JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
ENVIRONMENTAL ENGINEERING MASTER’S PROGRAM

Removal of pollutants from coffee Processing wastewater using indigenous natural coagulants: optimization through Response Surface Methodology (RSM)

By
Moltot Getahun Gebre

A Thesis Submitted to graduate study of Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering, Environmental Engineering Chair in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Engineering

July ,2021
Jimma, Ethiopia

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Main Advisor: Prof., Dr.-Ing Esayas Alemayehu (PhD)

Co-advisor: Mr. Adisu Befekadu(MSc)

July, 2021
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DECLARATION

I declare that this research entitled **"Removal of Pollutants from coffee Processing wastewater using indigenous natural Coagulants: Optimization Through Response Surface Methodology (RSM)"** is my own work with the exception of quotations or references which have been attributed to their sources or authors. This thesis has not been previously submitted to any other university for requirements of degree.

Moltot Getahun Gebre ______________ ____________________

NAME SIGNATURE DATE

With my consent as a university supervisor, this research has been submitted for examination.

Main Advisor: Prof., Dr.-Ing Esayas Alemayehu (PhD) __________ 16th July 2021

NAME SIGNATURE DATE

Co-advisor: Mr. Adisu Befekadu (MSc) _____________ _____________

NAME SIGNATURE DATE

ABSTRACT

In coffee - producing countries, the uncontrolled disposal of coffee wastewater effluent is a significant concern because it shows a high concentration of suspended solids, organics, organic and inorganic matter, nitrate, phosphate and produces adverse effects on the receiving bodies of water. This causes many serious health problems among residents of nearby areas, such as spinning feeling, eye, ear, and skin irritation, stomach pain, nausea, breathing problems, and forms eutrophication on freshwater zone. This study conducted to investigate the coffee processing wastewater effluent potential treatment of selected natural coagulants Acanthus stem, Aloe Vera, and Moringa stenopetala individually and in the blend form within the framework of central composite design- response surface methodology (CCD-RSM) for the optimization process. Grap/hand sampling technique used, and Jar test conducted to evaluate coagulation ability by varying design parameters such as pH (3.0, 7.0, and 11.0), coagulant dosage (0.75,1.25, and 1.75g), stirring speed (40,80,120rpm), and stirring time (15, 30 and 45 min). Coagulation - flocculation process experiment conducted to analyze and investigate the coffee processing wastewater potential treatment of selected natural coagulants in terms of color, turbidity, COD, NO_3,*and* PO_4^{3-} *removal. Design expert (11.1.02) was used for statistically analyzing the experimental data with ANOVA and to evaluate the optimum condition or value of both process factors with respective responses. Optimum conditions and responses from the numerical and experimental optimization system for pH, coagulant dosage, agitation speed, and agitation time were studied. Therefore, according to the experimentally analyzed result, the optimum conditions obtained from the numerical optimization system for coagulant dosage, pH, agitation speed, and agitation time were 0.750g, 8.76, 80.73rpm and 19.23min respectively when the blended form of the three coagulants namely, Acanthus stem, Moringa powder, and Aloe-vera used as a natural coagulant. Under these optimum responses from numerical optimization, about 99.99%,98.70%, 98.41%, 99.12% and 99.63% for Color, Turbidity, COD,* NO_3 *,and* PO_4^{3-} *removal efficiency was obtained respectively. Even if all coagulants are best, the more effective result was found using the blended form of coagulant for coffee effluent treatment over the individual.*

Keywords: *Coffee Processing Wastewater Effluent; Natural Coagulants; Optimization; Removal Efficiency; Response Surface Methodology*

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ABBREVIATIONS

AS	Acanthus Sennii
BBD	Box-Behnken Design
BOD	Biochemical Oxygen Demand
CCD	Central Composite Design
COD	Chemical Oxygen Demand
CPEWW	Coffee Processing Effluent Wastewater
CWW	Coffee Wastewater
DoE	Design of Expert
EPA	Environmental Protection Agency
ETB	Ethiopian Birr
JIT	Jimma Institute of Technology
JUEEL	Jimma University Environmental Engineering Laboratory
JUEHL	Jimma University Environmental Health Laboratory
LT	Laboratory Technician
MCL	Maximum Contamination Level
NTU	Nephelo Turbidity Unit
PCP	Personal Care Products
PI	Personal Investigator
RSM	Response Surface Methodology
SC	Sample Collector
TDS	Total Dissolved Solid
TS	Total Solids
TSS	Total Suspended Solid
WASS	Wet Acanthus Sennii Stem
WCPEWW	Wet Coffee Processing Effluent WasteWater
WHO	World Health Organization
WW	WasteWater

CHAPTER 1

INTRODUCTION

1.1 Background

Currently, coffee (Coffea arabica Linnaeus.) is one of the most importantly traded agricultural commodities between different countries next to petroleum (Bekeko, 2013). It is cultivated in about 80 countries globally and gives rise to a considerable business worldwide(Murthy *et al.*, 2012). Ethiopia is the origin of highland coffee (Coffea arabica Linnaeus), a plant earlier known as Jasminum Arabica laurifolia Jussieu. This coffee tree species, the world's only native coffee, has traditionally been cultivated and collected as a wild tree in the highland woods of southwestern Ethiopia, according to (Schmitt, 2006). (Usually in the former Kaffa Province).

According to (Alves *et al.*, 2017), one of the critical residues of the coffee industry, produced in large quantities during post-harvest processes, mainly through the application of wet processing technology, is coffee processing wastewater. In coffee-producing countries, the uncontrolled disposal of this effluent is of great concern because it shows a high concentration of suspended organics such as sugars, pectin’s, proteins, and polyphenols, and produces adverse effects on the receiving bodies of water (Dadi *et al.*, 2018). This effluent is released directly to the surrounding water bodies, causing many serious health problems among residents of nearby areas, such as spinning feeling, eye, ear, and skin irritation, stomach pain, nausea, and breathing problems (Padmapriya *et al.*, 2015). According to (Ye *et al.*, 2020), the wastewater produced by the wet processing method of coffee cherry pulping is high in organic pollutants such as carbohydrates, fibers, polyphenols, pectins, proteins, and other related nutrients like nitrate and phosphate. The greater solids, BOD, and COD contents in coffee wastewater are due to these fundamental reasons. At the point of waste disposal, it creates objectionable odor, insect reproduction, and vectors. The fermentable sugars from these solids often shift the pH from neutral to acidic wastewater. The wastewater often has a distinctive dark brown color. This results in the degradation in the receiving freshwater zones of dissolved oxygen molecules. The solid digested coffee cherry mucilage precipitates on the surface of water bodies, creating an anaerobic condition in the water from this layer of crust. Threatening the endurance of marine life and voicing the need for adequate recycling before its discharge (Camargo and Alonso, 2006).

As society develops, so does the amount of wastewater emitted, as well as the degree of pollution of surface water, groundwater, and the environment caused by these discharges (Merghem *et al.*, 2016). Due to a lack of monitoring facilities in Ethiopia, particularly in the Jimma Zone, effluent created from coffee processing is frequently dumped directly into the river system without treatment. As a result, the water quality deteriorates. As a result, it poses risks to the ecological system and human well-being that merit scientific investigation. Thus, it's critical to clean effluent from coffee manufacturing before it's discharged into a river system. Therefore, attention is now focused on discovering the best wastewater treatment technology using sustainable technology. Many approaches implemented to treat coffee effluents, such as treatment systems using an acidification pond accompanied by neutralization, biogas reactor Up-flows Anaerobic Sludge Blanket (UASB), and build wetland reactor (Marlek *et al.*, 2012; Puebla *et al.*, 2014), sedimentation and filtration(Bui, 2017), coagulation (*Novitaet et al.,2012*), phytoremediation, ion exchange and reverse osmosis (Rizwana *et al.*,2014), and chemical flocculation and advanced oxidation processes. Other researchers have also proposed electrochemical treatment, anaerobic reactors (Asha and Kumar, 2015; Said *et al.*, 2020), and activated carbon adsorption (Deviete *et al.*, 2008).

The chemical cost in water treatment is considered one of the significant contributors. Due to the high cost of conventional synthetic coagulants, finding out natural and locally available coagulants that used for small-scale and household water treatment units is an interesting area of research.

Because of its excellent performance and efficacy, coagulation is a commonly utilized water and wastewater treatment technology. Various inorganic salts are commonly employed as coagulants; however, there are certain drawbacks to using these chemical coagulants, such as high costs, significant sludge volumes, and even the possibility of harming human health. Natural-based coagulants were investigated to minimize and replace chemical coagulants that solve these problems.

There are several methods for water coagulation; the most common is the use of inorganic coagulants such as alum. Although the use of alum is cost-effective, there are other demerits associated with its use which includes its non-biodegradable nature and can cause serious environmental problems during the treatment and disposal of the sludge(Camacho *et al.*, 2017). Alum is expensive, and evidence indicates that aluminum is highly neurotoxic and may be involved in the development of Alzheimer's disease (Rajendran *et al.*, 2015).

The jar test is the most frequent method for analyzing and optimizing the coagulation-flocculation processes. The test consists of a sequence of three phases of simultaneous batch experiments, namely fast mixing, slow mixing, and sedimentation (Muruganandam *et al.*, 2017). A pilot-scale evaluation of the treatment chemicals used in a specific water plant is the jar test. It simulates the coagulation/flocculation process found in water treatment plants. Jar test helps operators determine if they are using the right amount of treatment chemicals, and thus, improves the plant's performance. Saving money is another significant justification for performing the jar tests. Overfeeding or overdosing, especially with coagulants, is one of the common issues in water treatment. Water quality may not be hurt by this, but it does cost a lot of money.

Adepoju and Eyibio (2016) justify that the use of a single modeling and optimization variable approach is obsolete and does not display interaction in a process between other variables. Response Surface Methodology (RSM) is an optimization approach consisting of experimental design, analysis, and modeling of the experimental variables through partial regression fighting(Wang *et al.*, 2011). It can combine several variables at a time and demonstrate reciprocal interaction on the performance of a method. It also decreases the number of experimental runs required to provide adequate information for statistically appropriate outcomes (Betiku and Adesina, 2013).

Thus, to minimize problems that have been stated above on synthetic coagulant, this study was focused on the investigation of the potential treatment of locally available, Acanthus sennii, Aloe Vera, and Moringa stenopetala as low-cost coagulant for the treatment of physicochemical and bacteriological properties of CPWW. It also investigated the amount of coagulant dose, stirring time, stirring speed, and PH for maximum reduction of Color, Turbidity, COD, NO_3, and PO_4^{3-} level was a major concern in this work. This treatment consists of the quick dispersion of the coagulating agent in the water to be treated, followed by intense agitation, which is commonly defined as quick mixing. In this paper, the potential removal efficiency of selected natural coagulant for CPWW wastewater treatment evaluated, its limits analyzed, and the optimum use and dosage assessment evaluated.

1.2 Statement of the Problems

Environmental pollution is one of the most significance challenges human beings face. Water quality change due to industrial pollution is one of the significant environmental concerns throughout developing countries, including Ethiopia. In coffee-producing countries, the uncontrolled disposal of coffee wastewater effluent is great concern because it shows a high concentration of suspended organics, organic and inorganic matters, nitrate, phosphate, and low in pH value.

This produces adverse effects on the receiving bodies of water, causing many serious health problems among residents of nearby areas, such as spinning feeling (Feeling drunk) 89%, eye and ear irritation (burning inside) 32%, and skin irritation85%, stomach pain 42%, nausea 25%, and breathing problems 75% (Padmapriya et al., 2015). It forms eutrophication on freshwater zone that disturb aquatic life and the whole ecosystem by reducing the amount of water and dissolved oxygen in the receiving body.

Eutrophication which is caused by CPWW nutrients especially, by nitrate and phosphate, is a serious problem that may permanently eliminate waters from surface water bodies. Even though the Jimma zone is one of Ethiopia's most well-known coffee-producing regions, it lacks proper methods to control effluent generated from its wet coffee processing industries. As a result, the effluent was discharged directly to the land and receiving water body.

In general, the impact of wet coffee processing wastewater on the Jimma zone, particularly the Mana area, has not been well investigated, and no mitigation action has been made to build a sustainable environment. As a result of uncontrolled effluent discharge into water bodies or dry lands, water quality and environmental sustainability worsen, posing a risk to aquatic life, humans, animals, and the entire ecology. Therefore, to overcome this problem it is important to treat effluents in coffee industry as per WHO permissible limit, before discharging either in the water body or land surface.

1.2.1 The Gap of knowledge between natural coagulation and other treatment methods

Several methods developed for the treatment of WCPWW, but most of them are either too expensive or harmful to the environment. Coagulation-flocculation is one of the most effective and efficient wastewater treatment methods, and many chemical coagulants such as aluminum salt, ferric salt, and synthetic polymers have been widely used in water purification since ancient times. These chemical coagulants, on the other hand, release hazardous compounds into the environment, which are dangerous to human health. Furthermore, they are useless in low-temperature water, are quite expensive, generate considerable amounts of sludge, and have a major impact on the pH of the treated water. They also induce human disorders such as "Alzheimer's" (Rajendran *et al.*, 2015).

These demerits from the use of inorganic coagulants lead to global research interest in naturally occurring biomaterial derivative organic coagulants that can be renewable, environmentally sustainable and can also provide additional benefits of lower costs, local availability, and sustainability for wastewater treatment (Saleh and Gupta, 2012). In general, coagulation and flocculation with the use of natural coagulants to remove pollutants from water and wastewater were encouraged by different investigators and confirmed in terms of their efficiency.

This research fills the gap mentioned with the treatment methods above, by employing a natural coagulant that is renewable, cost-effective, ecologically friendly, locally available, non-toxic, non-corrosive, and highly biodegradable and does not produce huge amounts of sludge.

Therefore, this study investigates the effectiveness of wet AS stem, Moringa powder, Aloe vera gel, and the blended form of coagulants by conducting preliminary experiments on color, turbidity, COD, NO_3, and PO_4^{3-}reduction efficiency by optimizing the process using RSM to determine the optimum condition of the factors and value of the response, this important to reduce overdosage or under dosage problems, finally implies sound performance of the process and economic safety was achieved. Acanthus sennii plant is a new discovery for water and wastewater treatment in this study, that it has never been used for treatment in any published article other than for medical purposes.

1.3 Objectives

1.3.1 General objective

General objective of this study was to investigate coffee wastewater treatment potential of natural coagulants (AS, moringa stenopetala, and aloe vera) individually and in blended form by optimizing the process using RSM.

1.3.2 Specific objectives

The specific objectives of this work are:

- To characterize the physiochemical parameters of coffee effluent wastewater sample in terms of color, turbidity, COD, $NO_{3,}$ and PO_4^{3-}
- To determine the optimum value of operating parameters to maximize pollutants removal efficiency.
- To determine the interactive effects of these operating parameters using RSM.
- To compare the efficiency of AS, moringa, aloe vera coagulants individually and blended form of each response using both experimental and optimized values.

1.4 Research questions

1. What are physiochemical parameters of coffee wastewater sample characterized in terms of Color, Turbidity, COD, NO_3, and PO_4^{3-}?
2. How can pollutants removal efficiency optimize the optimum condition of design parameters?
3. What are the operating parameters, and how their interactive effects can be determined?
4. How can the efficiency of selected coagulants have compared individually as well as in the blended form, and which one is more effective?

1.5 Significance of study

This study was introducing the application of Acanthus sennii, Aloe vera, Moringa stenopetala, and blended form of natural coagulant, that may help the the country to reduce importing and transportation chemical-based coagulants via replacing them with plant-based coagulant which has higher attribute than the current one. The wet coffee processing industries may benefit from the results of the study since it gives as guidelines for treating raw wet coffee processing wastewater before releasing it to the environment. If, once the research is done successfully and implemented, it is expected to have the following significances.

- Reduce the cost of chemical coagulant for CPWW treatment
- Farmers who cultivate the plant should benefited financially
- Create employment for the local people

Therefore, as stated above, this thesis work will have significance for the society, environment and country. The general usage of natural coagulants in cost savings, health benefits, and environmental sustainability.

1.6 Scope of study

This study was limited to characterization of raw wastewater from wet coffee processing plant collected from Jimma zone, Mana district coffee processing industry, analyze the treatment potential of selected natural coagulants individually and blended form, and conformation of their effectiveness by conducting a preliminary experiment on color, turbidity, COD, NO_3 and PO_4^{3-} removal efficiency, optimizing the process, and determination of the more efficient one, showing the interactive effects of parameters on the response using RSM.

1.7 Limitation of study

The study mainly focused on the treatment of wastewater generated from the wet coffee processing industry did not include the detailed assessment and investigation of adverse effects caused by this effluent on human and animal health, receiving water bodies, aquatic life, and the surrounding environment. The parameters assessed in this study are also specific and selected, i.e., there was no complete assessment of all coffee wastewater constituents except focusing on the selected five parameters. Potential treatment of AS plant in the form of dry powder and different parts such as root, seed, and a leaf of the plant were not studied, but focused on the wet stem of AS. The researcher also faced difficulties in obtaining modern and updated laboratory equipment as well as chemicals and reagents that used for the five selected responses determination at laboratory. But the research focused on obtaining the necessary materials during the entire study period with maximum effort.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Water in nature is almost completely free of contaminants in its evaporation state, but as it passes through the hydrologic cycle, it may acquire many impurities as it comes in contact with materials in the air, on the surface, and beneath the surface of the earth.

Additional impurities are released from industrial and domestic waste, agricultural chemicals, and other, less visible pollutants lead to human activities. In both suspended and dissolved form, the impurities accumulated in water can be Suspended material consists of particles greater the molecular size supported within the water by buoyant and viscous forces. A dissolved substance is made up of molecules or ions retained by water's molecular structure. Most of industrial unit's present practice is to release wastewater into the local environment without treatment. When untreated or poorly treated effluent enters a water body, it either dissolves or remains suspended in the water body, polluting the water body. Industries that are persuaded to believe that huge volumes of wastewater created during basic industrial processes cannot be avoided. As a result, they become slack in terms of pollution prevention, and the wet coffee processing industry is one example.

2.2 critique of existing literature review relevant to the study

Nowadays, the growth of the human population has led to the development of different industries to fulfilling human needs. This phenomenon, eventually, has caused the excessive use of resources of the earth, such as soil, air, water, etc. According to the author’s justification, the coffee cherry pulping wastewater produced from the wet processing method is highly rich in organic contaminants such as carbohydrates, fibers, polyphenols, pectin’s, proteins, and other related nutrients such as nitrate, phosphate(Ye *et al.*, 2020). The higher solids, higher organic and inorganic matters, nitrate and phosphate contents in coffee wastewater are due to these fundamental reasons. At the point of waste disposal, it creates objectionable odor, insect reproduction, and vectors.

The fermentable sugars from these solids often shift the pH from neutral to acidic wastewater. This contributes to the loss in the receiving freshwater zones of dissolved oxygen molecules. The solid digested coffee cherry mucilage floats on the surface of water bodies, creating an anaerobic conditions in the water from this layer of crust, and threatening the endurance of marine life and voicing the need for adequate recycling before its discharge (Camargo and Alonso, 2006).

The quick, immediate, and cost-effective point-of-use technology called coagulation eliminates turbid, colloidal, suspended, and dissolved natural or chemical organic compounds from industrial wastewater. The process that underlies the principle of coagulation during wastewater treatment must be understood. Cation or anion-enriched polyelectrolytes, often non-ionic functional groups, are commonly used as coagulants to extract pollutants from wastewater. It is also very imperative to remember many other influential parameters, such as pH, dose, and coagulant form.

According to (Menkiti and Onukwuli 2012), justifications that researchers have focused on the synthesis and, or derivatives of coagulant materials from inorganic and organic sources to enhance the coagulation-flocculation process of wastewater. Conventionally recognized coagulants such as hydrolyzing metal salts of aluminum and iron in the form of $AlCl_3$, $Al_2(SO_4)_3$, $FeCl_3$, and $Fe_2(SO_4)_3$ are inorganic materials used during coagulation-flocculation processes (Nekouei *et al.*, 2015). However, the use of these coagulant materials has its drawbacks, including the rapid dilution formation of the coagulant species and the uncontrollability of the hydrolyzing species formation. (Burakov *et al.*, 2018). Alum is also expensive, and evidence indicates that aluminum is highly neurotoxic and may be involved in developing Alzheimer's disease. (Rajendran *et al.*, 2015). These demerits from the use of inorganic coagulants lead to global research interest in naturally occurring biomaterial derivative organic coagulants that can be renewable, environmentally sustainable and can also provide additional benefits of lower costs, local availability, and sustainability for wastewater treatment (Saleh and Gupta, 2012)

Coagulation-flocculation is a simple and quick procedure for treating effluents, and coagulant selection should be based on the coagulant's appropriateness, availability, and cost (Rao, 2015). The typical water purification methods using synthetic materials such as aluminum sulfate (alum) and calcium hypochlorite are not successful because these materials are imported, making the cost of water mostly costly in the most economically developed countries relatively costly and not affordable for most rural populations (Hendrawati *et al.*, 2016).

There are natural ingredients that can be obtained from tropical plants which used as coagulants, including moringa seeds (Moringa stenopetala). The use of natural ingredients to clear muddy water from local indigenous plants is not a new concept.

According to (Khannous *et al.*, 2011), response surface methodology (RSM) has been successfully applied to various processes for optimizing variables using experiment design, such as central composite design (CCD), face-centered composite design (FCCD), and

Box-Behnken design (BBD). BBD consumes limited time with fewer experimental runs than others, is reliable, and is widely used in industrial research where the system response is influenced by three process variables. RSM is generally used more often than ANN (Artificial Neural Network), although both techniques have been considered to be suitable methods for the modeling and optimization of wastewater purification. It approximates all kinds of non-linear functions, while RSM is only helpful for quadratic approximations (Rajendra *et al.*, 2009).

