table 8. Effect of NLS dose on turbidity at pH 5

Sample	Amount of NLS (ml)	pH	Ini. turbidity (FAU)	Final turbidity (FAU)	Removal efficiency (%)
Control	0	5	16890	14828	12.21
A	0.3	5	16890	364	97.84
B	0.5	5	16890	457	97.29
C	1	5	16890	466	97.24
D	1.5	5	16890	516	96.94
E	2	5	16890	609	96.39

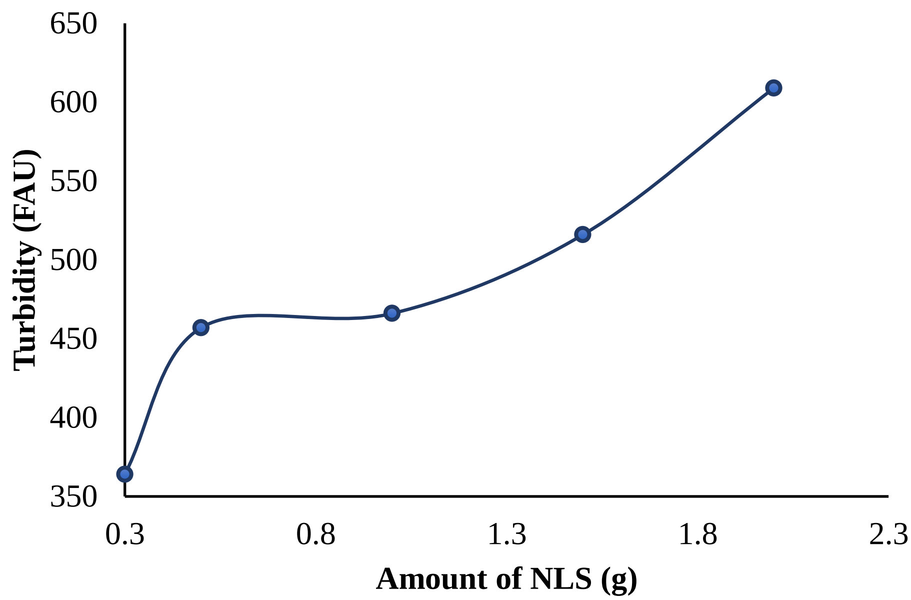

Figure 26. Effect of NLS dose on turbidity at pH 5

Conclusions

The findings of this experiment affirm the effectiveness of Neem coagulant in mitigate in the turbidity of paint industry wastewater. Notably, at pH 5, the application of the coagulant resulted in a substantial reduction in turbidity, achieving a maximum removal efficiency of 97.84% with a dosage of 0.3g of Neem per 200ml of wastewater.

4.2.3 Treatment of PIW at pH 6.5 using NLS

The experiment encompasses varying quantities of NEEM extract solution ranging from 0 to 2 ml. Six 200 mL samples of wastewater with a pH of 6.5 were subjected to the same coagulation-flocculation method. Coagulation is set for 5 minutes at 200 rpm, followed by flocculation for 10 minutes at 50 rpm, and settling for 30 minutes.

Experiment Objectives

In this experiment, NEEM Extract solution is utilized to treat wastewater with an initial pH of 6.5 which is the original pH of raw wastewater.

Outcomes

- Turbidity values decreased significantly at pH 6.5, results are shown in table 9.
- NEEM leaf solution functioned as a coagulant.
- Highest turbidity reduction of 98.95% achieved at 0.5 ml in 200ml of wastewater with NEEM leaf solution as shown in figure 27.

Table 9. Effect of NLS dose on turbidity at pH 6.5

Sample	Amount of NLS (ml)	pH	Ini. turbidity (FAU)	Final turbidity (FAU)	Removal efficiency (%)
Control	0	6.5	16890	13654	19.61
A	0.3	6.5	16890	300	98.22
B	0.5	6.5	16890	178	98.95
C	1	6.5	16890	281	98.34
D	1.5	6.5	16890	347	97.95
E	2	6.5	16890	483	97.14