2.3. Industrial effluents

In recent decades, the increasing rise in industrial activity and water usage worldwide has led to the release of several pollutants into the aquatic environment, such as toxic heavy metals, dyes, and pesticides amongst other harmful contaminants(Abdolali *et al.*, 2014). The discharge of industrial wastewaters and domestic wastes has had a significant negative impact on aquatic bodies as a result of the rapid increase in industrialization and urbanization, amongst these, the most prominent sources of anthropogenic activity are contaminants such as heavy metals that are transmitted to the environment by the continuous discharge of sewage and industrial waste(Lakherwal, 2014).

Owing to its harmful effects on the well-being of human health, fauna, and flora, the presence of these hazardous and non-biodegradable heavy metals found in wastewater is a significant concern. Governments have also placed limitations on the quality of wastewater, forcing companies to introduce appropriate treatment options before disposal(Ronda *et al.*, 2013). With sustainability at the forefront of industrial activities, compliance with regulations is crucial for the industrial sector. Because many rural regions lack access to safe drinking water, people rely on these sources of water.

Wet processing of coffee cherry pulping wastewater is highly rich in organic contaminants such as sugars, fibers, polyphenols, pectin’s, proteins, and other associated nutrients such as nitrate, phosphate, etc. (Ye *et al.*, 2020). The greater solids, higher organic and in organic matter, nitrate and phosphate contents in coffee wastewater are due to these fundamental reasons. At the point of waste disposal, it creates objectionable odor, insect reproduction, and vectors. The fermentable sugars from these solids often shift the pH from neutral to acidic wastewater.

The wastewater has a distinctive dark brown color as well. This contributes to the loss in the receiving freshwater zones of dissolved oxygen molecules. The solid digested coffee cherry mucilage floats on the surface of water bodies, creating an anaerobic condition in the water from this layer of crust. Color and turbidity are two significant pollutants in industrial wastewater (Verma *et al.*, 2012). The industries such as pulp, paper, rubber, textile, and polymer are the main sources of surface and underground water polluters. The disposal of wastewater into surface waters such as rivers and lakes limit the transmission of light through water, reducing photosynthesis and the amount of dissolved oxygen in the water.

2.4 Coagulation flocculation process to remove color, COD and other nutrients from wastewater

The purification process typically includes the removing of the dissolved and suspended impurities to improve the turbidity and color of water through sedimentation by allowing suspended particles to settle down by gravity. However, these colloidal particles are too tiny to settle individually; hence they must agglomerate to increase their weight to settle by gravity. On its surface, each of the suspended tiny particles typically has a negative electrical charge. These particles that charged negatively will repel each other. They remaining suspended rather than clumping together and settling at the bottom. This has resulted in a mechanism called coagulation being created in preparation for sedimentation. In raw water, coagulation refers to chemically destabilizing suspended matter to form larger agglomerates known as flocs. Coagulants are chemicals that used to separate raw water from color, turbidity, and other nutrients. They achieve this by facilitating the formation of large agglomerates that can settle at the bottom and removed in downstream sedimentation processes. Synthetic coagulants classified into metal salts (e.g., aluminum and ferric salts) and poly aluminum chloride (PAC) (Yang *et al.*, 2010).

2.5. Type of coagulants

2.5.1. Natural coagulants

Natural coagulants have been used in drinking water treatment since ancient (Choy *et al.*, 2015). These coagulants are used for colloidal particle destabilization, and have antimicrobial and heavy metal removal properties (Al-Anizi *et al.*, 2014). The use of natural plant-based coagulants to remove turbidity in water is not a new concept, as different researchers researched on various plant extracts to assess their ability to remove turbidity in water. Moringa Oleifera seeds contain proteins that, when inserted into water, create a positive charge, resulting in the electrostatic attraction of negatively charged particles in the water. Studies have shown that Moringa stenopetala is non-toxic, less costly than chemical coagulants, biodegradable, and thus eco-friendly, and creates fewer sludge volumes (Judith *et al.*, no date).

There are some studies in the recent literature that have used natural coagulants for water treatment and turbidity removal. Silva floc, a tannin-based coagulant product, was investigated for river water clearing (Sánchez-Martín *et al.*, 2010).With a 20 mg/L dose of the coagulant, the authors were able to remove 90% of the turbidity in neutral pH. Total coliforms were also reduced by up to 70% with the coagulant. Polyphenol concentration in the treated water was very low (about 0.4 mg/L). Furthermore, rather than increasing organic matter content, it was reduced by around 30%. Following the addition of the coagulant, total organic matter rose linearly. After the flocculation process, no additional rise was seen, and all organic matter added by the coagulant was eliminated.

Natural organic coagulants have received greater attention as a result of the concerns outlined above, as well as difficulties in administering mineral coagulants. These coagulants may be a better option for removing turbidity from drinking water than other methods. They have the advantages of human health safety, biodegradability, decreased dose requirements, and less sludge generation due to the lack of residual heavy metals (Kumar *et al.*, 2017). In comparison to the efficacy of chitosan and conventional coagulants (alum and ferric chloride) in terms of turbidity and natural organic matter removal, natural flocculants carry the danger of residual organic matter, which might act as a precursor matter for disinfection by-products (DBPs) (Kumar *et al.*, 2017).

2.5.2 Advantage of natural coagulant over chemical coagulants

- Sustainability refers it is a natural, abundant, renewable sources, more eco-friendly, and reduce chemical dependency.
- Sludge refers in terms of reducing sludge volume, biodegradable, higher nutritional sludge value, and disposing of treatment.
- The cost was explained in terms of lower sludge handling and treatment cost, local materials, and local labor, no pH and alkalinity adjustment, lower procurement cost, lower coagulant dose and lower cost.
- The nature of the coagulant explains in terms of non-corrosive, non-toxic, highly biodegradable, and safe.

2.5.2 Chemical coagulants

Conventional water treatment plants in developing countries use synthetic coagulants, mainly alum, due to their high turbidity removal efficiency. Alum, however, is expensive, and research suggests that aluminum is neurotoxic mainly and may be involved in developing Alzheimer's disease (Rajendran *et al.*, 2015). Alum also increases the concentration of treated water in the total dissolved solids and creates high amounts of sludge that is not biodegradable and difficult to dispose of. Therefore, these disadvantages require considerable research concerning the production of alternative coagulants that are cost-effective and environmentally sustainable. These alternatives come in the form of natural coagulants that, because they are locally available, are considered to be environmentally friendly and cheaper.

Commonly used chemical coagulants are:

- Alum: $Al_2(SO_4)_3.18H_2O$
- Ferric chloride: $FeCl_3$
- Ferric sulfate: $FeSO_4$
- Polyelectrolytes (Polymers)

2.6 Similarities of Acanthus sennii with other natural coagulants

Many properties make Acanthus Sennii similar with other natural coagulants due to the chemical composition they have.

2.6.1 Similarities of Acanthus sennii and Moringa stenopetala

The main similarity of these two plants is that the plants serve health purposes in curing many diseases and hence safe for health. Moringa oleifera is a medicinal plant commonly used to treat ailments such as ulcers, wounds, arthritis, heart problem, cancer, stroke, obesity, anemia, and liver damage in folkloric medicine of Africa and Asia. Gas chromatography-mass spectrometry has been used to analyze the chemical constituents of the methanolic extract of Moringa oleifera leaves and seeds. Methanolic; these are, 9-octadecenoic acid (20.89%), L-(+)-ascorbic acid- 2,6 dihexadecanoate(19.66%), 14–methyl-8-hexadecenal (8.11%), 4-hydroxyl-4-methyl-2-pentanone (7.01%), 3-ethyl-2, 4-dimethylpentane (6.14%), phytol (4.24%), octadecamethyl Cyclopentasiloxane (1.23%), 1, 2-benzene dicarboxylic acid (2.46%), 3, 4-epoxyethanone comprising (1.78%), N-(-1-methylethyllidene)-benzene ethanamine (1.54%), 4, 8, 12, 16- tetramethylheptadecan-4-olide (2.77%), 3-5-bis (1, 1- dimethyl ethyl, dimethylsilyl)-phenol (2.55%), 1, 2, 3-propane triol -9 octadecenoic acid (1.23%), 3, 7, 11, 15-tetramethyl-2 hexadecene-1-ol (1.17%), hexadecanoic acid (2.03%), and 1, 2, 3-propane triol -9 octadecenoic acid (1.23 percent). In methanolic seed extract, five chemical constituents have been identified and are oleic acid (84%), L-(+)-ascorbic acid-2, 6-dihexadecanoate (9.80%), 9-octadecenoic acid (1.88%), methyl ester-hexadecanoic acid (1.31%) and 9-octadecenamide acid (1.88%) (0.78 percent). The results obtained showed that Moringa oleifera methanolic leaf extract has more chemical constituents than seeds containing 9-octadecenoic acid (20.8%) as the highest leaf and 84% oleic acid crop. These chemical compounds may be responsible for the therapeutic benefits of Moringa oleifera leaves and seeds (Aja *et al.*, 2014).

2.6.2. Similarities of Acanthus sennii and Cactus

The results for preliminary phytochemical screening carried out on the Cactus rods powder were: tannins, saponins, and mucilage's, which are proteins in nature. The presence of mucilage's and tannins is related directly to the flocculation property of the plant (Gebresamuel and Gebre-Mariam, 2011) (Aja *et al.*, 2014).

Figure 2.1: Acanthus sennii plant

Aloe Vera is known to contain over 75 active nutrients, making it one of a kind. The presence of so many nutrients in a single plant is sporadic. It contains vitamins, minerals, amino acids, sugars, enzymes, and other nutrients, making it a nutritional powerhouse. Both Aloe vera and Moringa oleifera are similar in their constituents, especially in terms of protein and carbohydrate.

Figure 2. 2: Aloe vera plant

2.7 Tannin Based Coagulants for Wastewater Treatment

Most vegetable water-soluble polyphenolic compounds are tannins. They are polymers ranging in molecular weight from 500 to several thousand Daltons. Trees are familiar sources of tannin, such as Schinopsis balansae (Quebracho), Castanea sativa (Chestnut), or Acacia mearnsii de Wild (Black wattle). For centuries, tannins have been used in tanning processes (since. 1500 BC). They have also been commonly used in many industries for use in the medical field (anti-inflammatory, antidiarrheal, hemostatic, anti-hemorrhoidal, anti-viral, and antibacterial properties) (Ashok and Upadhyaya, 2012) to the food sector (as an antioxidant and for clarifying beer, fruit juices, and wine) and ink manufacture (Corder *et al.*, 2006) (iron gallate ink).

In addition, tannins are employed in surface coatings and polymers (Grigsby *et al.*,2015),manufacturing adhesives, and water purification(Sánchez-Martín *et al.*, 2010). Moreover, the presence of phenolic groups with an anionic disposition (deprotonation and formation of resonance stabilized pentoxides) tannins can be used as natural coagulants for the treatment of drinking water, wastewater, and industrial effluents because of their chemical structure. The effectiveness of tannins as coagulants in water clarity is significantly influenced by their chemical structure, which is influenced by the plant from which they were extracted (Sánchez-Martín *et al.*, 2010)

CHAPTER 3
MATERIALS AND METHODS

3.1 Materials

3.1.1. Equipment and Materials

The equipment and tools that used throughout the experiments to achieve the objective of the study were: jar test apparatus, refrigerator, oven, measuring cylinder, beakers, magnetic stirrer, weight balance, pipette, the crucible, domestic mill, sieve, filter paper, pH meter, digital Nephelo turbidity meter, HANNA Instrument (HI-93703), COD digester, UV; Spectrophotometer (model-6700), heater, glove, acanthus sennii, Moringa, aloe vera, CPWW sample, polyethylene bottle, thermometer, burette, kits, spoons and,

3. 1.2. Chemicals and reagents

3.1.2.1 Chemicals

- Concentrated Sulfuric acid (H_2SO_4) for pH adjustment, and sulfuric acid reagent preparation with silver sulfate.
- Sodium hydroxide (NaOH) for pH adjustment.
- Silver sulfate (Ag_2SO_4)
- Mercuric sulfate ($HgSO_4$)
- Potassium hydroxide (KOH)

3.1.2.2 Reagents

- Potassium dichromate reagent
- Ferrous ammonium sulfate (FAS) reagent
- Ferrion red indicator
- Sulfuric acid reagent (Ag_2SO_4+ H_2SO4)
- Distilled water to prepare reagent, to calibrate the instruments, and to rinse purpose.
- EDTA
- Phenol di sulfonic acid
- stannous chloride solution

3.2. Methods

3.2.1. Sample Collection

This study, grap/hand sampling technique was used to take samples from Jimma zone, Mana district wet coffee processing effluent sample by direct filling of the container. The sample collected was 108 litters which is equal to the number of runs conducted in coagulation-flocculation process for this study. Clean Plastic containers (polyethylene terephthalate (PET) used for sample collection after cleaned with detergent, rinsed with tap water, soaked in 10% of concentrate nitric acid, and rinsed with deionized water. Finally, the collected sample transported to Jimma University Environmental Engineering (JUEE) laboratory and preserved in a refrigerator at four °C for two days to minimize the chance of their characteristics changes until analysis done.

3.2.2 Preparation of coagulants

Plant material was selected considering the information of previous studies where they have shown good properties, such as coagulant activity, availability and nutrient composition, especially the content of protein, and carbohydrates. In this study, wet acanthus stems of aloe Vera, matured moringa stenopetala seed indicated with white and dry fruits, as natural coagulant used. The moringa stenopetala seeds collected locally from Wolayta Sodo. It was sundried for 6-7 days. Then the chaff surrounding the seed kernel removed , and the kernels are ground finely to powder form by using pestle and mortar and sieved to size 600μm(Tunggolou and Payus, 2017). This was the coagulant prepared from moringa seed. Sample of the mature fresh Aloe vera 30–40 cm long was collected in a polyethylene plastic bag from Jimma zone Seka district. It was then washed and split in half using a knife, and the thick slimy gel recovered in 1 liter beaker. 50 ml of recovered gel was introduced into 500 ml of distilled water and stirred using a magnetic stirrer for half an hour. Then, the solution strained through a sieve of 25 mm(Adugna, 2018). Finally, the filtrate collected and stored in a refrigerator not exceeding 48 hours to avoid spoilage by microorganisms.

The very immature small stems of AS and the softest top part of the matured stems collected from Jimma Town around St. Gabriel church and cut down into different small pieces by using a knife. By washing the small pieces of AS stem with distilled water to remove extra impurities then debarked. The debarked stems were divided apart using a knife and stored inside a cleaned bucket. After this step, the divided small pieces of the stem where then added to the washed and dried mortar laboratory. By using the cleaned pestle with mortar, the stems were pounded and changed into paste. After enough pounding done, the paste of the stem was taken by spoon and added into a clean ampoule for the subsequent use of the coagulation experiment.

Figure 3.1: Photographic representation of WCPWW treatment using wet AS, moringa, aloe vera and blended form coagulants.

3.2.3 Experimental procedure

A jar test is the most widely used experimental method for the coagulation and flocculation process of water and wastewater treatment. A conventional jar test apparatus was used for this study to conduct the experiment using natural coagulants.

This carried out as a batch test consisting of four beakers together of 1-liter capacity with four spindle stirrers. Before the operation of the test, the sample was mixed homogeneously. This study consists of a batch experiment of rapid mixing, slow mixing, and sedimentation process. The apparatus normally consists typically six rotating paddles or stirrers, and beakers. But for this study, four 100ml beakers were used for the three coagulants and the blended one by considering time, runs, and sample water and then finally the optimal condition considered to compare the pollutant removal efficiency of coagulants from the whole runs of the experiment.

The jar test apparatus has a maximum stirring capacity of 300 revolutions per minute (rpm). The jar test experiment for this study done by setting the apparatus at 150rpm for uniform dispersion or mixing of dosed coagulant and sample for 2 minutes, 30-40 rpm for15 minute and 60 minutes given for settlement or sedimentation of dispersed, coagulated, and flocculated particles at the bottom of the beaker this was common for all experiments. In this study, stirring speed of 40rpm, 80rpm, and 120 rpm stirring time of 15 min, 30min, and 45min, coagulant dosage of 0.75g, 1.25g, and 1.75g, and pH 3, 7, and 11 used for the jar test analysis and the optimum condition selected out of each factor respectively.

The experiment performed by using a wet coffee processing wastewater sample having constant turbidity, color, other components. Every four beakers of the three coagulants and blended coagulants filled by the same water sample and having the same adjusted pH, dosage of coagulant, stirring speed, stirring time, and settling time for each batch of an experiment. All experiments performed according to the order of treatment combinations were set based on factors involving in this study, dosage, pH, stirring speed, and time. According to (Alo *et al.*, 2012), the correct concentration of stock solution was put into each beaker and the speed was dropped to 50 rpm and continued for 25 minutes after which the paddles were stopped and the water was allowed to settle for 1 hour. A clean water sample was obtained after 1 hour and stored in a conical flask at 4 ^{O}C for future analysis. The selected input variable trial interval in this study, chosen randomly, but consider or by taking care of trials already checked by previous researchers to prevent the redundancy of experimental tests at the same condition as well as to check the effectiveness of the selected coagulants at the new conditions, and in addition to this the pH trial interval are chosen to check the effectiveness of selected coagulants at 3(extremely acidic), 7.0 (neutral)and 11(extremely basic).

3.3 Research design

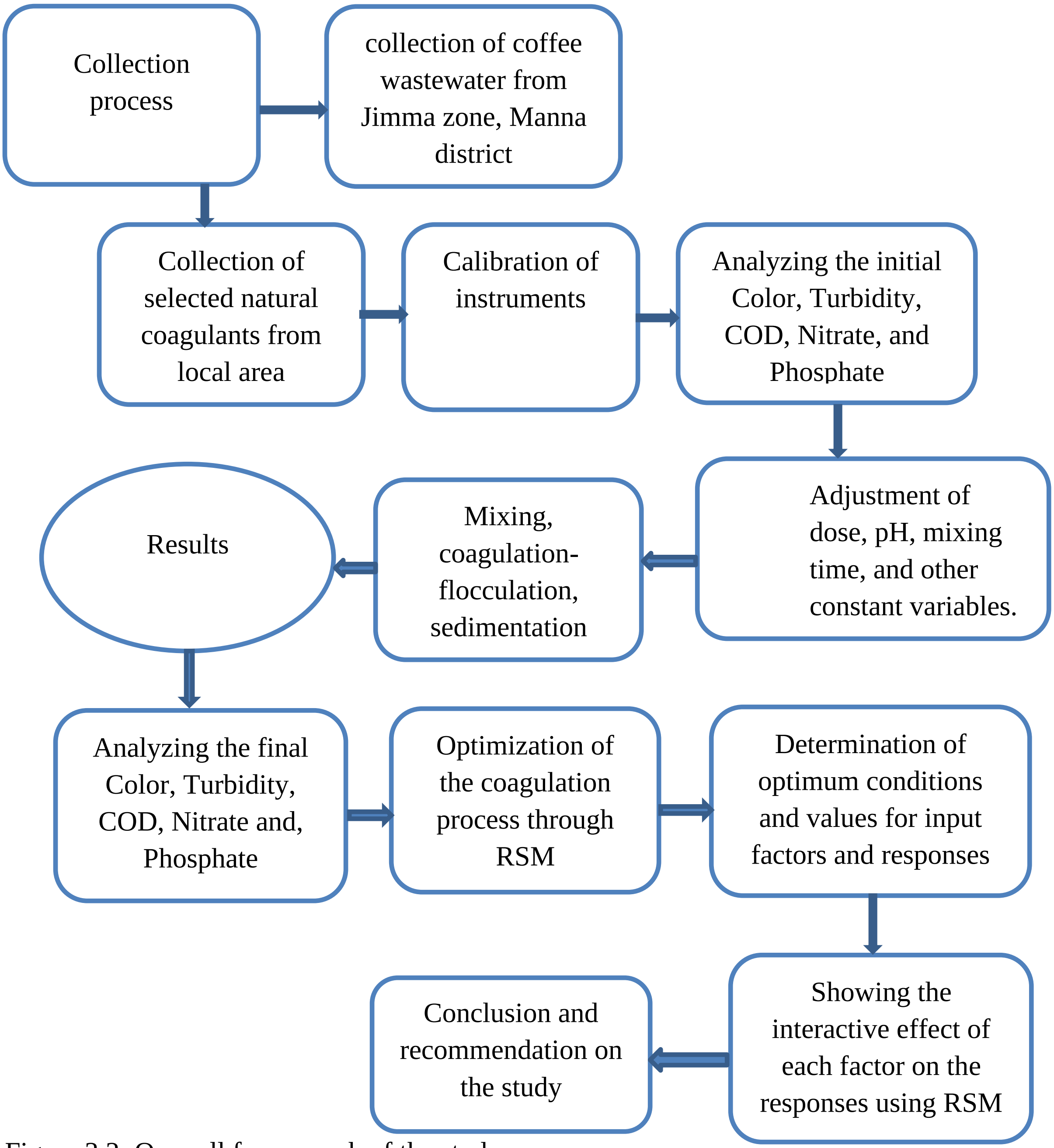


Figure 3.2: Over all frame work of the study

3.4 Study period

The study conducted from February 2021 to July 2021. This duration includes all works starting from material, and sample collection, experimental sample test, experimental result analysis and writing up of thesis

3.5 Study variables

3.5.1 Dependent variables of this research

- Percentage removal efficiency of natural coagulants on specified operating parameters (Color, turbidity, COD, nitrate, and phosphate removal)

- Process optimization using RSM

3.5.2 Independent variables of this research

- Operating parameters such as:
  - pH
  - Dosage
  - Agitation time
  - Agitation speed

3.6 Analysis of parameters

3.6.1 PH Measurements

The pH measurement of the samples carried out using the pH meter (model-pH3310). The wastewater sample was investigated directly before the treatment, and H_2SO_4 & Na (OH) used to adjust a pH during the experiment by varying the value 3, 7 and 11 to see the effect on the responses. But before starting the experiment pH meter was calibrated using three buffer solutions (pH = 3, pH = 7 and pH = 11). After calibration of the pH meter, the pH value reading conducted.

3.6.2 Turbidity removal efficiency determination

The primary purpose of the coagulation/flocculation process is the removal of turbidity from the wastewater. The cloudiness of waters is referred to as turbidity and has its origin from particles suspended in the water. Turbidity measures the extent of light is either absorbed or scattered by suspended material in water. Turbidity measurements conducted using a digital Nephelo turbidity meter, HANNA Instrument (HI-93703). By calibrating this apparatus with distilled water then the raw coffee wastewater sample and coagulated water measured for turbidity determination. The values were determined when the display is stable in NTU. The turbidity removal percentage calculated as a function on the initial turbidity (T_i) and residual turbidity of the sample (T_f), according to Eq. (3.1):

$$Percentage\ turbidity\ removal = \frac{T_i - T_f}{T_i} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3.1$$

Where, T_i = initial turbidity before treatment, T_f = final turbidity after TT

3.6.3 Color removal efficiency determination

The color of the untreated and treated samples was measured at a maximum wavelength of 450 nm using a UV; Spectrophotometer (model-6700). From this, the higher absorbance reading indicates, the more the presence of color in water. The percentage color removal calculated by the equation (3.2):

$$Percentage\ color\ removal = \frac{Absi\ - Abst}{Absi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3.2$$

Where, Abs_i = initial color absorbance before TT, Abs_f = final absorbance after TT

3.6.4 Chemical oxygen demand (COD) removal efficiency determination

The COD concentration was measured by using the COD reactor (HACH- type). The dichromate method is the American Public Health Association (APHA) standard method for determining COD using potassium dichromate. The amount of dichromate; determined by direct titration using Ferrous Ammonium Sulfate (FAS) as the titrant and ferroin (1, 10 phenanthroline ferrous sulfate) as the indicator. During the titration, the titrant ($Fe^{2+)}$ reacts instantly with hexavalent chromium (Cr^{6+}) to form trivalent chromium (Cr^{3+}) and ferric ion (Fe^{3+}), which shown below

$$3Fe^{2+}+Cr^{6+} \rightarrow 3Fe^{3+}+Cr^{3+} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

The COD value determined by using the dichromate; closed reflux method strictly following the APHA. The organic matter present in the sample gets oxidized completely by K_2Cr2O_7 in the presence of H_2SO_4 to produce CO_2 and H_2O. The excess $K_2Cr_2O_7$ remaining after the reaction titrated with ferrous ammonium sulfate (FAS). The Dichromate consumed gives the O_2 required for oxidation of the organic matter. Procedures that will be used for COD determination are: To a 0.05 gram of mercuric sulphate, 2.5 ml sample, add 1.5 ml of $K_2Cr_2O_7$ reagent and 3.5 ml of H_2SO4 reagent carefully, employ a hot blank (distilled water is taken instead of the sample), reflux the mixture on a hot plate for two hours, cool the mixture to room temperature and titrate the excess dichromate; with ferrous ammonium sulfate (0.1 M) using ferroin indicator. The end result is a dramatic color shift from blue–green to reddish-brown, however the blue–green color may return within minutes. Repeat the same procedure for the blank solution (Distilled water).

$$COD\ (\frac{mg}{L}) = \frac{V_{blank}\ - V_{sample} * N * 8 * 1000}{V_{sample\ taken}} (\frac{mg}{L}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where,

V_{Blank} - Volume of FAS used for blank solution N – Normality of FAS

V_{Sample}- Volume of FAS used for the sample solution

The percentage removal of COD in the effluent calculated using the equation.

$$Percentage\ COD\ removal \quad = \frac{COD_o\ - COD_f}{COD_o} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3.5$$

Where, COD_0 and COD_f in (mg/L) are the Chemical Oxygen Demand at raw sample (before being coagulated) or before reaction and after coagulant dosage (after being coagulated) or after reaction, respectively

3.6.5 Nitrate removal efficiency determination

Phenoldisulfonic Acid Method

- The absorbance was measured at 410 nm against a blank made up of the same quantities of reagents used in the samples.
- A calibration curve Constructed in the range 0-2 mg/L NO_3 – N by adding 0, 0.2, 0.5, 1.0, 3.0, 5.0, and 10 mL of standard nitrate solution to separate evaporating dishes and treating them in the same way as the sample.
- The μg of NO_3- N Determined in the sample by referencing the calibration curve.
- Calculation:

$$\frac{mg}{L} NO_3 = \frac{\mu g\ NO_3 - N\ X\ 4.427}{mL\ sample} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

3.6.6 Phosphate removal determination

Stannous Chloride Method

- A calibration curve was Constructed in the range 0-30 Phosphate (PO_4^{3-}) μg/100 mL by adding 0, 0.2, 0.5, 1.0, 3.0, 5.0-, and 6-mL Standard Phosphate Solution. mL to separate evaporating dishes and treating them in the same way as the sample.
- 0.05 ml 1 drop of phenolphthalein indicator solution added to the sample to check if the sample turns pink, and the strong acid solution added dropwise until the color discharged.
- With a measuring pipette, 4 mL acid- molybdate solution added to each of the standards, and sample.
- They were mixed thoroughly by inverting each flask four to six times.
- With a medicine dropper, 0.5 mL (10 drops) of stannous chloride solution added to each standard and sample.
- Stoppered and mixed by inverting each flask four to six times
- After 10 minutes, but before 12 minutes, the color photometrically at 690 nm measured using distilled water as blank.
- A calibration curve was Constructed using the standards and determine the amount of phosphate in μg present in the sample.
- Calculation

Calculation

$$\frac{mg}{L} PO_4^{3-} = \frac{\mu g\ phosphate}{Ml\ of\ sample} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

3.7 Experimental design and data presentation

Response Surface Methodology (RSM) is an optimization approach consisting of experimental design, analysis, and modeling of the experimental variables through partial regression fighting(Wang *et al.*, 2011). It can combine several variables at a time and demonstrate reciprocal interaction on the performance of a method. It also decreases the number of experimental runs required to provide adequate information for statistically appropriate outcomes (Betiku and Adesina, 2013). The central composite design (CCD) and the Box-Behnken design are the two most common designs used in RSM (BBD). CCD with RSM was adopted in the current study to optimize experimental parameters such as different operating parameters such as current density, follow rate, and effluent concentration on COD removal and power consumption(Asaithambi and Matheswaran, 2016). Face-center experimental plan implemented as a CCD. A CCD made face-centered by choosing $\alpha = 1$. Face-center is having the star points at the face of the cube portion on the design. The choice of face-centered CCD made considering that it is an option in the CCD design and due to the cumbersome nature of the design. Also, face-centered option ensures that the axial runs were not any more extreme than the factorial portion the independent variables selected for this study were pH (A), coagulant dosage (B), stirring speed (C), and stirring time (D). A total of 27 experiments conducted for each response. Mathematically, Eq. (3.8) is used to determine the total number of runs performed. The total number of experiments, N with k factors is: $N = 2^k + 2k + n$…………………eq (3.8) where k is the number of factors and n is the center points. According to equation 3.8, 27 experimental runs were required for each four coagulants total runs of 108 conducted.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Physiochemical Characterization of raw wet coffee Effluent

Table 4.1 shows the results of the experimental analysis conducted to determine the initial physiochemical character of the coffee wastewater samples. As shown in Appendix A, the collected samples were red and dark-brown in color, and the measuring average result was 3 Abs, indicating that they were highly colored. The pH of the effluent was found to be 4.75 on average. This suggested that the coffee industry's effluent is more acidic in nature. The average results for turbidity and COD were 145 NTU and 7603.2 mg/l, respectively, indicating that the water was highly turbid and had greater levels of organic and inorganic matters. Furthermore, the effluent sample's experimental result showed an average nitrate concentration of 20.21 mg/l. Finally, the average phosphate concentration was 9.10 mg/l. As a result, according to (Alemayehu and Rani, 2008), reports based on WHO (1995) guidelines, all values for initial characterization of untreated coffee wastewater sample are above permissible limits. The preliminary physiochemical characteristics of average untreated coffee effluent wastewater sample were summarized under Table 4.1.

Table 4.1:physiochemical Characteristics of Manna district raw coffee wastewater

Characteristics	Unit	Value	WHO (1995) permissible limits for irrigation
PH	_	4.75	6.5-8-5
Temperature	^{o}C	26.89	20
Color	Abs	3.00	Clear
Turbidity	NTU	145	5-10
COD	mg/l	7603.2	300
Nitrate	mg/L	20.21	5
Phosphate	mg/L	9.10	5

4.2. Effect of individual design parameters on the removal efficiency

Design parameters such as pH, coagulant dosage, stirring speed, and time all affected the coagulation and flocculation process. Their impact was most noticeable on coagulant efficiency, each response, and each other, as the increment or decrement of one parameter influences the other. Based on this, they may have a positive or negative impact on removal efficiency. As a result, the color, turbidity, COD, NO_3 , and PO_4^{3-} efficiency of the selected natural coagulants depended on the input factors throughout the coagulation and flocculation process.

4.2.1. pH

The pH of the sample water was 4.75, but it was adjusted in three ranges for this experimental study: 3.0, 7.0, and 11.0 to test the coagulant's efficiency in acidic, neutral, and alkaline conditions. As shown in figure 4.1, the experimental results show that pH affects the removal efficiency of selected natural coagulants on color, turbidity, COD, NO_3 ,and PO_4^{3-}. As a result, as the alkalinity of the sample increases, the coagulant effectiveness increases up to pH 7 and decreases slightly from pH 7-11. However, it is almost ineffective at pH 3 in acidic conditions. The removal capacity has gradually declined as pH decrease beyond three, and as pH approaches acidic, it is proved to decrease the solubility of selected natural coagulant. Because, as pH decreased beyond the optimum positive charges of selected coagulant surface increased significantly. Consequently, the contribution charge neutralization roles of the coagulant to destabilize the particles become less (Yang *et al.*, 2010). Moreover, at pH 7 the result showed that flocs produced by selected natural coagulant were rapid and caused a large flocs formation, which was necessary for the easiness of the settlement. Generally, it is vital to optimize pH value in coagulation-flocculation process to maximize removal efficiency.

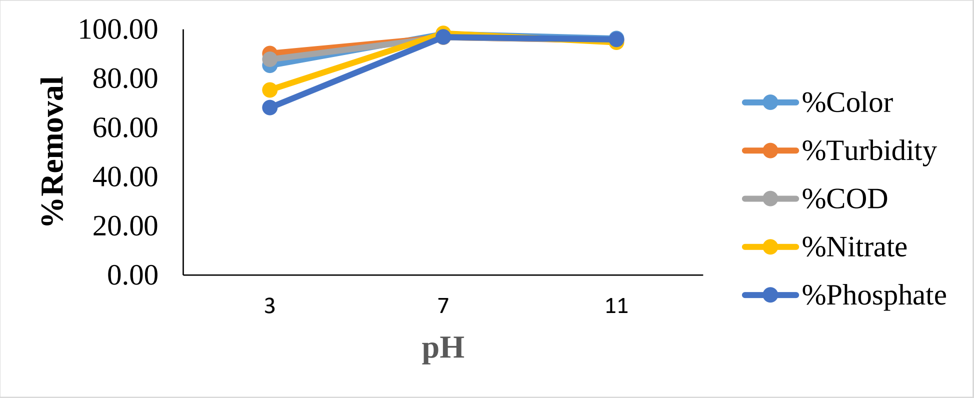


Figure 4.1: pH effect on removal efficiency using AS

Figure 4.1 shows, pH affects the removal efficiency of wet acanthus sennii stem on Color, Turbidity, nitrate, and phosphate. Hence, as the alkalinity of the sample increase, the coagulant effectiveness is increases. But it is almost noneffective at pH 3 in acidic conditions, and it is more effective at pH 7 and slightly declines up to pH 11.

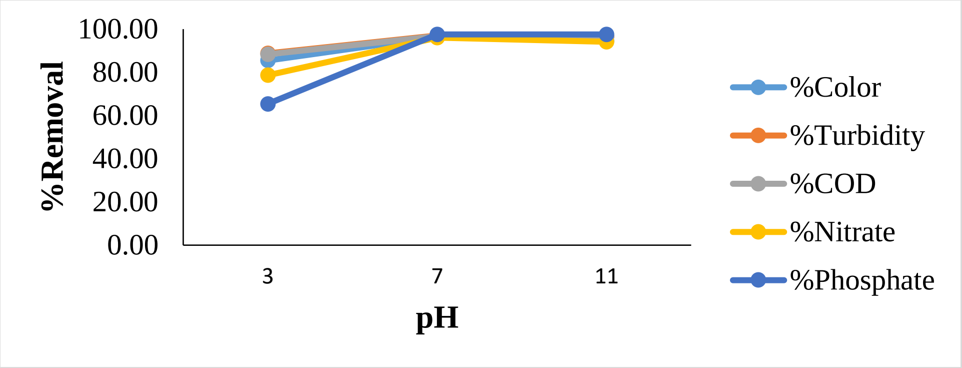


Figure 4. 2: pH effect on removal efficiency using moringa powder

As shown in figure 4.2, the use of aloe vera gel in the coagulation CPEWW treatment process affects removal efficiency. In this case, as the alkalinity of the water sample increases, so does the effectiveness of this coagulant; it is most effective at neutral and basic conditions and fails at acidic conditions, particularly for COD, nitrate, and phosphate removal. This maybe as pH decreased beyond the optimum positive charges of moringa surface increased significantly. Consequently, the contribution charge neutralization roles of the coagulant to destabilize the particles become less.

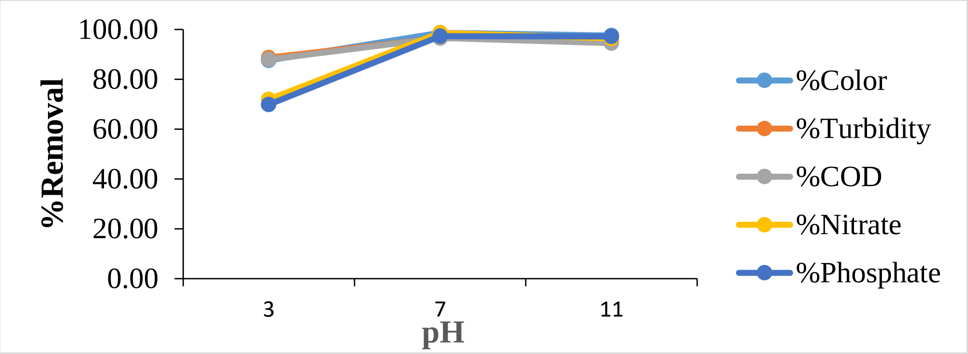


Figure4.3: pH effect on removal efficiency using aloe vera

As shown in figure 4.3, usage of aloe vera gel for coagulation CPWW treatment process affects the removal efficiency of the process. In this case, as the alkalinity of the water sample increase the effectiveness of this coagulant also increase, it is best in removal efficiency at neutral and basic conditions and fails at acidic condition.

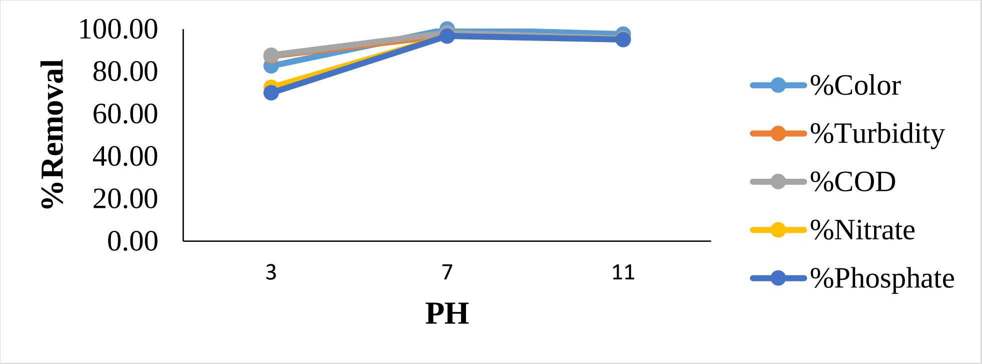


Figure 4.4: pH effect on removal efficiency using blended form coagulant

figure 4.4 shows, usage of blended form for coagulation CPEWW treatment process also affects the removal efficiency of the process. Hence as the alkalinity of the water sample increases, the effectiveness of a blended coagulant also increases; it, is best in removal efficiency at neutral and basic conditions.

4.2.2. Coagulant dosage

Coagulant dose is one of the most critical parameters to consider when determining the performance of coagulants in coagulation and flocculation. Essentially, insufficient dosage or overdosing would result in poor process performance(Rao, 2015). As a result, it is critical to determine the optimum dose to reduce dosing costs and sludge formation while also achieving peak performance in the treatment process. Experiments conducted to test the effects of coagulant doses ranging from 0.75 to 1.75g. As a result, there was continuous removal of Color, Turbidity, COD, $NO_3,$ and $PO_4^{3-}$with increases in coagulant doses up to 1.25g and then a decrease from 1.25-1.75g because the removal rate of Color, Turbidity, COD, nitrate, and phosphate was low when the amount of dose was less than 1.75g because the amount of coagulant was insufficient to destabilize the particles. However, when the coagulant dose is more than 1.25g, the aggregated particles redistribute and disturb particle settling due to the excess amount of the coagulant added. As each experimental run demonstrated, when the dosage increased, the sample water became turbid and colorful.

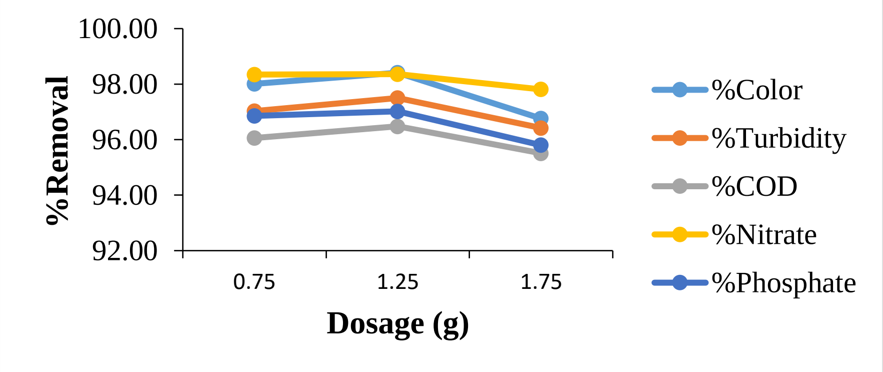


Figure 4. 5: AS dosage effect on the removal efficiency

Figure 4.5 shows, the coagulant dosage has a significant effect on the removal efficiency of Color, Turbidity, COD, $NO_{3,}$ and PO_4^{3-}, coagulant dosage has a significant effect on its removal efficiency. As each experimental run show, when dosage increase, the sample water was being turbid and colorful in the case of AS dosage; this, maybe because, Color of the AS plant and due to the active site of the coagulant. Therefore, dosage should optimize to keep the range of best removal efficiency for coagulant dosage and reduce cost. According to (Camacho *et al.*, 2017), the optimum dosage of coagulant is defined as a value above which there is no significant increase in removal efficiency with further addition of the coagulant.

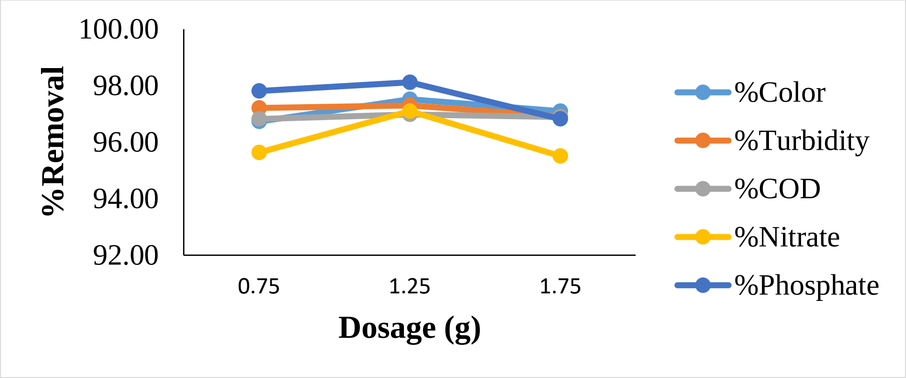


Figure 4.6: Moringa powder dosage effect on removal efficiency

According to each experiment, increasing the dosage of moringa powder results in an increase in water clarity, but increasing the further dosage results in a decrease in water quality. This maybe because when overdosing occurs, the water takes on the Color of moringa powder, turning white and cloudy, and becoming turbid, as well as producing more sludge. Figure 4.6 shows that removal efficiency increases when coagulant dosage is 0.75g-175g, but it decreases after 1.25g – 1.75g for Color, Turbidity, nitrate, and phosphate removal.

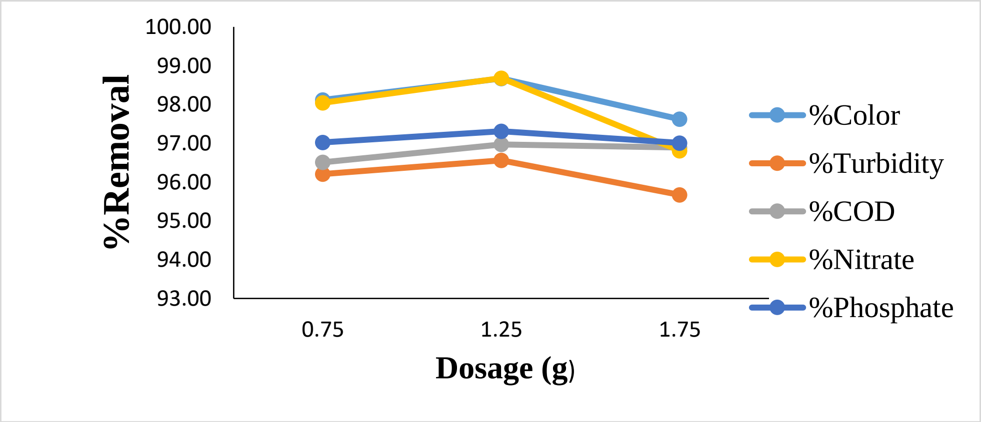


Figure 4.7: Aloe vera dosage effect on the removal efficiency

AS shown in figure 4.7, coagulant dosage also has a significant effect when aloe vera gel used as a coagulant for CPEWW. In case the removal efficiency increases in the interval of 0.75g-1.25 and it declines from 1.25g-1.75g.