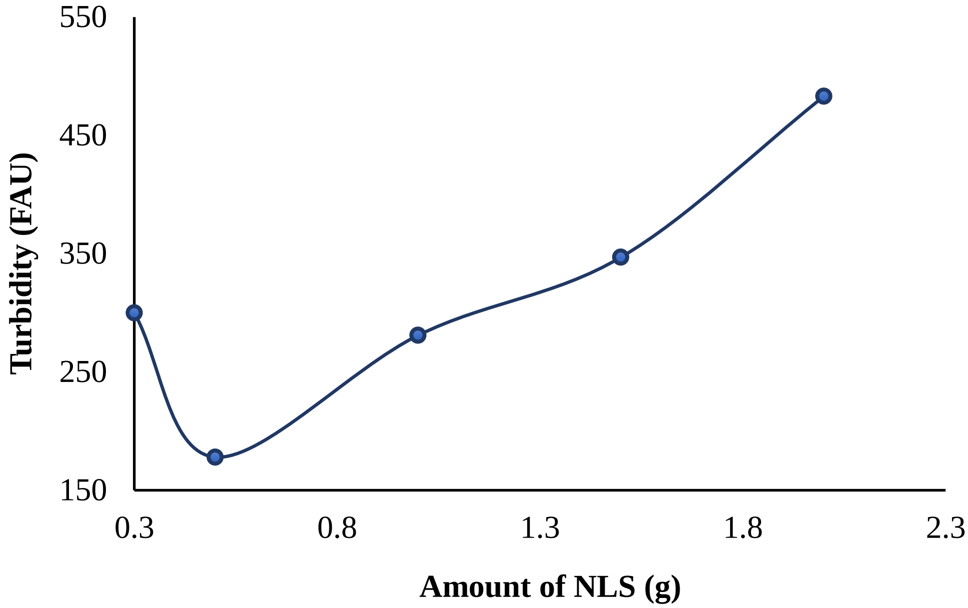

Figure 27. Effect of NLS dose on turbidity at pH 6.5

Conclusions

The results of this experiment underscore the efficacy of Neem coagulant in addressing the turbidity challenges posed by paint industry wastewater. Particularly noteworthy is the substantial reduction in turbidity observed at the natural pH of the raw paint water, measured at 6.5. The application of the coagulant yielded remarkable results, achieving a maximum removal efficiency of 98.95% with a dosage of 0.5g of Neem per 250ml of wastewater.

4.2.4 Treatment of PIW at pH 7 using NLS

The pH of the wastewater is adjusted to 7 by adding 1ml of 1 molar solution of NaOH. The experiment encompasses varying quantities of Neem extract solution ranging from 0 to 2.5 ml. Six 200 mL samples of wastewater with a pH of 7 are subjected to the same coagulation-flocculation method. Coagulation is set for 5 minutes at 200 rpm, followed by flocculation for 10 minutes at 50 rpm, and settling for 30 minutes as shown in figure 28.

Experiment objectives

In this experiment, NEEM Extract solution is utilized to treat wastewater.

Outcomes

- pH adjusted to 7 for the experiment.
- Significant decrease in turbidity observed as shown in figure 29.
- Highest turbidity removal efficiency of 97.25% achieved with 0.5 ml of NEEM coagulant in 200ml of wastewater as shown in table 10.

Figure 28. Settlement of samples treated with NLS at pH 7

Table 10. Effect of NLS dose on turbidity at pH 7

Sample	Amount of NLS (ml)	pH	Ini. turbidity (FAU)	Final turbidity (FAU)	Removal efficiency (%)
Control	0	7	16890	12877	23.76
A	0.5	7	16890	465	97.25
B	1	7	16890	921	94.55
C	1.5	7	16890	987	94.16
D	2	7	16890	1147	93.21
E	2.5	7	16890	1398	91.72