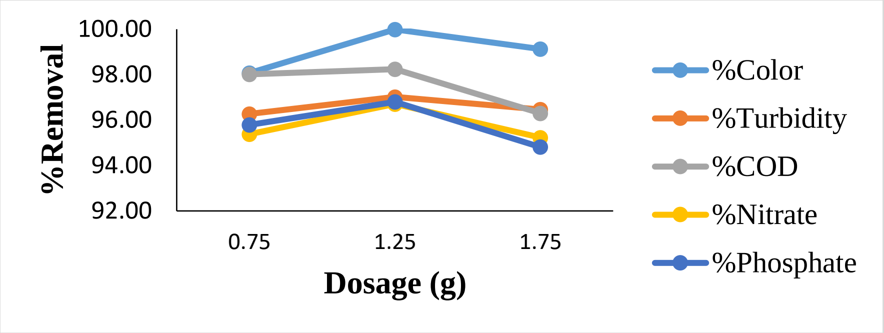


Figure 4.8: Blended dosage effect on the removal efficiency

Figure 4.8 also shows that the removal efficiency increases when the dosage is between 0.75g and 1.75g and slightly decreases when the dosage is more than 1.25g.

4.2.3. Stirring time

The Time of macro floc formation (flocculation time) is an essential operating parameter in any water treatment plant that performs coagulation–flocculation operations. Figure 4.9, depicts the effect of flocculation time on the removal of Color, Turbidity, COD, nitrate, and phosphate by varying the time from 15 to 45 minutes while holding other parameters constant the experimental result shows that there was a continuous removal of Color, Turbidity, COD, $NO_{3,}$ and PO_4^{3-}, while increasing the mixing time from 15to 30 minutes. Collisions between coagulants and colloids are ineffective at precipitating suspended solids in wastewater when the mixing Time is short (30 minutes). On the other hand, a longer mixing Time (>30 minutes) increases flocs breakage, and limits the size of the floc formed, resulting in a decrease in removal efficiency. It is critical to optimize the mixing Time to improve the coagulation's removal performance.

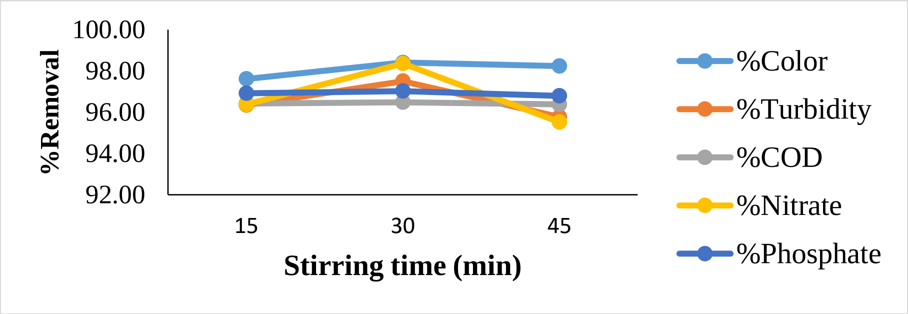


Figure 4.9: Stirring time effect on the removal efficiency using AS

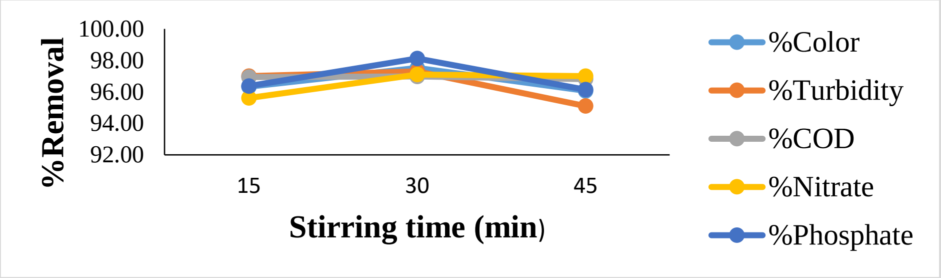


Figure 4.10: Stirring time effect on the removal of efficiency using moringa powder

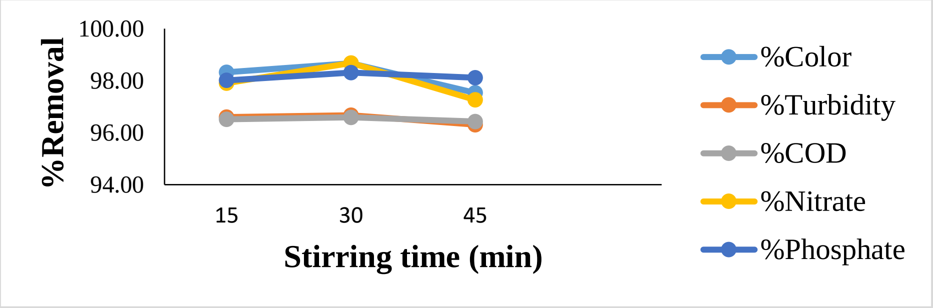


Figure 4.11: Stirring time effect on the removal efficiency using aloe vera

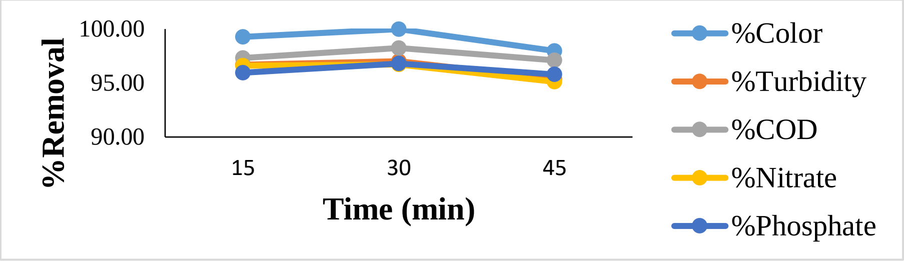


Figure 4.12: Stirring time effect on the removal efficiency using blended form coagulant

As shown in figure 4.9, 4.10, 4.11, and 4.12 the color, turbidity, nitrate, and phosphate removal efficiency of wet AS stem increased when the time is between 15-30 min. But its effectiveness slightly decreased when the time is above 30 min. For COD removal; it, is nearly constant within the selected time range. Normally, stirring time and speed highly interdependent in addition to other factors. Due to this for the experiments at high speed and long time the color, turbidity, COD, $NO_3,$ and PO_4^{3-}, of the sample was increase since colloidal particles breakdown again. Therefore, it requires more settling time for floc formation, agglomeration, and sedimentation. Therefore, it is of great importance to optimize the mixing Time to increase the removal performance of the coagulation.

4.2.4. Stirring speed

Stirring speed, according to the experimental details of this study, is critical in the coagulation and flocculation water treatment processes. In addition to its effect on the responses, it has an attractive physical property on the suspended flocs throughout each experimental trial at the given speed range. So, because this study attempted to test the effects of stirring speed on the coagulation process at 40, 80, and 120 rpm, some suspended small size flocs were dispersed on the entire surface of the sample water in a beaker at 40 rpm, and sedimentation time taken at this slow stirring speed. However, when the stirrer rotated at 80 and 120 rpm, suspended small size flocs gathered at the center of the sample water surface, demonstrating the formation of agglomeration of those small size flocs that quickly and easily settled.

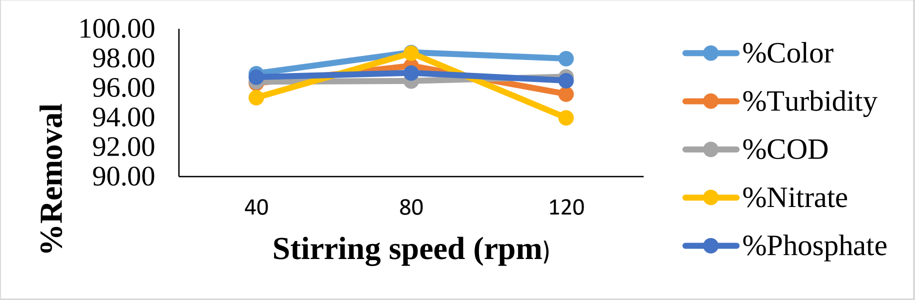


Figure 4.13: stirring speed effect on the removal efficiency using AS

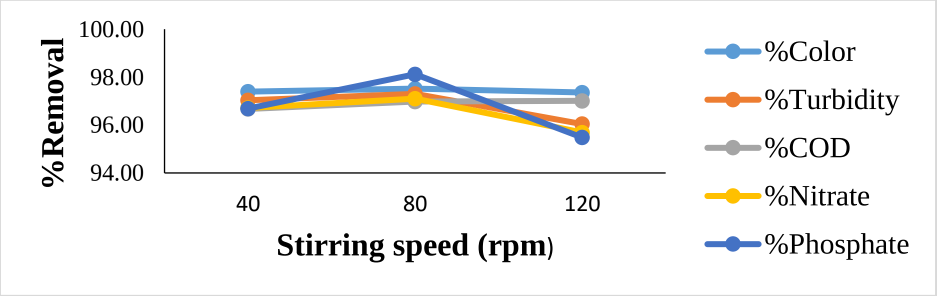


Figure4.14: Stirring speed effect on the removal efficiency using moringa

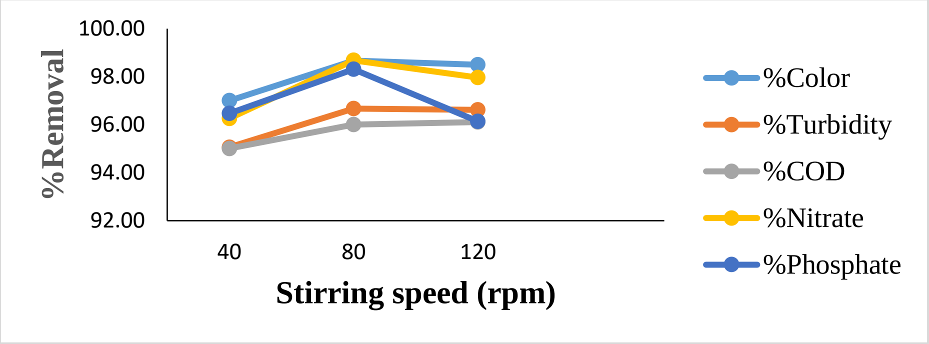


Figure 4.15: Stirring speed effect on the removal efficiency aloe vera

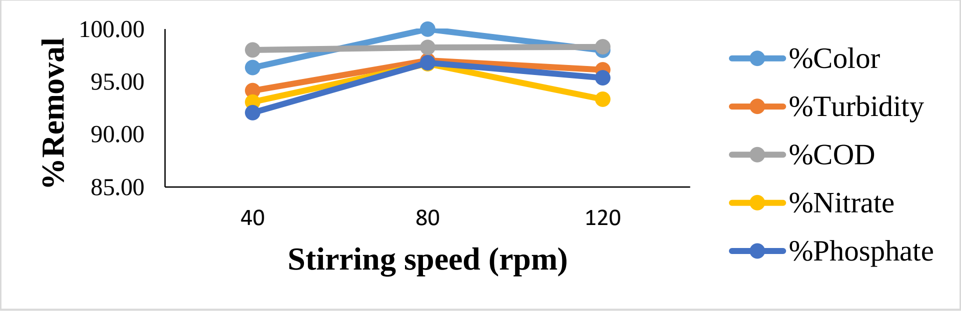


Figure 4.16: Stirring speed effect on the removal efficiency using a blended coagulant

In general, as shown in figures 4.14, 4.15, and 4.16 for moringa powder, aloe vera, and the blended form of the three coagulants, as the stirring speed increases, the process's removal efficiency on color, turbidity, nitrate, and phosphate increases between 40-80rpm and decreases when it greater than 80rpm. This, is due to the breakdown of the flocs and the re-dispersion of colloidal and suspended particles at high speed in Color, Turbidity, nitrate, and phosphate. Therefore, the optimum value is found to be 80 rpm. However, COD removal efficiency increases continuously in the selected ranges, which may be due to the oxidizer's rapid oxidation of organic pollutants.

4.2.5. Coagulant dosage effect on the sample water pH

According to the experimental results, when all coagulants (i.e., wet AS stem, Moringa powder, aloe vera, and a blended form of the three coagulants) applied at acidic conditions of the sample water, there was a slightly incremental effect on the final pH of the coagulated water when the dose increased from 0.75 to 1.75, the pH of the coagulated water also increased from 3 to approximately 3.65. However, when the dosage applied at neutral and basic conditions at the same dosage intervals, the pH of the final coagulated sample water was reduced or dropped from 7 to 6.12 and from 11 to 8.45, respectively. This, could be because, the pH of the coagulants contributes to the alkalinity of the sample water.

4.3. Statistical Analysis of the Experimental Results

As shown in Table 4.2 below, the levels are given based on the factorial design; is 2k factorial design. In a 2k factorial design, each control variable measured at two levels, which coded to take the values −1, 1, that correspond to the so-called low and high levels, respectively, of each variable. This design consists of all possible combinations of such levels of the k factors. All the data were analyzed using Design; expert® 11.1.0.2 software to decide the effects of operating parameters; coagulant dose, pH, and mixing Time. The dependent variable used as a response parameter was the percentage of removal. All experiments carried out in a randomized order to minimize unexpected variability in the observed response due to extraneous factors. The design model of the experiments is quadratic polynomial and the center point per block is five using Design; expert® 11 software.

In this study, the Color, Turbidity, COD, nitrate, and phosphate removal efficiency of wet AS stem, moringa powder for WCPEWW sample treatment were experimentally determined and statistically analyzed using central composite design;(CCD), part of response surface methodology (RSM). Analysis of variances (ANOVA) was used for graphical analyses of the data to obtain the interaction between the process variables and the responses. The quality of the fit quadratic model expressed by the coefficient of determination, R^2, and its statistical significance was checked by the *F*-test. Model terms were selected or rejected based on the *P*-value (probability) with a 95% confidence level. Three-dimensional (3D) surface plots were obtained based on the effects of the levels of four factors.

Table 4.2: Experimental and levels of the independent variables

Factor	Name	Units	Type	Minimum	Maximum	Coded Low	Coded High	Mean	Std. Dev.
A	coagulant dosage	G	Numeric	0.7500	1.75	-1 ↔ 0.75	+1 ↔ 1.75	1.25	0.4160
B	PH	-	Numeric	3.00	11.00	-1 ↔ 3.00	+1 ↔ 11.00	7.00	3.33
C	stirring speed	rpm	Numeric	40.00	120.00	-1 ↔ 40.00	+1 ↔ 120.00	80.00	33.28
D	stirring Time	minute	Numeric	15.00	45.00	-1 ↔ 15.00	+1 ↔ 45.00	30.00	12.48

Table 4-3:Design Summary of factorial designs

File Version	11.1.2.0		
Study Type	Response Surface	Subtype	Randomized
Design Type	Central Composite	Runs	27
Design Model	Quadratic	Blocks	No Blocks
Build time (ms)	2.00		

All physiochemical Characteristics of treated water including pH value, Experimental design matric and response based on the experimental run value for (AS, moringa, aloe vera, and blended) coagulant, and photographic representation during experiment provided under appendix A, B, C, D, E, F and G.

4.2. 1 Experimental variables effect for (%) of Color using AS

Table4. 4: Model Summary Statistics for (%) of Color using AS

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	3.85	0.6505	0.5870	0.5203	448.12	
2FI	4.49	0.6550	0.4394	-0.0690	998.67	
Quadratic	**0.5544**	**0.9961**	**0.9914**	**0.9785**	**20.09**	**Suggested**
Cubic	0.4963	0.9989	0.9931	0.9262	68.98	Aliased

As sown in table 4.4, the selected model, a quadratic model, suggested for further investigation. R^2 is the coefficient of determination that ensures the quality and performance of the quadratic model. The close relationship between adjusted and predicted R^2 also indicates the excellent performance of the model. The Predicted R^2 of 0.9785 is in reasonable agreement with the Adjusted R² of 0.9914; i.e., the difference is less than 0.2. The value of R² is also greater than 0.752, which fulfils the recommended value.

Table4.5: ANOVA for (%) of color using AS
**Response 1: color removal efficiency **

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	930.50	14	66.46	216.22	< 0.0001	Highly significant
A-coagulant dosage	1.89	1	1.89	6.14	0.0290	significant
B-PH	601.47	1	601.47	1956.69	< 0.0001	Highly significant
C-stirring speed	2.25	1	2.25	7.31	0.0192	significant
D-stirring time	2.12	1	2.12	6.90	0.0221	significant
AB	2.45	1	2.45	7.97	0.0154	significant
AC	1.28	1	1.28	4.15	0.0642	
AD	0.0025	1	0.0025	0.0081	0.9296	
BC	0.2116	1	0.2116	0.6884	0.4229	
BD	0.1936	1	0.1936	0.6298	0.4428	
CD	0.0552	1	0.0552	0.1797	0.6792	
A²	0.3384	1	0.3384	1.10	0.3147	
B²	125.02	1	125.02	406.72	< 0.0001	Highly significant
C²	0.1844	1	0.1844	0.5998	0.4536	
D²	0.0763	1	0.0763	0.2481	0.6274	
Residual	3.69	12	0.3074			
Lack of Fit	3.05	10	0.3047	0.9490	0.6156	not significant
Pure Error	0.6421	2	0.3210			
Cor Total	934.19	26				

From table (4.5), The Model F-value of 216.22 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, B² are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.95 implies the Lack of Fit is not significant relative to the pure error. There is a 61.56% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.2. Final equation in terms of coded factors for (%) of using AS

Color removal efficiency = 97.85-0.3239A+5.78B+0.3533C-0.3433D+0.3912AB+-‘0.2825AC+0.0125AD-0.1150BC+0.110BD-0.0588CD-0.3628A^2-6.97B^2-0.2678C^2+0.1722D^2………………………………………………………………… (4.1)

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients

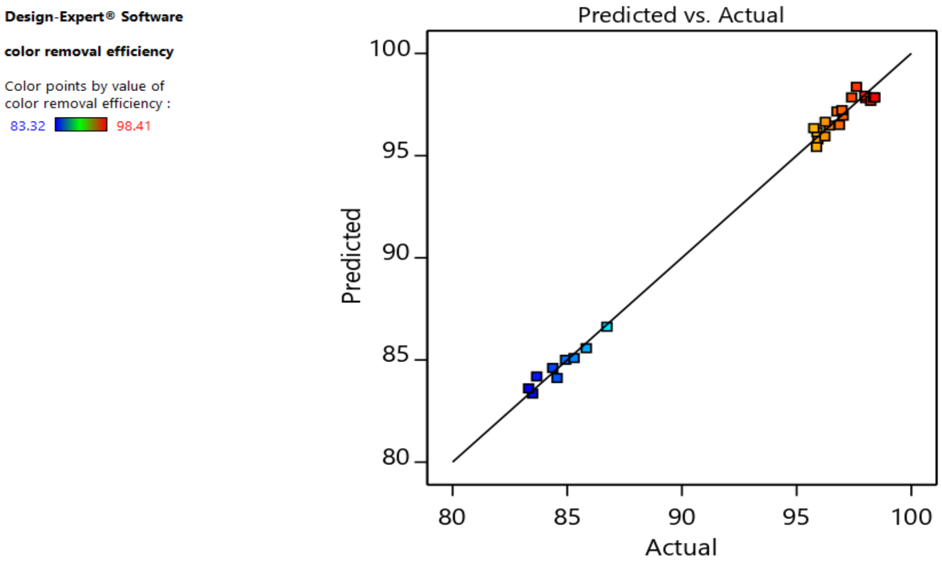


Figure4.17: Predicted versus actual value for color removal using AS stem

The performance of the model equation analyzed based on the adequacy, significance, the effects of the interacting operating parameters, and optimization for maximum efficiency. The predicted values from the model compared with the experimental values for color removal using wet AS also figure 4.17 shows that the model predictions match with the experimental values and the data points close to the diagonal line.

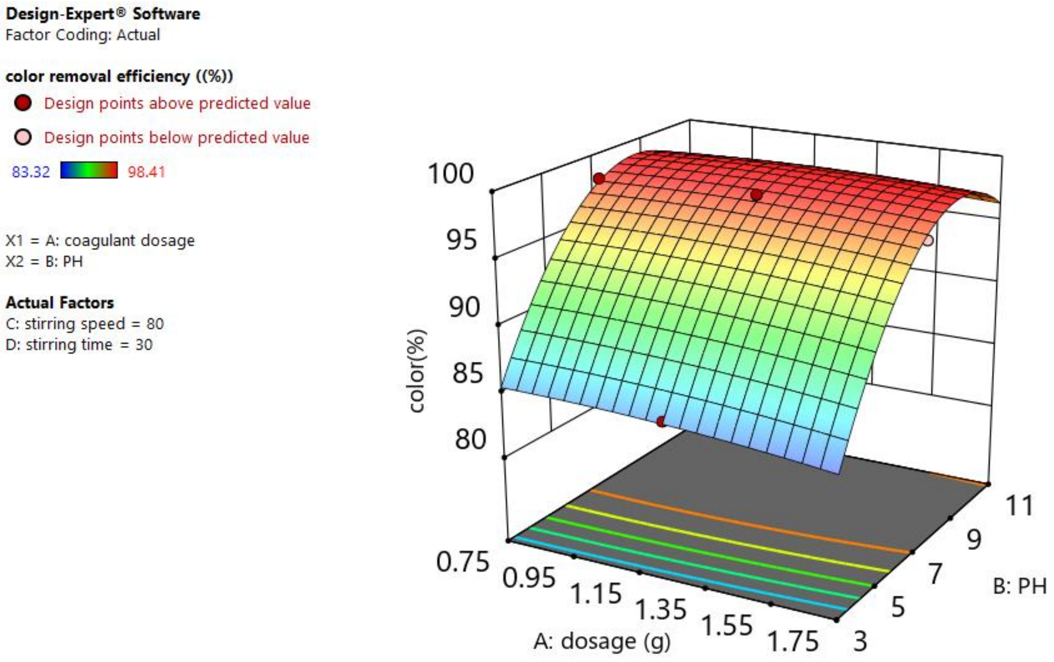


Figure 4.18: 3D plot of the interaction effect of dose and pH on (%) of color using AS

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.18. The percent of color removed using AS is affected by pH and coagulant dose.