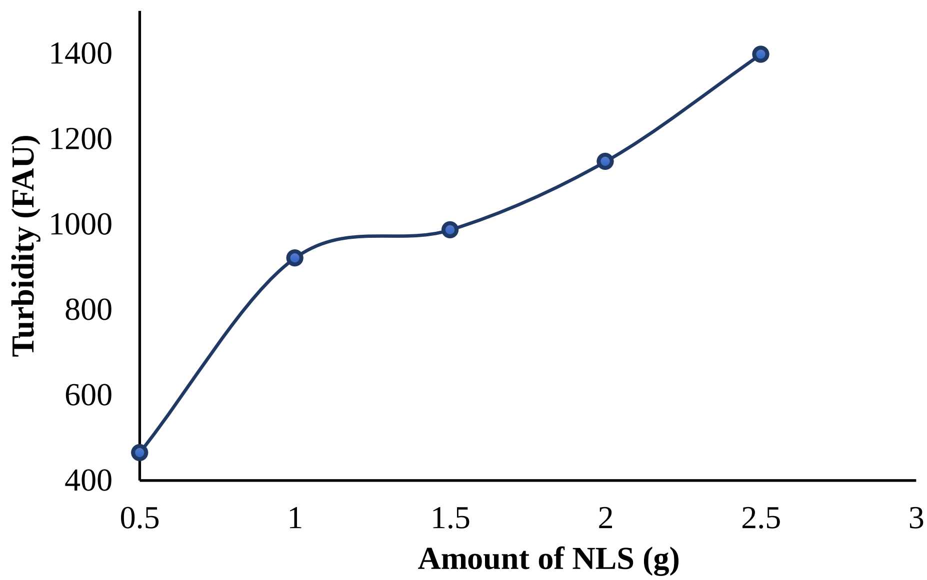

Figure 29. Effect of NLS dose on turbidity at pH 7

Conclusions

This experiment demonstrates the efficacy of Neem coagulant in effectively reducing the turbidity of paint industry wastewater. By adjusting the wastewater pH to 7, significant improvements were observed. The application of the coagulant achieved a notable maximum removal efficiency of 97.25% with a dosage of 0.5g of Neem per 200ml of wastewater, highlighting its potential as a sustainable solution for turbidity management in this context.

4.2.5 Treatment of PIW at pH 8 using NLS

The pH of the wastewater is adjusted to 8 by adding 5ml of a 1 molar solution of NaOH. The experiment encompasses varying quantities of NEEM extract solution ranging from 0 to 2 ml. Six 200 mL samples of wastewater with a pH of 6.5 are subjected to the same coagulation-flocculation method. Coagulation is set for 5 minutes at 200 rpm, followed by flocculation for 10 minutes at 50 rpm, and settling for 30 minutes.

Experiment objectives

In this experiment, NEEM Extract solution is utilized to treat wastewater.

Outcomes

- pH adjusted to 8 for the experiment.
- Decrease in turbidity observed as shown in figure 30.
- Highest turbidity removal efficiency of 86.15% achieved with 0.8 ml of NEEM coagulant in 200 ml of wastewater as shown in table 11.

Table 11. Effect of NLS dose on turbidity at pH 8

Sample	Amount of NLS (ml)	pH	Ini. Turbidity (FAU)	Final Turbidity (FAU)	Removal Efficiency (%)
Control	0	8	16890	11825	28.99
A	0.5	8	16890	2580	84.72
B	0.8	8	16890	2340	86.15
C	1	8	16890	2645	84.34
D	1.5	8	16890	2713	83.94
E	2	8	16890	2800	83.42

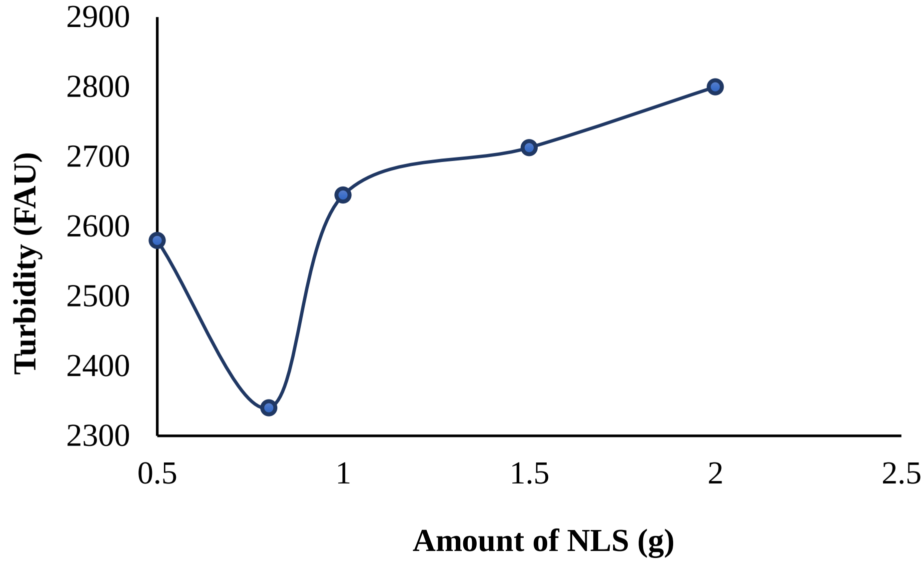

Figure 30. Effect of NLS dose on turbidity at pH 8

Conclusions

This experiment reaffirms the effectiveness of Neem coagulant in reducing the turbidity of paint industry wastewater. When the pH of the wastewater was adjusted to a more basic level, a reduction in removal efficiency was observed compared to pH levels of 7 and 6.5. Despite this, the application of the coagulant still achieved a notable maximum removal efficiency of 86.14% with a dosage of 0.8g of Neem per 200ml of wastewater. These findings emphasize the potential of Neem coagulant as a sustainable solution for turbidity management in the paint industry.

4.2.6 Treatment of PIW at pH 9 using NLS

In this experiment, NEEM Extract solution is utilized to treat wastewater. The pH of the wastewater is adjusted to 9 by adding 7ml of a 1 molar solution of NaOH. The experiment encompasses varying quantities of NEEM extract solution ranging from 0 to 2.5 ml. Six 200 mL samples of wastewater with a pH of 6.5 are subjected to the same coagulation-flocculation method. Coagulation is set for 4 minutes at 200 rpm, followed by flocculation for 10 minutes at 50 rpm, and settling for 30 minutes.

Outcomes

- pH adjusted to 9 for the experiment.
- Trend of decrease in turbidity observed as shown in figure 31.
- Highest turbidity removal efficiency of 86.86% was achieved with 0.5 ml of NEEM coagulant in 200 ml of wastewater as shown in table 12.

Table 12. Effect of NLS dose on turbidity at pH 9

Sample	Amount of NLS (ml)	pH	Ini. Turbidity (FAU)	Turbidity (FAU)	Removal Efficiency (%)
Control	0	9	9430	2264	44.45
A	0.5	9	16890	2219	86.86
B	1	9	16890	2453	85.48
C	1.5	9	16890	2881	82.94
D	2	9	16890	2910	82.77
E	2.5	9	16890	2998	82.25

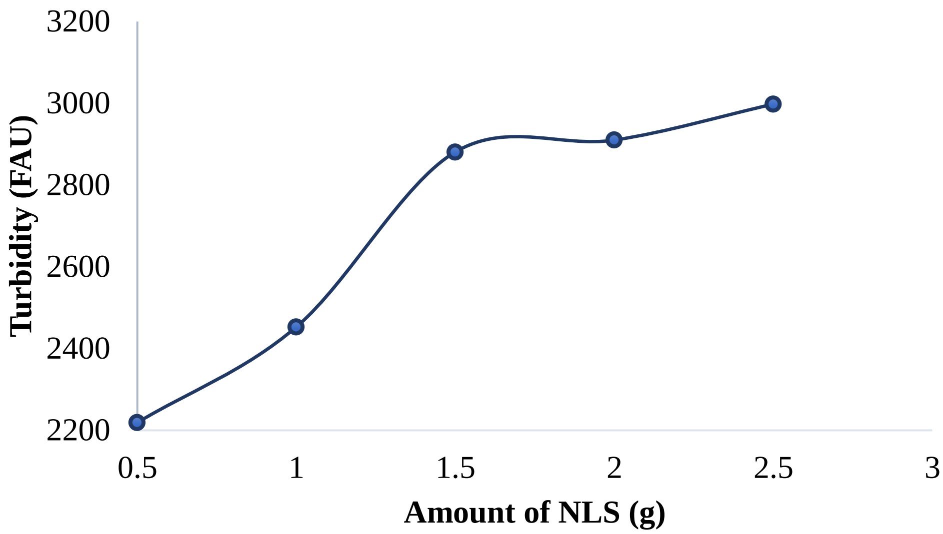

Figure 31. Effect of NLS dose on turbidity at pH 9

Conclusions

At a basic pH level of 9, the utilization of the coagulant still yielded significant results. Notably, a maximum removal efficiency of 86.86% was attained with a dosage of 0.5g of Neem per 200ml of wastewater.

4.3 Resource recovery

Within the context of the thesis, the sludge derived from treating Paint Industry Wastewater (PIW) with natural coagulants has been repurposed into a bio-fertilizer. Moringa plants were selected as test subjects to evaluate the bio-fertilizer's efficacy as shown in figure 32. Over a two-week observation period, plants treated with the sludge-based bio-fertilizer demonstrated significant growth compared to control groups as shown in figure 33. This outcome underscores the potential of utilizing waste-derived resources for sustainable agricultural practices and environmental stewardship.

Figure 32. Before addition of Bio-Sludge

Figure 33. After two weeks growth of Moringa

4.3 Wastewater characterization after treatment

After the treatment of paint industry wastewater by conducting a series of experiments the most optimum results were obtained by using 2.5 ml per liter of NLS in which the 0.125 grams is Neem. The characterization after the treatment of PIW at its natural pH is shown in table 13. The final treated water using NLS and settled sludge is shown figure 34.