As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

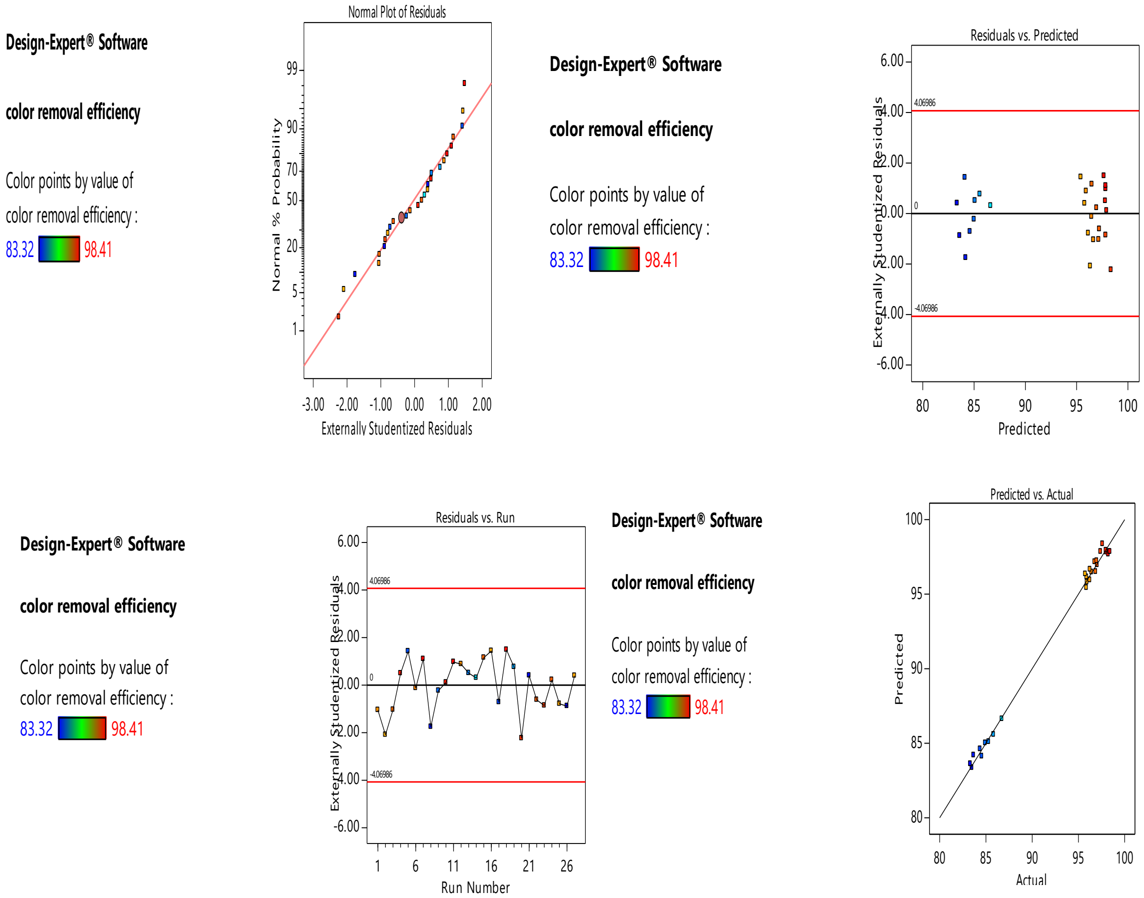


Figure 4. 19: Diagnostics graphs in terms of coded factors for (%) of Color using AS

The normal probability plot, as shown in figure 4.19 above, indicates that the residuals follow a normal distribution; in this experiment, the points in the plots fit to a straight line in the figure, indicating that the quadratic polynomial model satisfies the assumptions of analysis of variance (ANOVA), i.e., the error distribution is approximately normal. The residuals should be structureless if the model is correct and the assumptions are met; in particular, they should be unconnected to any other variable, including the expected response. Plotting the residuals against the fitted (predicted) values is a straightforward check. The assumption of constant variance is tested by plotting the residuals against the rising expected response values. The plot shows random scatter which justifying no need for an alteration to minimize personal error.

4.3.4. Experimental variables effect for (%) of turbidity using AS

Table 4. 6:Model Summary Statistics for (%) using AS

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.27	0.6533	0.5903	0.5212	156.22	
2FI	2.63	0.6608	0.4488	-0.0782	351.78	
Quadratic	**0.4621**	**0.9921**	**0.9830**	**0.9702**	**9.72**	**Suggested**
Cubic	0.4982	0.9970	0.9802	0.9326	22.01	Aliased

Table 4.6, shows that the model summary statistics from the ANOVA result show that the selected model, the quadratic model, has been suggested for further study. The Predicted R^2 of 0.9702 is in reasonable agreement with the Adjusted R^2 of 0.9830; i.e., the difference is less than 0.2. The value of R^2 is also greater than 0.752, which fulfils the recommended value.

Table 4.7: ANOVA for (%) of Turbidity
Response 2: turbidity removal efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	323.72	14	23.12	108.30	< 0.0001	Highly Significant
A-coagulant dosage	1.71	1	1.71	8.02	0.0151	significance
B-PH	207.94	1	207.94	974.00	< 0.0001	Highly Significant
C-stirring speed	1.02	1	1.02	4.79	0.0491	significance
D-stirring time	2.49	1	2.49	11.68	0.0051	significance
AB	0.8556	1	0.8556	4.01	0.0684	
AC	0.0650	1	0.0650	0.3046	0.5912	
AD	0.2256	1	0.2256	1.06	0.3242	
BC	0.0009	1	0.0009	0.0042	0.9493	
BD	0.9409	1	0.9409	4.41	0.0576	
CD	0.3364	1	0.3364	1.58	0.2333	
A^2	0.1259	1	0.1259	0.5898	0.4573	
B^2	35.08	1	35.08	164.33	< 0.0001	Highly Significant
C^2	0.7742	1	0.7742	3.63	0.0811	
D^2	0.5062	1	0.5062	2.37	0.1495	
Residual	2.56	12	0.2135			
Lack of Fit	1.69	10	0.1695	0.3909	0.8733	not significant
Pure Error	0.8672	2	0.4336			
Cor Total	326.28	26				

The Model F-value of 108.30 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.39 implies the Lack of Fit is not significant relative to the pure error. There is an 87.33% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.5. Final equation in terms of coded factors for (%) of turbidity using AS

Turbidity removal efficiency $=96.58-0.3083A+3.40B-0.2383C-0.3722D+0.2312AB-0.0638AC-0.118AD-0.0075BC+0.2425BD-1450CD+0.2213A^2-3.69B^2-0.5487C^2-0.4437D^2$…………………………………………………………………… ……...(4.2)

Where, A= coagulant dosage(g/L), B = PH, C = stirring time (minute) and D = stirring speed(rpm).

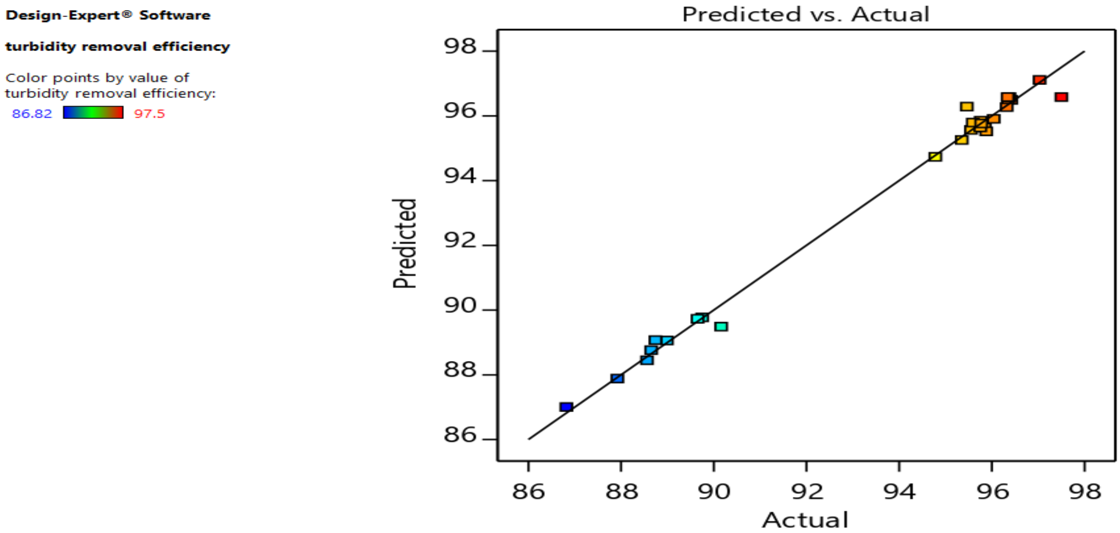


Figure 4. 20: Predicted versus the actual value of response turbidity for AS treatment

As shown in figure 4.20 predicted verses actual value of turbidity removal using AS stem. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

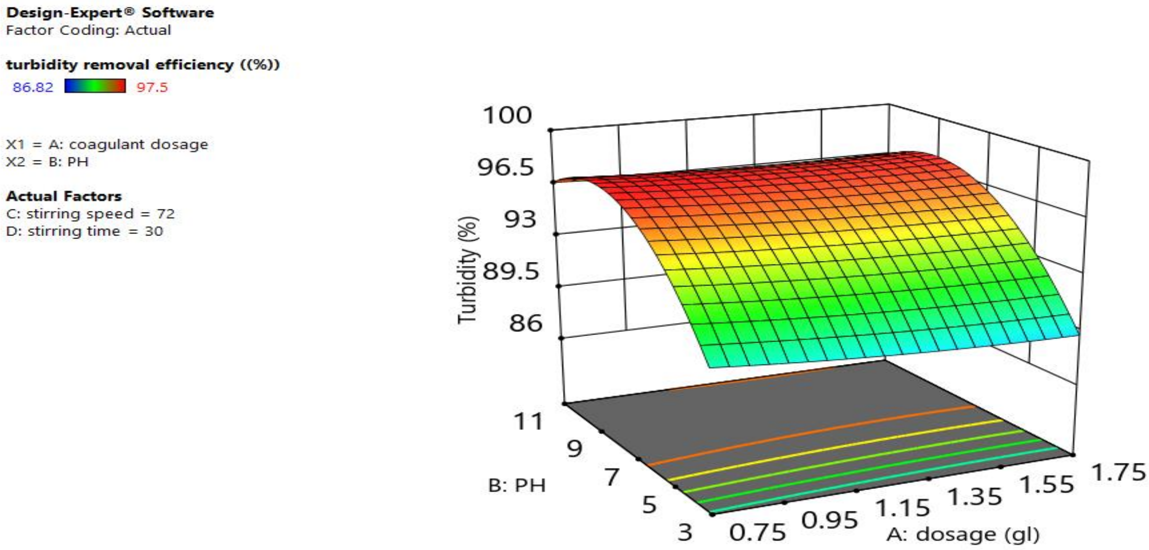


Figure 4.21: 3D plot of the interaction effect of dose and pH on (%) of Turbidity

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.21. The percent of turbidity removed using AS is affected by pH and coagulant dose. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.6. Experimental variables effect for (%) of COD using wet AS

Table 4.8: Model Summary Statistics for (%) of COD using AS

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.45	0.6729	0.6134	0.5562	178.69	
2FI	2.86	0.6758	0.4731	0.0327	389.47	
Quadratic	**0.4035**	**0.9951**	**0.9895**	**0.9785**	**8.64**	**Suggested**
Cubic	0.5529	0.9970	0.9803	0.7176	113.71	Aliased

Table 4.8 shows that, the model summary statistics of ANOVA result show that the quadratic is best for further investigation than the selected model. The Predicted R^2 of 0.9785 is in reasonable agreement with the Adjusted R^2 of 0.9895; i.e., the difference is less than 0.2.

Table 4.9: ANOVA for (%) of COD using AS
Response 3: COD removal efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	400.67	14	28.62	175.78	< 0.0001	Highly significant
A-coagulant dosage	1.50	1	1.50	9.19	0.0104	significant
B-PH	267.58	1	267.58	1643.42	< 0.0001	Highly significant
C-stirring speed	0.8364	1	0.8364	5.14	0.0427	significant
D-stirring time	1.02	1	1.02	6.25	0.0279	significant
AB	0.0001	1	0.0001	0.0006	0.9806	
AC	0.9604	1	0.9604	5.90	0.0318	significant
AD	0.0756	1	0.0756	0.4645	0.5085	
BC	0.0380	1	0.0380	0.2335	0.6376	
BD	0.0484	1	0.0484	0.2973	0.5956	
CD	0.0289	1	0.0289	0.1775	0.6810	
A^2	0.5911	1	0.5911	3.63	0.0810	
B^2	54.52	1	54.52	334.84	< 0.0001	Highly significant
C^2	0.2725	1	0.2725	1.67	0.2201	
D^2	0.0473	1	0.0473	0.2902	0.5999	
Residual	1.95	12	0.1628			
Lack of Fit	1.38	10	0.1376	0.4768	0.8265	not significant
Pure Error	0.5774	2	0.2887			
Cor Total	402.62	26				

The Model F-value of 175.78 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AC, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.48 implies the Lack of Fit is not significant relative to the pure error. There is an 82.65% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.7. Final equation in terms of coded factors for (%) of COD using AS

COD removal efficiency =96.43-02883A+3.86B+0.2156C-0.2378D+0.0025AB+0.0487BC-0.0550BD-0.0425CD-0.4794A2-4.60B2+0.3256C^2+0.1356D^2…………………………. ……………………………….(4.3)

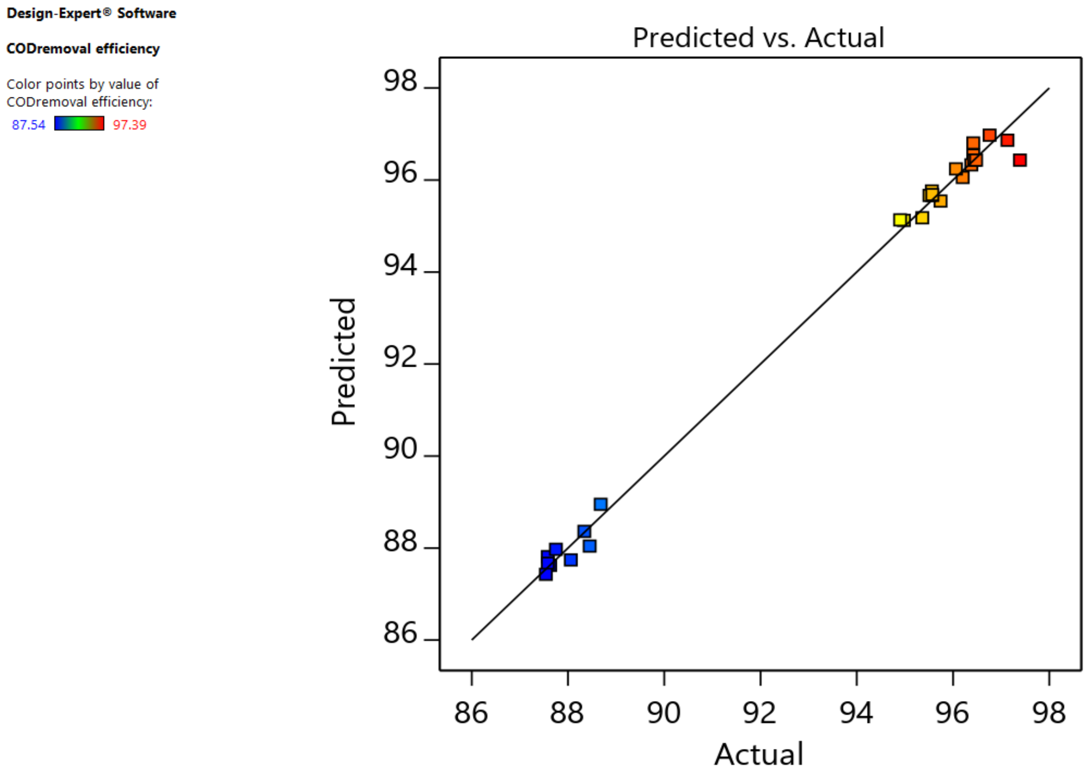


Figure 4. 22: Predicted versus actual value for COD removal using acanthus AS

As shown in figure 4.22, predicted versus the actual value of COD removal using AS stem. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

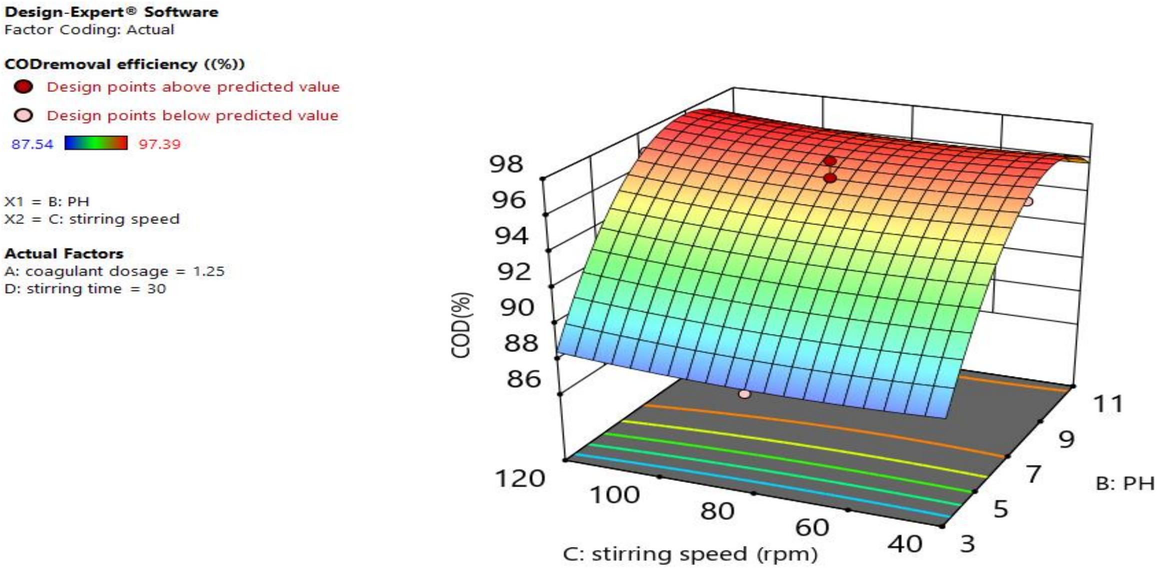


Figure 4. 23: 3D plot of the interaction effect of dose and pH on (%) of COD using AS

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.23. The percent of COD removed sing AS is affected by pH and coagulant dose. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.8 ANOVA for response surface quadratic model for (%) of nitrate using AS

Table 4.10: Model Summary Statistics for (%) of nitrate using AS

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	7.19	0.5920	0.5178	0.4222	1608.98	
2FI	7.97	0.6353	0.4074	-0.1467	3193.02	
Quadratic	**1.54**	**0.9897**	**0.9777**	**0.9347**	**181.95**	**Suggested**
Cubic	1.17	0.9980	0.9872	0.6846	878.27	Aliased

Table 4.10 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table4.11: ANOVA for (%) of nitrate using AS
**Response 4: Nitrate removal efficiency **

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2755.88	14	196.85	82.61	< 0.0001	Highly significant
A-coagulant dosage	12.02	1	12.02	5.04	0.0443	significant
B-PH	1602.91	1	1602.91	672.66	< 0.0001	Highly significant
C-stirring speed	13.18	1	13.18	5.53	0.0366	significant
D-stirring time	20.18	1	20.18	8.47	0.0131	significant

AB	83.72	1	83.72	35.13	< 0.0001	Highly significant
AC	8.32	1	8.32	3.49	0.0862	
AD	10.79	1	10.79	4.53	0.0547	
BC	9.24	1	9.24	3.88	0.0724	
BD	8.18	1	8.18	3.43	0.0887	
CD	0.4830	1	0.4830	0.2027	0.6606	
A^2	4.66	1	4.66	1.96	0.1871	
B^2	353.10	1	353.10	148.18	< 0.0001	Highly significant
C^2	11.00	1	11.00	4.62	0.0528	
D^2	1.56	1	1.56	0.6534	0.4346	
Residual	28.60	12	2.38			
Lack of Fit	27.92	10	2.79	8.29	0.1123	not significant
Pure Error	0.6734	2	0.3367			
Cor Total	2784.47	26				

The Model F-value of 82.61 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 8.29 implies the Lack of Fit is not significant relative to the pure error. There is an 11.23% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.9. Final equation in terms of coded factors for (%) of nitrate using AS

Nitrate removal efficiency $=97.160+0.8172A+9.44B+0.8556C-1.06D-2.29AB+0.722AC-0.8213AD-0.7600BC+0.7150BD-0.1738CD+1.35A^{2}-11.72B2-2.07C^{2}-0.7781D^{2}$……………………………………………………………………………(4.4)

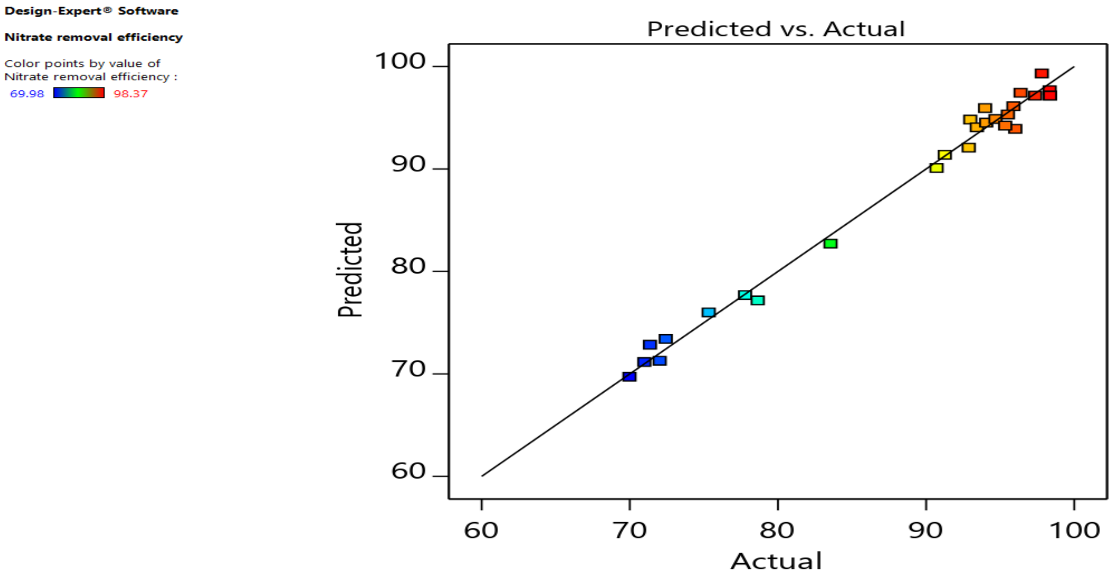


Figure 4. 24: Predicted versus actual values of response color for AS stem

As shown in figure 4.24 From the plot, as shown above, the normal probability plot indicates the residuals following a normal distribution. In the case of this experiment, the points in the plots shows fit a straight line in the figure; this, shows that the quadratic polynomial model satisfies the analysis of the assumptions variance (ANOVA) ,i.e.the error distribution is approximately normal

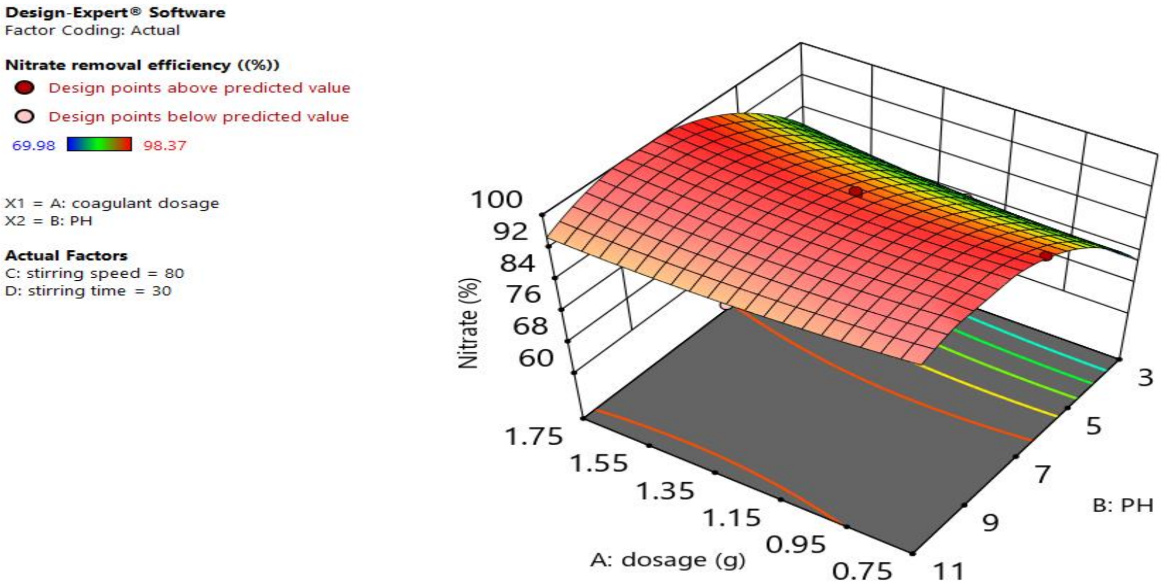


Figure 4. 25: 3D plot of the interaction effect of dose and pH on (%) of nitrate using AS

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.25. The percent of nitrate removed by AS is affected by pH and coagulant dose. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.10 ANOVA for response surface quadratic model for phosphate removal

Table 4.12: Model Summary Statistics for (%) of phosphate using AS

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	7.83	0.7203	0.6695	0.6166	1846.97	
2FI	9.12	0.7236	0.5508	0.1533	4078.81	
Quadratic	**1.08**	**0.9971**	**0.9937**	**0.9804**	**94.42**	**Suggested**
Cubic	0.4838	0.9998	0.9987	0.9903	46.87	Aliased

Table 4.12 shows that the quadratic model type has been suggested for further study based on the model summary statistics from the ANOVA results. Furthermore, because the difference between the adjusted R^2 and the predicted R^2 is less than 0.2, there is a good agreement. The value of R^2 is also greater than 0.752, which fulfils the recommended value.

Table 4.13: ANOVA for (%) of phosphate using AS

Response 5: phosphate removal efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4803.13	14	343.08	292.95	< 0.0001	Highly significant
A-coagulant dosage	8.61	1	8.61	7.35	0.0189	significant
B-PH	3446.99	1	3446.99	2943.28	< 0.0001	Highly significant

C-stirring speed	6.54	1	6.54	5.58	0.0358	significant
D-stirring time	7.72	1	7.72	6.59	0.0246	significant
AB	0.1073	1	0.1073	0.0916	0.7674	
AC	0.4193	1	0.4193	0.3580	0.5607	
AD	1.01	1	1.01	0.8581	0.3725	
BC	5.35	1	5.35	4.57	0.0539	
BD	7.17	1	7.17	6.12	0.0293	
CD	1.59	1	1.59	1.36	0.2660	
A^2	0.2728	1	0.2728	0.2330	0.6380	
B^2	556.09	1	556.09	474.83	< 0.0001	Highly significant
C^2	0.0033	1	0.0033	0.0028	0.9586	
D^2	0.0970	1	0.0970	0.0829	0.7784	
Residual	14.05	12	1.17			
Lack of Fit	13.38	10	1.34	3.96	0.2185	not significant
Pure Error	0.6761	2	0.3380			
Cor Total	4817.19	26				

The Model F-value of 292.95 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, BD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 3.96 implies the Lack of Fit is not significant relative to the pure error. There is a 21.85% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.11. Final equation in terms of coded factors for (%) of phosphate using AS

Phosphate removal efficiency = 96.76+0.697A+13.84B-0.6028C+0.6550D-0.0819AB+0.1619AC-0.2506AD+0.5781BC-0.6694BD-0.3156CD-0.3257A2-14.71B^2-0.0357C^2+0.1943D^2………………………………………………………………. (4.5)

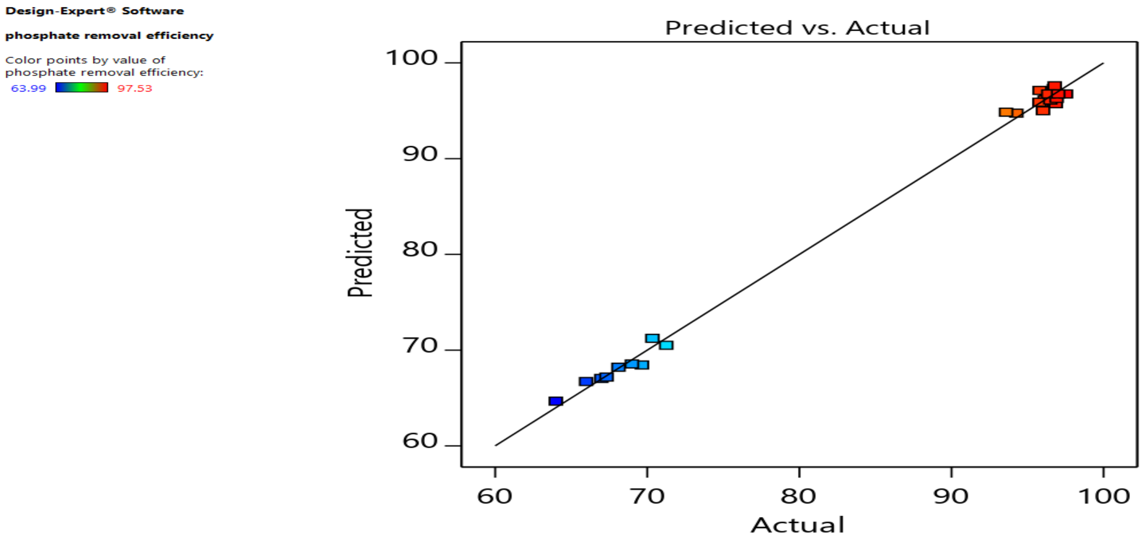


Figure 4.26 Predicted versus actual values of response color for AS

As shown in figure 4.26 predicted versus the actual value of phosphate removal AS stem Hence, the points concentrated towards the diagonal line, about the mean indicate the is a close relation and agreement between the predicted and actual experimental value.

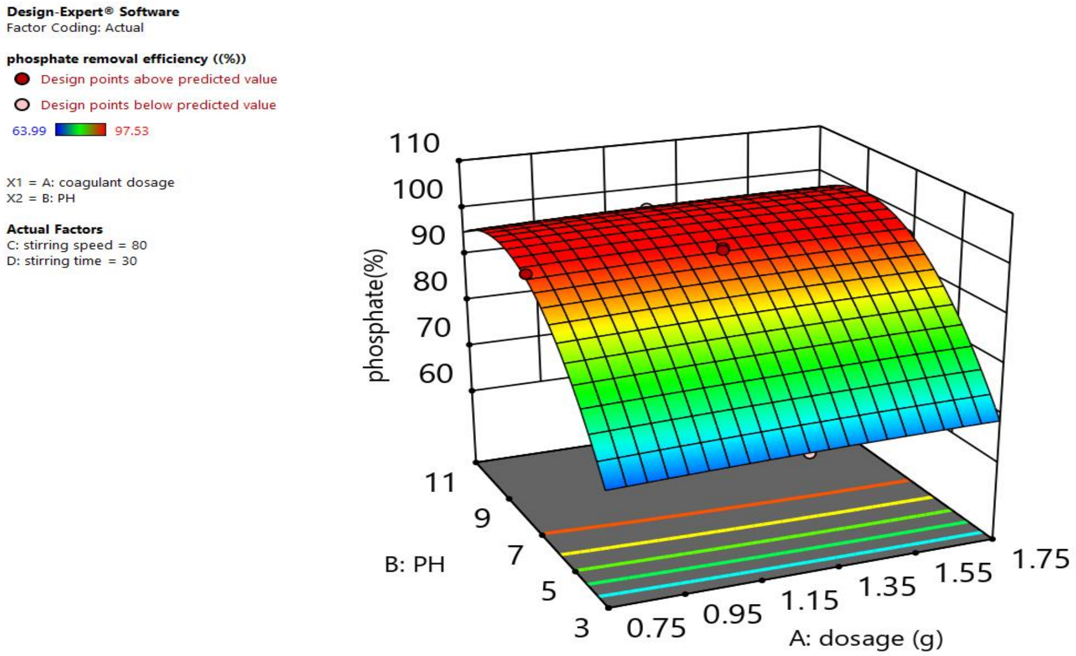
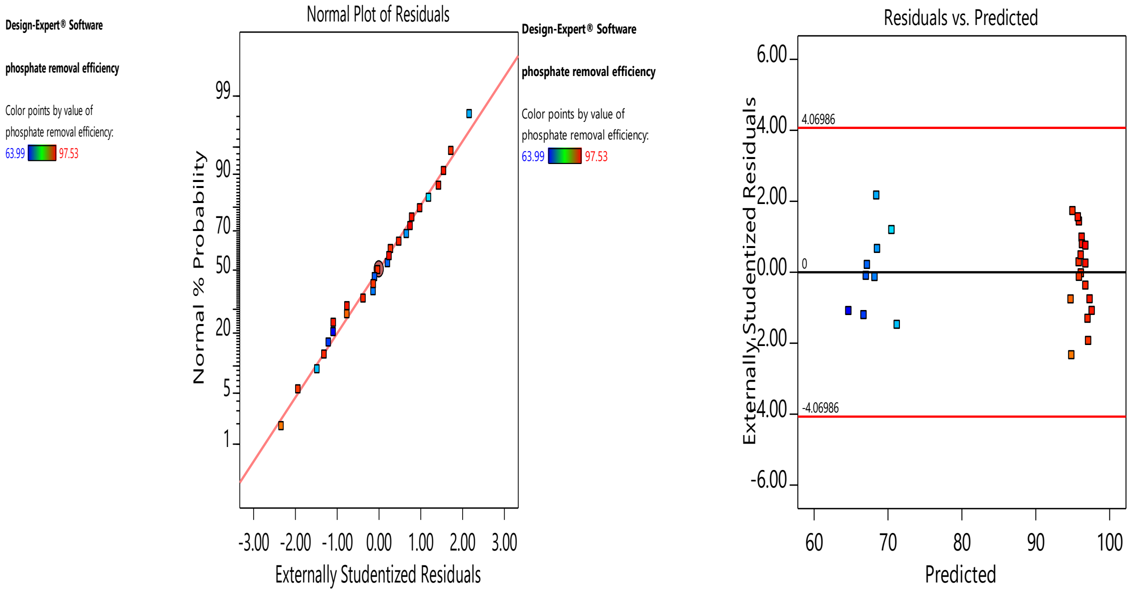


Figure 4. 27: 3D plot of the interaction effect of dose and pH on (%) of phosphate using AS

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.27. The percent of phosphate removed using AS is affected by pH and coagulant dose. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.



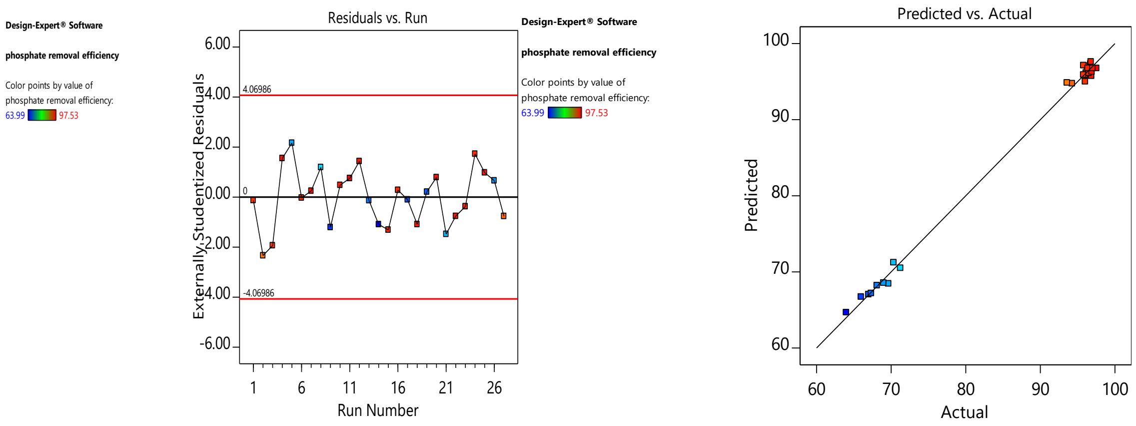


Figure 4.28: Diagnostics graphs in terms of coded factors for (%) of phosphate using AS

The normal probability plot, as shown in figure 4.28 above, indicates that the residuals follow a normal distribution; in this experiment, the points in the plots fit to a straight line in the figure, indicating that the quadratic polynomial model satisfies the assumptions of analysis of variance (ANOVA), i.e., the error distribution is approximately normal. The residuals should be structureless if the model is correct and the assumptions are met; in particular, they should be unconnected to any other variable, including the expected response. Plotting the residuals against the fitted (predicted) values is a straightforward check. The assumption of constant variance is tested by plotting the residuals against the rising expected response values. The plot shows random scatter which justifying no need for an alteration to minimize personal error.

4.3.12 Experimental variables effect for (%) of color using moringa

The coagulation and flocculation process using moringa powder also affects the Color, Turbidity, COD nitrate and phosphate removal efficiency as the operating parameters vary. In this case, the general trend of the process was the same with the AS stem.

Table4. 14: Model Summary Statistics for (%) of Color using Moringa

Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Linear	3.78	0.6354	0.5691	0.4777	450.11	
2FI	4.13	0.6832	0.4853	0.0116	851.82	
Quadratic	**1.19**	**0.9801**	**0.9570**	**0.8581**	**122.33**	**Suggested**
Cubic	1.17	0.9937	0.9590	-0.4009	1207.33	Aliased

Table 4.14shows that, the model summary statistics from ANOVA result show that quadratic model type has been suggested for further study. And also, since the difference between the adjusted R^2 and the predicted R^2 is less than 0.2, there is a good agreement, the model performance was good to predict the experimental data.

Table 4. 15: ANOVA for (%) of Color using Moringa
**Response 1: color removal efficiency **

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	844.71	14	60.34	42.29	< 0.0001	Highly significant
A-coagulant dosage	8.88	1	8.88	6.22	0.0282	significant
B-PH	522.61	1	522.61	366.31	< 0.0001	Highly significant
C-stirring speed	8.58	1	8.58	6.02	0.0304	significant
D-stirring time	7.50	1	7.50	5.26	0.0407	significant
AB	11.61	1	11.61	8.14	0.0145	significant
AC	0.3752	1	0.3752	0.2630	0.6174	
AD	2.86	1	2.86	2.01	0.1819	
BC	15.07	1	15.07	10.57	0.0070	
BD	10.38	1	10.38	7.28	0.0194	
CD	0.9555	1	0.9555	0.6697	0.4291	
A^2	0.0946	1	0.0946	0.0663	0.8011	
B^2	116.23	1	116.23	81.47	< 0.0001	Highly significant
C^2	1.11	1	1.11	0.7776	0.3952	
D^2	0.7173	1	0.7173	0.5028	0.4918	
Residual	17.12	12	1.43			
Lack of Fit	16.53	10	1.65	5.63	0.1600	not significant
Pure Error	0.5869	2	0.2934			
Cor Total	861.83	26				

The Model F-value of 42.29 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise**.** P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, BC, BD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 5.63 implies the Lack of Fit is not significant relative to the pure error. There is a 16.00% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.13. Final equation in terms of coded factors for (%) of color using moringa

Color removal efficiency =96.78-0.7022A+5.39B-0.6906C-0.6456D+0.8519AB-0.1531AC+0.4231AD+0.9706BC-0.8056BD+0.2444CD+0.1919A^2-6.72B^2+0.6569C^2-0.5281D^2………… ……………………………………………………………………(4.6)

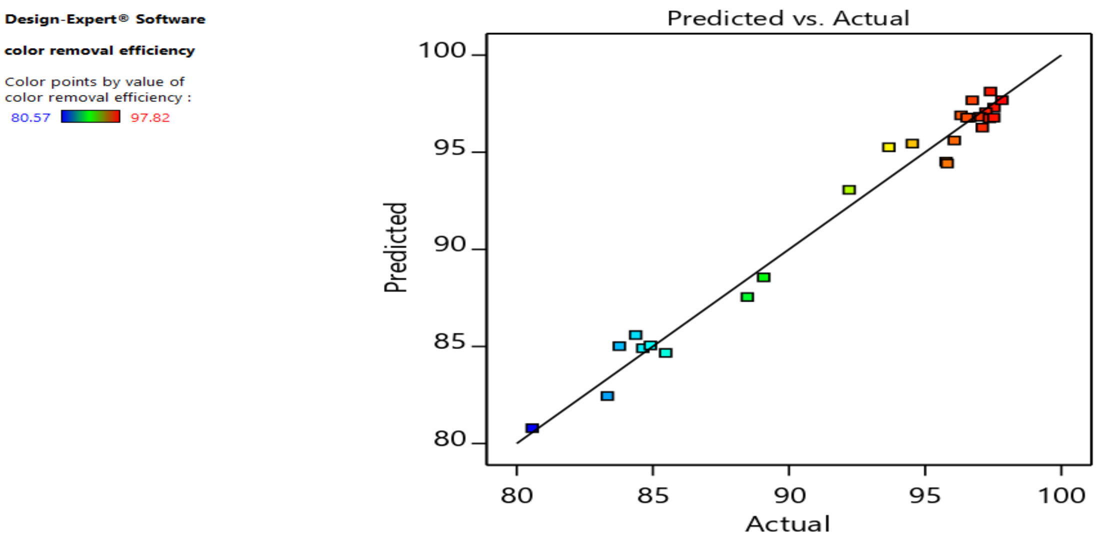


Figure 4. 29 Predicted versus actual values of response color for moringa

As shown in figure 4.29, predicted versus the actual value of color removal using moringa powder. Hence, the points scattered along the diagonal line about the mean indicate the is a close relation and agreement between the predicted and actual experimental value. But points those further away from the diagonal line indicate some disagreement between the predicted and actual value. General since most of the points close to the mean so there is a good agreement between the two values.

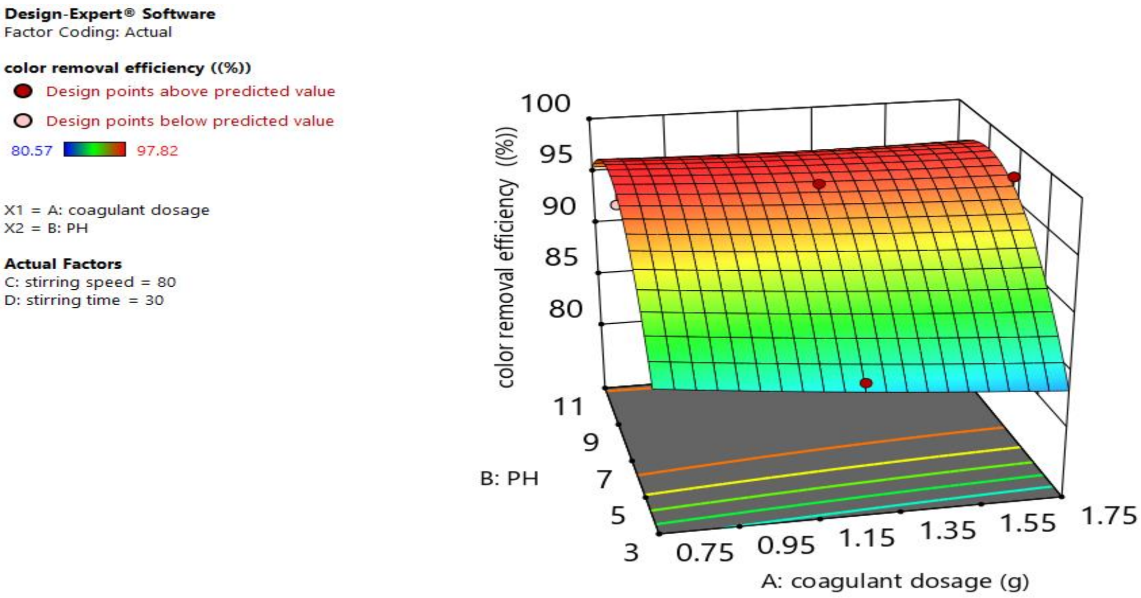


Figure 4. 30: 3D plot of the interaction effect of dose and pH on (%) of Color using Moringa

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.30. The percent of color removed using moringa is affected by pH and coagulant dose.