Table 13. Final characterization of paint industry wastewater

Parameter	Unit	Before treatment	After treatment	Removal efficiency (%)
Turbidity	FAU	16890	178	98.94
TSS	mg/L	2100	60	97.14
COD	mg/L	694	381	45.10
Hardness	ppm	433	190	56.12
TDS	mg/L	838	750	10.50
EC	S/m	3.8	2.5	-
pH	-	6.5	7.3	-

Figure 34: Treated PIW

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter aims to conclude the study on final remarks. The original study objectives are re-evaluated and finalized through an extensive review of the literature and the development of a framework. Suggestions for enhancement are provided.

5.2 Conclusions

On the basis of study conducted on "Sustainable Treatment of Paint Industry wastewater and Resource Recovery" the following conclusions can be drawn:

1. PIW can be treated by coagulation flocculation method.
2. *Azadirachta Indica* (Neem) serves as a good natural coagulant to treat PIW.
3. The PIW treatment process is significantly affected by change in pH.
4. *Calotropis Procera* (Sodom Apple) isn't suitable for the treatment of paint industry wastewater in Pakistan.
5. 2.5 ml of NLS per liter of PIW is the optimal concentration of coagulant which gives 98.95% removal efficiency at pH 6.5.
6. Sludge produced after the treatment of PIW can serve as an alternative bio-fertilizer.

This study emphasizes the suitability of *Azadirachta Indica* for the treatment of Paint Industry wastewater in Pakistan and as this tree shed its leaves every autumn which are wasted can be used as coagulant for industrial wastewater treatment. This will be a sustainable and environment friendly approach which also strengthens the circular and green economy of Pakistan.

5.3 Recommendations

Based on the study conducted on "Sustainable Treatment of Paint Industry wastewater and Resource Recovery" the following recommendations are proposed:

1. Unique Coagulant Solution

My thesis underscores the adoption of Azadirachta Indica (Neem) as a novel, sustainable coagulant for treating Paint Industry Wastewater in Pakistan. This innovative approach not only addresses environmental concerns but also offers a promising alternative to traditional chemical coagulants.

2. Promoting Water Reuse for Industrial Sustainability

A key recommendation emerging from my research is the implementation of a water reuse strategy within the industry. By reusing treated water, industries can significantly reduce their water footprint, contributing to enhanced sustainability and operational efficiency.

3. Valorizing Sludge for Biochar Production

Through comprehensive sludge characterization, my thesis advocates for the exploration of its potential in biochar production. This transformative approach presents a sustainable alternative to conventional fertilizers, aligning with principles of resource recovery and circular economy.

4. Advocating for Localized Solutions

The thesis accentuates the significance of utilizing locally available coagulants like Azadirachta Indica (Neem) for wastewater treatment. By promoting the use of indigenous resources, this recommendation not only fosters sustainability but also enhances cost-effectiveness and community engagement within the context of wastewater management.

A.1 SDG's Achievements

The project on "Sustainable Treatment of Paint Industry wastewater and Resource Recovery" also contributes towards the United Nations (UN) Sustainable Development Goals (SDGs).

SDG#3: Good Health and Well-Being

This project supports UN Sustainable Development Goal 3, Good Health and Well-being, by treating paint industry wastewater with natural coagulants. By implementing eco-friendly solutions, it reduces the release of harmful chemicals into the environment, thereby minimizing health risks associated with water contamination. This contributes to the promotion of healthier communities and environments, supporting overall well-being.

SDG#6: Clean Water and Sanitation

This project aligns with UN Sustainable Development Goal 6, Clean Water and Sanitation, by treating paint industry wastewater with natural coagulants. By utilizing environmentally friendly alternatives, it enhances water quality, reduces pollution, and promotes sustainable water management practices, thereby contributing to the availability of clean and safe water for communities and ecosystems.

SDG#13: Climate Action

This project contributes to the empowerment of UN Sustainable Development Goal No. 13, Climate Action, by employing natural coagulants in treating paint industry wastewater. By reducing reliance on synthetic chemicals and adopting eco-friendly alternatives, it mitigates greenhouse gas emissions and promotes sustainable practices, aligning with efforts to combat climate change.

SDG#13: Life Below Water

This project directly supports UN Sustainable Development Goal No. 14, Life Below Water, by treating paint industry wastewater with natural coagulants. By utilizing eco-friendly alternatives, it minimizes the release of harmful chemicals into aquatic ecosystems, thus promoting marine biodiversity and ensuring the health and sustainability of underwater life.

SUSTAINABLE DEVELOPMENT GOALS

3 GOOD HEALTH AND WELL-BEING

6 CLEAN WATER AND SANITATION

13 CLIMATE ACTION

14 LIFE BELOW WATER

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