As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.14. Experimental variables effect for (%) of turbidity using moringa

Table 4.16:Model Summary Statistics for (%) of Turbidity using moringa

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.51	0.6621	0.6007	0.5278	194.02	
2FI	2.85	0.6845	0.4873	-0.0044	412.73	
Quadratic	**0.7355**	**0.9842**	**0.9658**	**0.8999**	**41.13**	**Suggested**
Cubic	0.7822	0.9940	0.9613	0.1247	359.67	Aliased

The model summary statistics of ANOVA results in table 4.16 show that the quadratic model is best for further investigation. Furthermore, the coefficient of determination, R^2, has a high value. As a result, because the higher R^2 indicates model quality and performance, the selected quadratic model to predict experimental turbidity value is best for further study.

Table 4.17: ANOVA for the (%) of Turbidity using Moringa
Response 2: turbidity removal efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	404.42	14	28.89	53.40	< 0.0001	Highly significant
A-coagulant dosage	2.86	1	2.86	5.29	0.0401	significant
B-PH	260.99	1	260.99	482.40	< 0.0001	Highly significant
C-stirring speed	3.87	1	3.87	7.16	0.0202	significant
D-stirring time	4.36	1	4.36	8.06	0.0149	significant
AB	1.28	1	1.28	2.36	0.1504	
AC	0.1482	1	0.1482	0.2740	0.6102	
AD	3.22	1	3.22	5.96	0.0311	significant
BC	0.7056	1	0.7056	1.30	0.2757	
BD	3.80	1	3.80	7.03	0.0211	
CD	0.0272	1	0.0272	0.0503	0.8263	
A^2	0.2549	1	0.2549	0.4711	0.5055	
B^2	43.34	1	43.34	80.10	< 0.0001	Highly significant
C^2	0.1136	1	0.1136	0.2100	0.6550	
D^2	1.24	1	1.24	2.30	0.1555	
Residual	6.49	12	0.5410			
Lack of Fit	5.93	10	0.5932	2.12	0.3633	not significant
Pure Error	0.5605	2	0.2802			
Cor Total	410.92	26				

The Model F-value of 53.40 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AD, BD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 2.12 implies the Lack of Fit is not significant relative to the pure error. There is a 36.33% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.15 Final equation in terms of coded factors for (%) of turbidity using moringa

Turbidity removal efficiency $=97-0.3989A+3.81B-0.4639C-0.4922D+0.2825AB-0.0963AC-0.4488AD+0.2100BC+0.4875BD+0.0412CD+0.3148A^2-4.11B^2-0.2102C^2-0.6592D^2$………………………………………………………………………… (4.7)

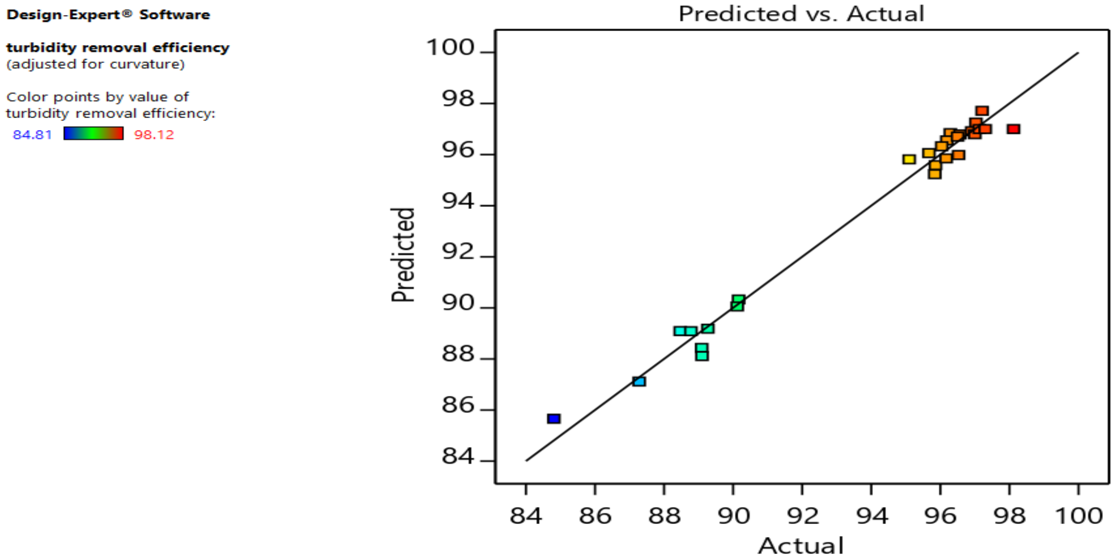


Figure 4.31: Predicted versus the actual value of response turbidity for moringa

As shown in figure 4.31 predicted versus the actual value of turbidity removal using moringa powder. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

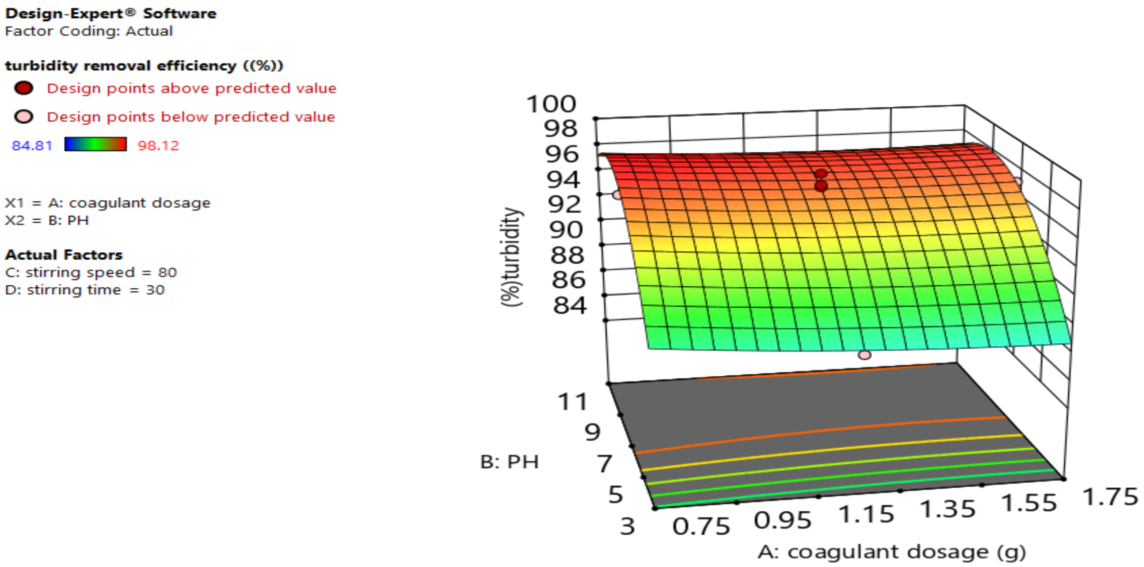


Figure 4.32: 3D plot of the interaction effect of dose and pH on (%) of Turbidity using Moringa

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure

4.32. The percent of turbidity removed using moringa is affected by pH and coagulant dose. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.16. Experimental variables effect for (%) of COD using moringa

Table 4.18:Model Summary Statistics for (%) of COD using moringa powder

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.48	0.6959	0.6406	0.5819	186.60	
2FI	2.91	0.6972	0.5080	0.0486	424.57	
Quadratic	**0.3370**	**0.9969**	**0.9934**	**0.9772**	**10.19**	**Suggested**
Cubic	0.3881	0.9987	0.9912	0.7189	125.44	Aliased

The model summary statistics of ANOVA results in table 4.18 show that the quadratic model is best for further investigation. The Predicted R^2 of 0.9772 is in reasonable agreement with the Adjusted R^2 of 0.9934; i.e., the difference is less than 0.2. As a result, because the higher R^2 indicates model quality and performance, the selected quadratic model to predict experimental value is best for further study.

Table 4.19: ANOVA for (%) of COD using moringa

Response 3: COD removal efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	444.91	14	31.78	279.84	< 0.0001	Highly significant
A-coagulant dosage	0.8149	1	0.8149	7.18	0.0201	significant
B-PH	308.10	1	308.10	2713.06	< 0.0001	Highly significant
C-stirring speed	0.8978	1	0.8978	7.91	0.0157	significant
D-stirring time	0.7280	1	0.7280	6.41	0.0263	significant
AB	0.0064	1	0.0064	0.0564	0.8164	
AC	0.2352	1	0.2352	2.07	0.1757	
AD	0.3136	1	0.3136	2.76	0.1224	
BC	0.0272	1	0.0272	0.2397	0.6332	
BD	0.0009	1	0.0009	0.0079	0.9305	
CD	0.0210	1	0.0210	0.1851	0.6746	
A^2	0.0272	1	0.0272	0.2392	0.6336	
B^2	52.37	1	52.37	461.14	< 0.0001	Highly significant
C^2	0.0357	1	0.0357	0.3141	0.5855	
D^2	0.0198	1	0.0198	0.1745	0.6835	
Residual	1.36	12	0.1136			
Lack of Fit	1.26	10	0.1264	2.57	0.3127	not significant
Pure Error	0.0985	2	0.0492			
Cor Total	446.27	26				

The Model F-value of 279.84 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 2.57 implies the Lack of Fit is not significant relative to the pure error. There is a 31.27% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.2.17. Final equation in terms of coded factors (%) of COD using moringa

COD removal efficiency $=96.98-0.2128A+4.14B+0.2233C-0.2011D-0.0200AB+0.1212AC-0.1400AD+0.0412BC-0.0075BD-0.0362CD-0.1028A^2-4.51B^2-0.1178C^2-0.0878D^2$…. ……………………………………………………………...(4.8)

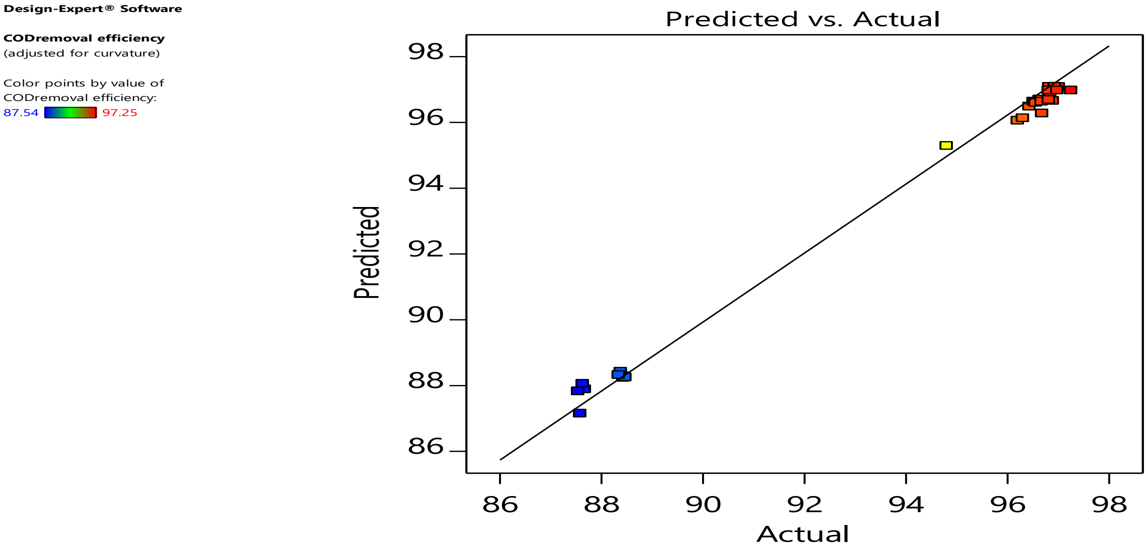


Figure4.33:Predicted versus the actual value of response COD for moringa

As shown in figure 4.33, predicted versus the actual value of COD removal using moringa powder. Hence, the points scattered along the diagonal line about the mean indicate the is a close relation and agreement between the predicted and actual experimental value.

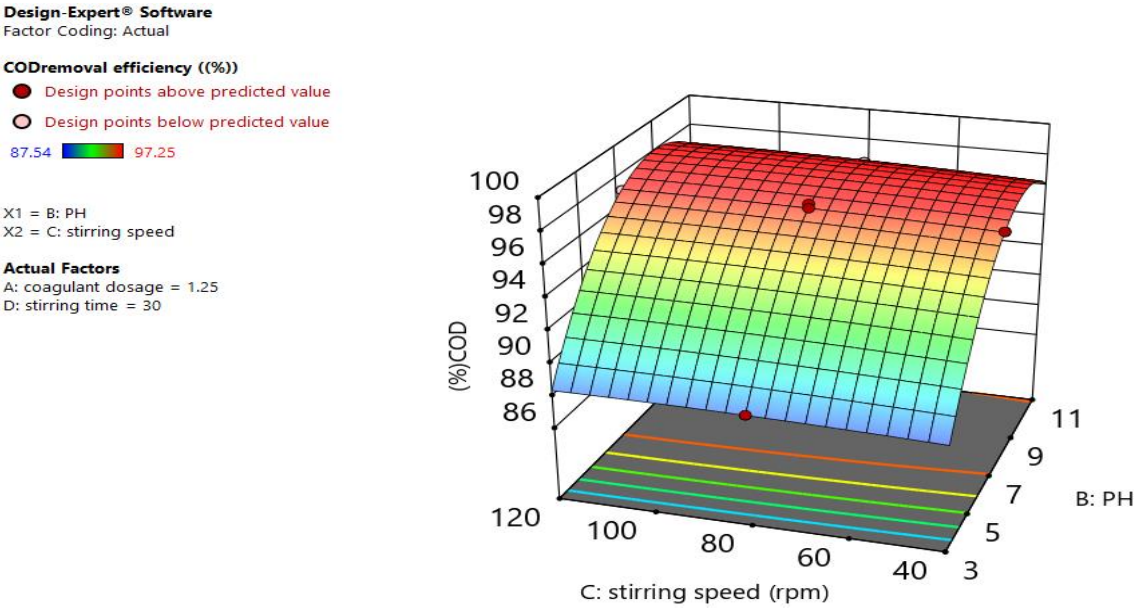


Figure 4. 34: 3D plot of the interaction effect of dose and pH on (%) COD using Moringa.

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure

4.34. The percent of COD removed using moringa is affected by pH and stirring speed. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.18 Experimental variables effect for (%) of nitrate using moringa

Table 4.20:Model Summary Statistics the (%) of nitrate using moringa powder

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	5.66	0.5843	0.5087	0.4147	990.72	
2FI	6.32	0.6219	0.3856	-0.1754	1989.48	
Quadratic	**1.57**	**0.9826**	**0.9623**	**0.8915**	**183.72**	**Suggested**
Cubic	0.9302	0.9980	0.9867	0.7884	358.13	Aliased

Table 4.20 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4.21: ANOVA for (%) of nitrate using moringa.
**Response 4: Nitrate removal efficiency **

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1663.12	14	118.79	48.40	< 0.0001	Highly significant
A-coagulant dosage	16.67	1	16.67	6.79	0.0230	significant
B-PH	944.97	1	944.97	385.00	< 0.0001	Highly significant
C-stirring speed	12.50	1	12.50	5.09	0.0435	significant
D-stirring time	14.83	1	14.83	6.04	0.0301	significant
AB	0.1296	1	0.1296	0.0528	0.8221	
AC	15.29	1	15.29	6.23	0.0281	significant
AD	15.84	1	15.84	6.45	0.0259	significant
BC	11.32	1	11.32	4.61	0.0528	
BD	4.73	1	4.73	1.93	0.1903	
CD	16.36	1	16.36	6.67	0.0240	significant
A^2	0.9075	1	0.9075	0.3697	0.5545	
B^2	247.17	1	247.17	100.70	< 0.0001	Highly significant
C^2	0.0033	1	0.0033	0.0014	0.9713	
D^2	0.0548	1	0.0548	0.0223	0.8837	
Residual	29.45	12	2.45			
Lack of Fit	27.96	10	2.80	3.75	0.2287	not significant
Pure Error	1.49	2	0.7452			
Cor Total	1692.57	26				

The Model F-value of 48.40 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AC, AD, CD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 3.75 implies the Lack of Fit is not significant relative to the pure error. There is a 22.87% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.19 Final equation in terms of coded factors for (%) of nitrate using moringa

Nitrate removal efficiency =96.45-0.9622A+7.25B+0.8333C-0.9078D-0.09000AB-0.9775AC+0.9950AD-0.8413BC+0.5437BD+1.01CD-0.5941A^2-9.8B^2+0.0359C^2+0.1459D^2………………………………………………………… (4.9)

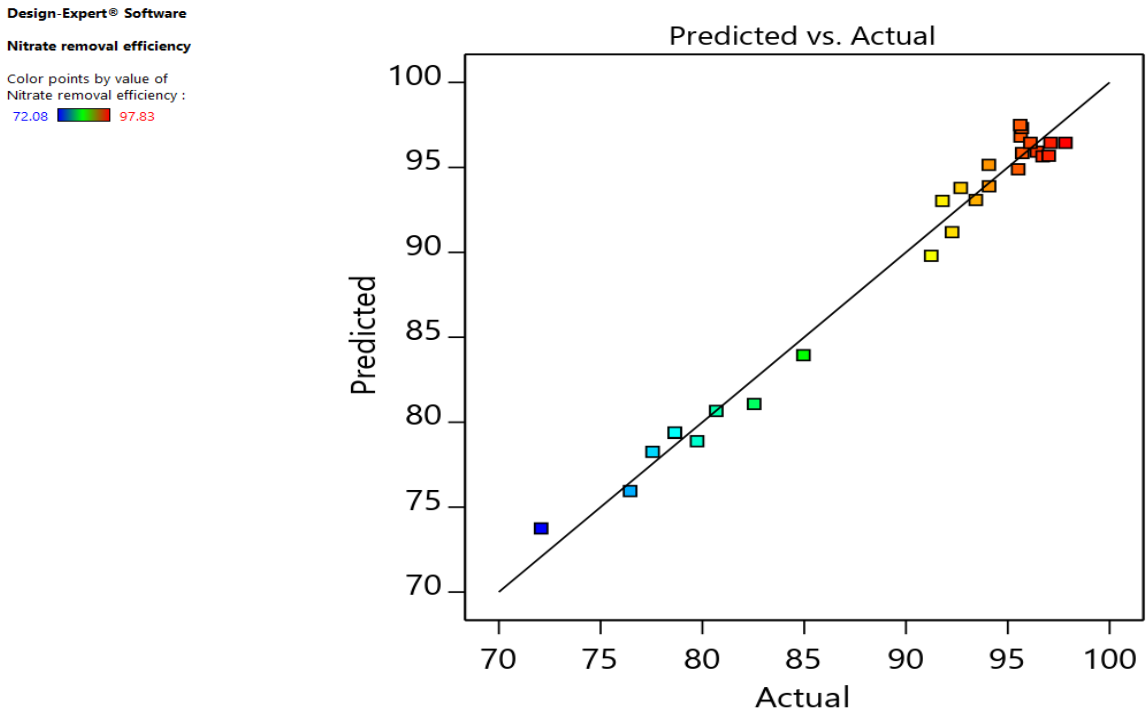


Figure 4. 35: Predicted versus the actual value of response nitrate for moringa

As shown in figure 4.35, predicted versus the actual value of nitrate removal using moringa powder. Hence, the points concentrated towards the diagonal line, about the mean indicate a close relation and agreement between the predicted and actual experimental value.

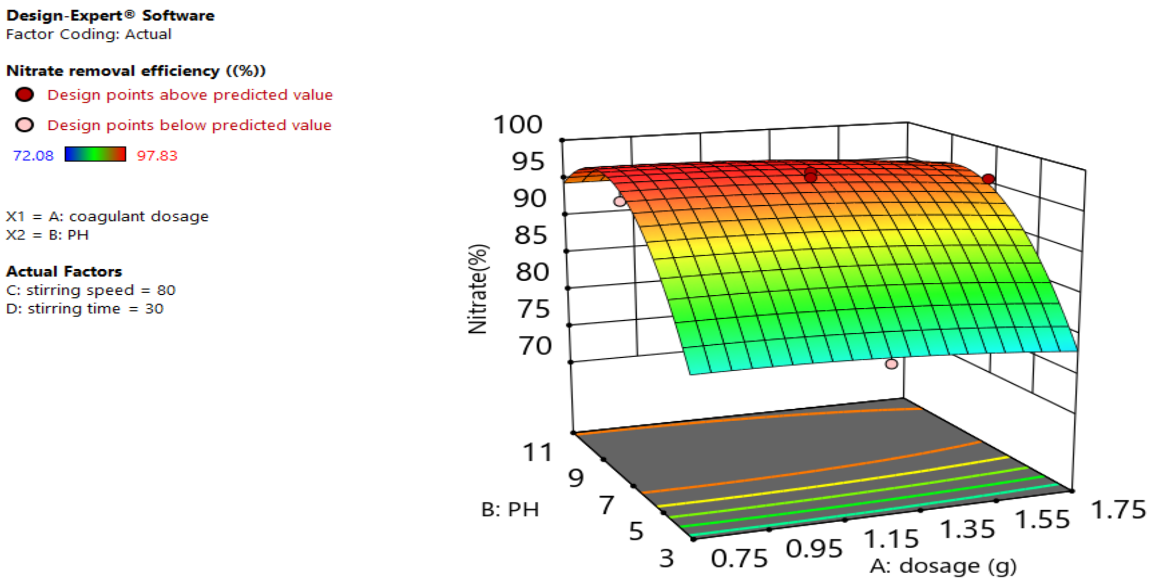


Figure 4.36: 3D plot of the interaction effect of dose and pH on (%) of nitrate using Moringa

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.36. The percent of nitrate removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.20 Experimental variables effect for (%) of phosphate using moringa

Table 4. 22:Model Summary Statistics for (%) removal of nitrate using moringa powder

Source	**Std. Dev.**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**PRESS**	
Linear	7.97	0.7279	0.6784	0.6033	2039.47	
2FI	8.29	0.7863	0.6527	0.3679	3249.69	
Quadratic	**2.63**	**0.9838**	**0.9650**	**0.8925**	**552.39**	**Suggested**
Cubic	1.14	0.9990	0.9935	0.9324	347.62	Aliased

Table 4.22 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4.23: ANOVA for (%) of phosphate using moringa
Response 5: Phosphate removal efficiency

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	5057.68	14	361.26	52.19	< 0.0001	Highly significant
A-coagulant dosage	52.02	1	52.02	7.52	0.0179	significant
B-PH	3547.07	1	3547.07	512.46	< 0.0001	Highly significant
C-stirring speed	66.28	1	66.28	9.58	0.0093	significant

D-stirring time	76.43	1	76.43	11.04	0.0061	significant
AB	58.48	1	58.48	8.45	0.0132	significant
AC	49.88	1	49.88	7.21	0.0199	significant
AD	12.76	1	12.76	1.84	0.1995	
BC	61.35	1	61.35	8.86	0.0115	significant
BD	102.97	1	102.97	14.88	0.0023	significant
CD	14.96	1	14.96	2.16	0.1673	
A^2	5.64	1	5.64	0.8142	0.3846	
B^2	530.96	1	530.96	76.71	< 0.0001	Highly significant
C^2	0.1612	1	0.1612	0.0233	0.8812	
D^2	0.4437	1	0.4437	0.0641	0.8044	
Residual	83.06	12	6.92			
Lack of Fit	79.76	10	7.98	4.83	0.1836	not significant
Pure Error	3.30	2	1.65			
Cor Total	5140.74	26				

The Model F-value of 52.19 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, AC, BC, BD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 4.83 implies the Lack of Fit is not significant relative to the pure error. There is aN18.36% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.21 Final equation in terms of coded factors for (%) of phosphate using moringa

$$\text{Phosphate removal efficiency} = 96.1+1.7A+14.04B-1.29C-2.06D-1.91AB-1.77AC+0.8931AD+1.96BC+2.54BD-0.9669CD+1.48A^2-14.37B^2+0.2504C^2+0.4154D^2 \quad \ldots\ldots \quad (4.10)$$

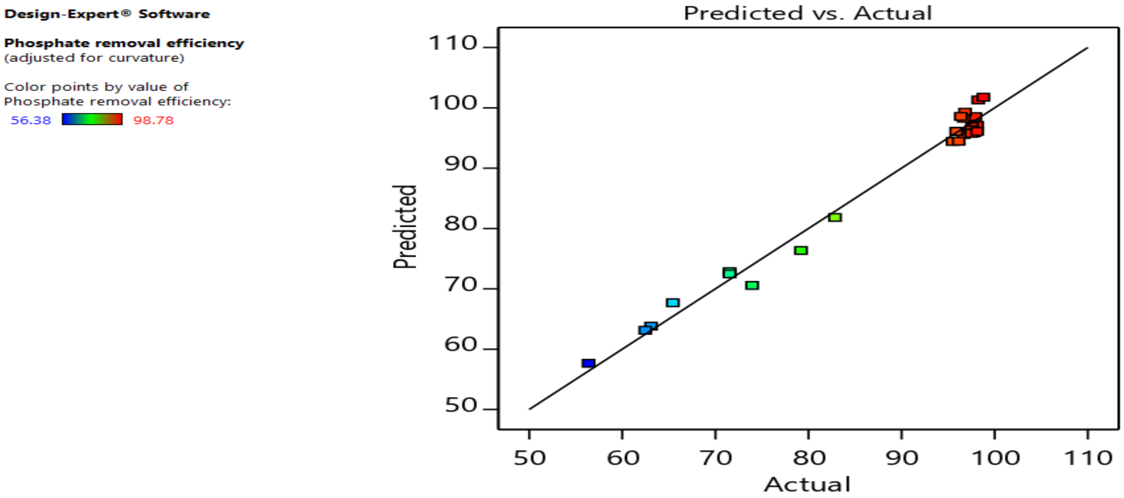


Figure 4. 37:Predicted versus the actual value of response turbidity for moringa

As shown in figure 4.37 predicted versus the actual value of turbidity removal using moringa powder. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

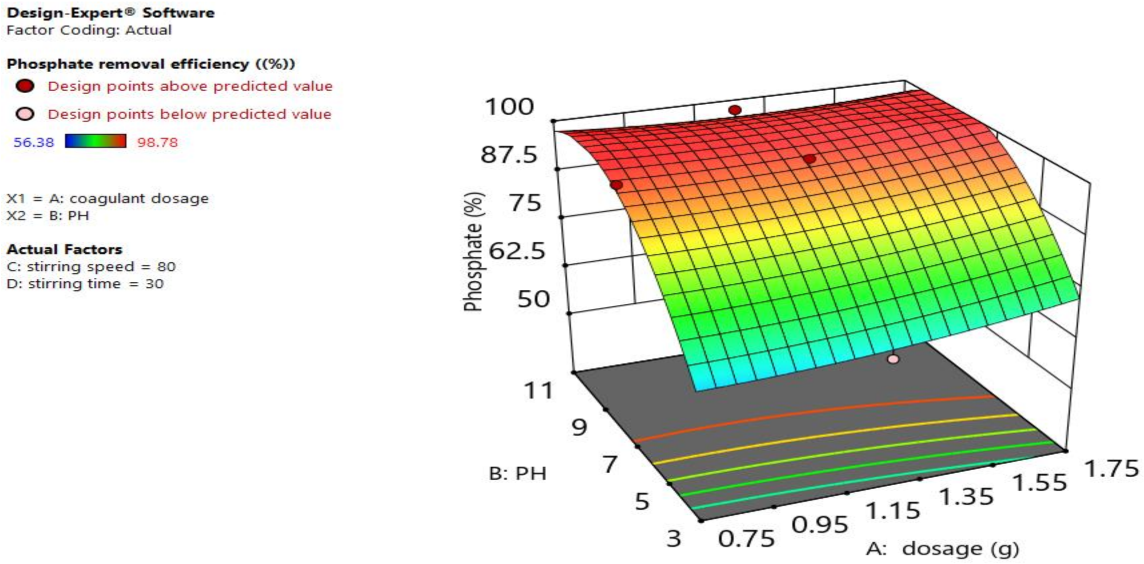


Figure 4.38:3D plot of the interaction effect of dose and pH on (%) of phosphate using Moringa

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.38. The percent of phosphate removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

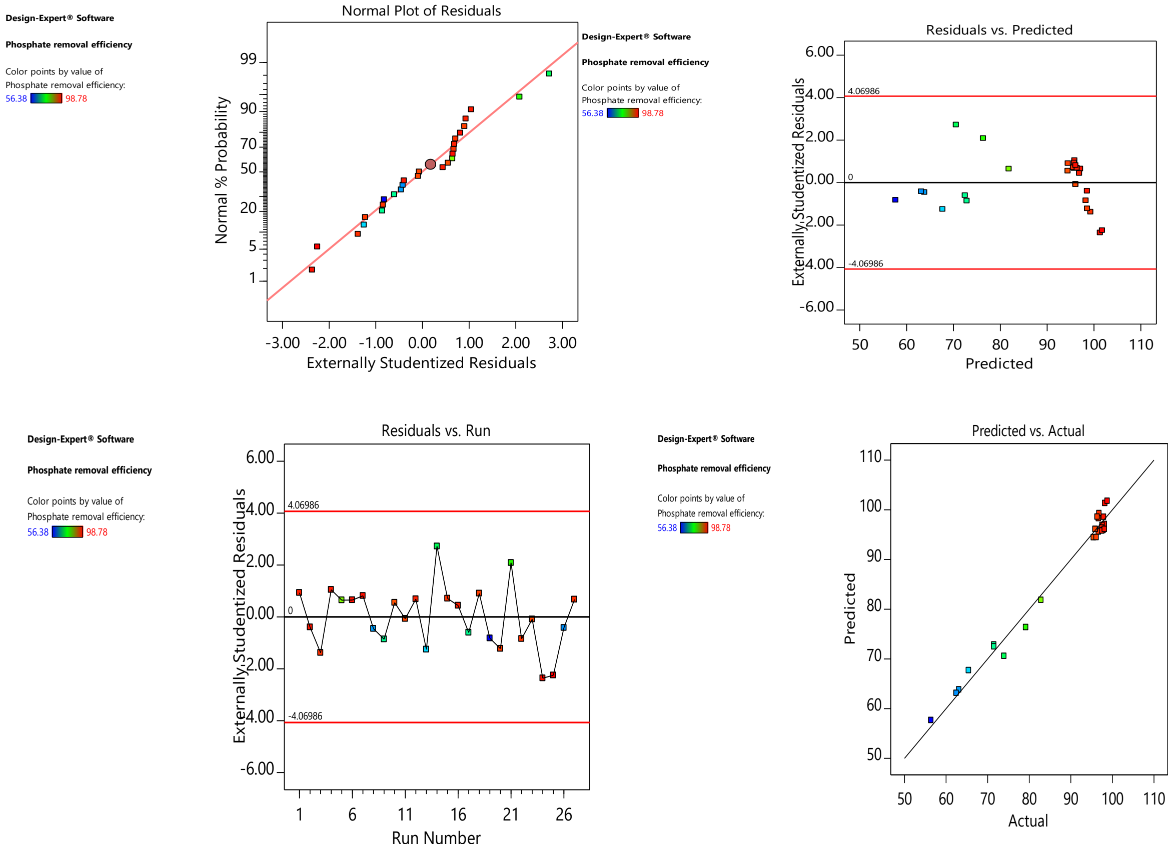


Figure 4. 39: Diagnostics graphs in terms of coded factors (%) of phosphate using Moringa

The normal probability plot, as shown in figure 4.39 above, indicates that the residuals follow a normal distribution; in this experiment, the points in the plots fit to a straight line in the figure, indicating that the quadratic polynomial model satisfies the assumptions of analysis of variance (ANOVA), i.e., the error distribution is approximately normal. The residuals should be structureless if the model is correct and the assumptions are met; in particular, they should be unconnected to any other variable, including the expected response. Plotting the residuals against the fitted (predicted) values is a straightforward check. The assumption of constant variance is tested by plotting the residuals against the rising expected response values. The plot shows random scatter which justifying no need for an alteration to minimize personal error.

4.3.21. Experimental variables effect for (%) of color using aloe vera.

The coagulation and flocculation process using moringa stenopetala powder also affects the color, turbidity, COD, nitrate, and phosphate removal efficiency as the operating parameters vary. In this case the general trend of the process was the same with AS stem and moringa powder

Table 4.24: model summary statistics for (%) of color using aloe vera

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	3.46	0.6478	0.5837	0.5064	369.43	
2FI	3.99	0.6599	0.4473	-0.1181	836.78	
Quadratic	**0.5649**	**0.9949**	**0.9889**	**0.9657**	**25.65**	**Suggested**
Cubic	0.4358	0.9990	0.9934	0.9810	14.19	Aliased

Table 4.24 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4. 25: ANOVA for (%) of Color using Aloe vera gel.

**Response 1: color removal efficiency **

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	744.60	14	53.19	166.69	< 0.0001	Highly significant
A-coagulant dosage	3.35	1	3.35	10.51	0.0071	significant
B-PH	474.73	1	474.73	1487.86	< 0.0001	Highly significant
C-stirring speed	2.18	1	2.18	6.85	0.0225	significant
D-stirring time	4.54	1	4.54	14.23	0.0027	significant
AB	3.56	1	3.56	11.17	0.0059	significant
AC	3.60	1	3.60	11.28	0.0057	significant
AD	0.3278	1	0.3278	1.03	0.3308	

BC	0.0333	1	0.0333	0.1044	0.7522	
BD	1.45	1	1.45	4.53	0.0547	
CD	0.0856	1	0.0856	0.2681	0.6140	
A^2	0.3461	1	0.3461	1.08	0.3182	
B^2	82.14	1	82.14	257.44	< 0.0001	Highly significant
C^2	0.6095	1	0.6095	1.91	0.1921	
D^2	0.2501	1	0.2501	0.7838	0.3934	
Residual	3.83	12	0.3191			
Lack of Fit	3.13	10	0.3130	0.8964	0.6347	not significant
Pure Error	0.6985	2	0.3492			
Cor Total	748.43	26				

The Model F-value of 166.69 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, AC, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.90 implies the Lack of Fit is not significant relative to the pure error. There is an 63.47% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.22. Final equation in terms of coded factors for (%) of color using aloe vera gel.

$$\text{Color removal efficiency} = 98.2-0.4317A+5.14B+0.3483C-0.5022D+0.4719AB-0.4744AC-0.1431AD-0.0456BC+0.3006BD-0.0731CD-0.3669A^2-5.65B^2-0.4869C^2-0.3119D^2 \ldots \ldots \quad (4.11)$$

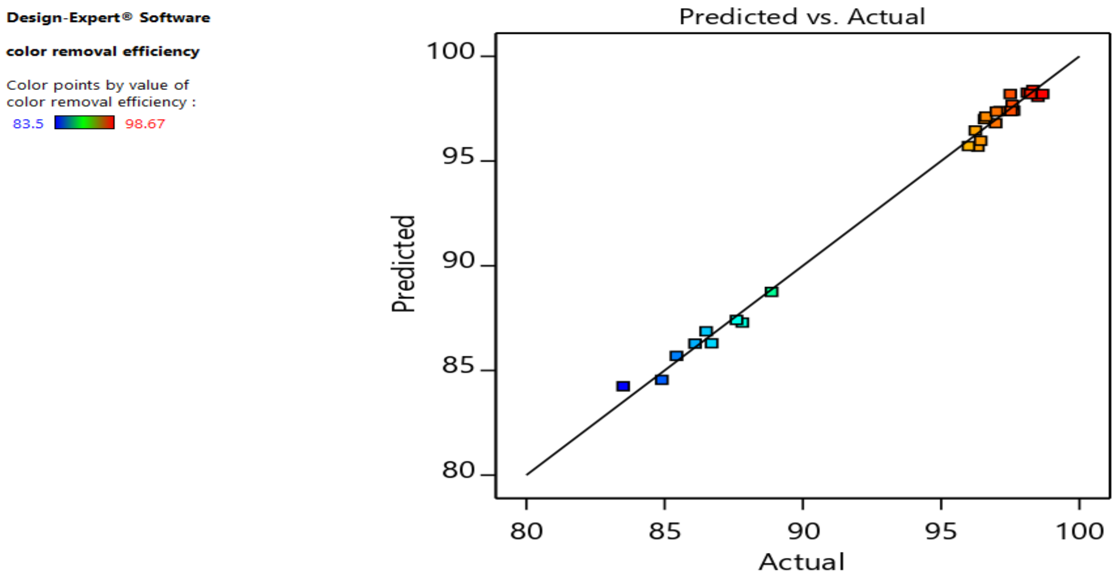


Figure 4.40: Predicted versus the actual value of response for (%) of color using aloe vera

As shown in figure 4.40, predicted versus the actual value of turbidity removal using moringa powder. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

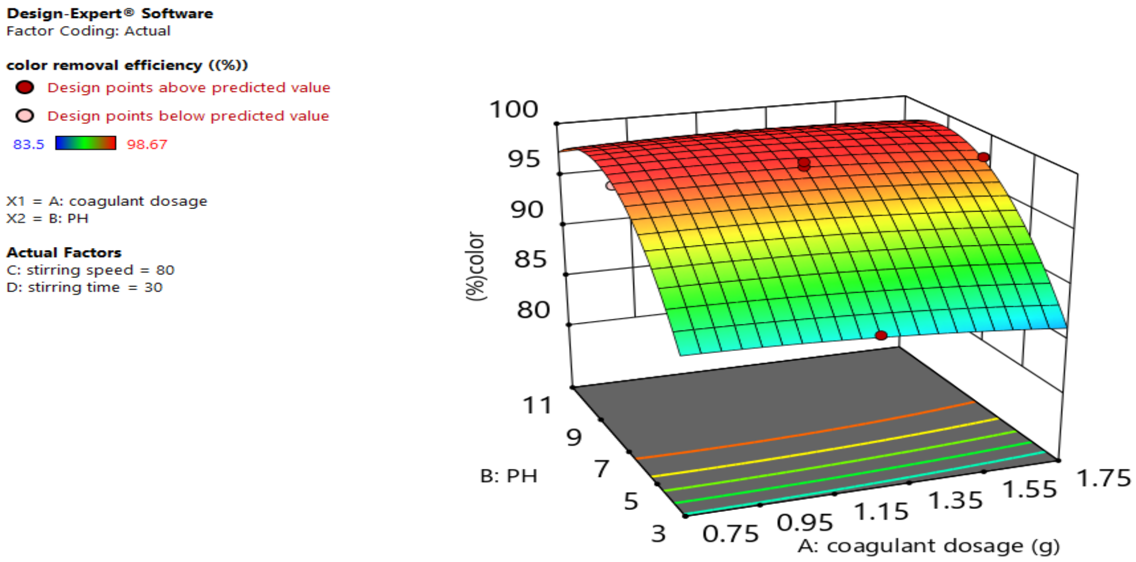


Figure 4. 41:3D plot of the interaction effect of dose and pH on percentage removal of Color using aloe vera.

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.41. The percent of color removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.23. Experimental variables effect for (%) of turbidity using aloe vera.

Table 4.26: Model Summary Statistics for (%) of turbidity using aloe vera gel

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.66	0.6460	0.5817	0.4996	219.49	
2FI	2.99	0.6739	0.4701	-0.0495	460.40	
Quadratic	**0.7554**	**0.9844**	**0.9662**	**0.9077**	**40.48**	**Suggested**
Cubic	0.6913	0.9956	0.9717	-0.0041	440.49	Aliased

Table 4.26 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4.27: ANOVA for (%) of Turbidity using Aloe vera gel.
Response 2: turbidity removal efficiency

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	431.83	14	30.84	54.06	< 0.0001	Highly significant
A-coagulant dosage	9.42	1	9.42	16.51	0.0016	significant
B-PH	268.27	1	268.27	470.19	< 0.0001	Highly significant
C-stirring speed	2.72	1	2.72	4.77	0.0495	significant
D-stirring time	2.98	1	2.98	5.23	0.0411	significant
AB	4.54	1	4.54	7.95	0.0155	significant
AC	0.9312	1	0.9312	1.63	0.2256	
AD	3.55	1	3.55	6.23	0.0281	significant
BC	1.23	1	1.23	2.16	0.1674	
BD	0.7396	1	0.7396	1.30	0.2771	
CD	1.24	1	1.24	2.18	0.1657	
A^2	0.3713	1	0.3713	0.6508	0.4355	
B^2	46.56	1	46.56	81.60	< 0.0001	Highly significant
C^2	0.5925	1	0.5925	1.04	0.3283	
D^2	0.0469	1	0.0469	0.0821	0.7793	
Residual	6.85	12	0.5706			
Lack of Fit	6.72	10	0.6722	10.75	0.0881	not significant
Pure Error	0.1251	2	0.0625			
Cor Total	438.68	26				

The Model F-value of 54.06 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, AD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 10.75 implies there is 8.81% chance that a Lack of Fit F-value this large could occur due to noise. Lack of fit is bad, so we want the model to fit. This relatively low probability (<10%) is troubling.

4.3.24. Final equation in terms of coded factors for (%) of turbidity using aloe vera.

Turbidity removal efficiency = $96.38-0.7233A+3.86B-0.388C-0.4072D+0.5325AB-0.2413AC+0.4712AD+0.2775BC+0.2150BD-0.2788CD-0.3800A^2-4.26B^2-0.4800C^2+0.1350D^2$……………………………………………………………(4.12)

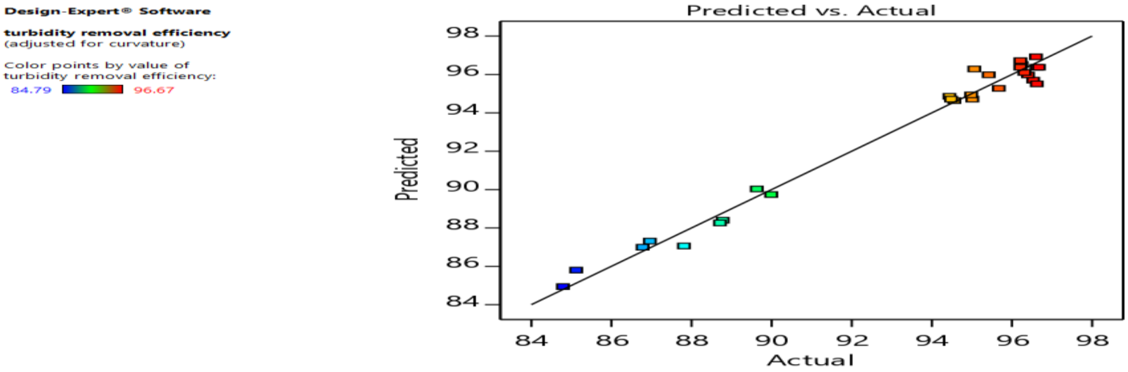


Figure 4. 42: Predicted verses actual value of response turbidity for aloe vera gel

As shown in figure 4.42 predicted versus the actual value of turbidity removal using moringa powder. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

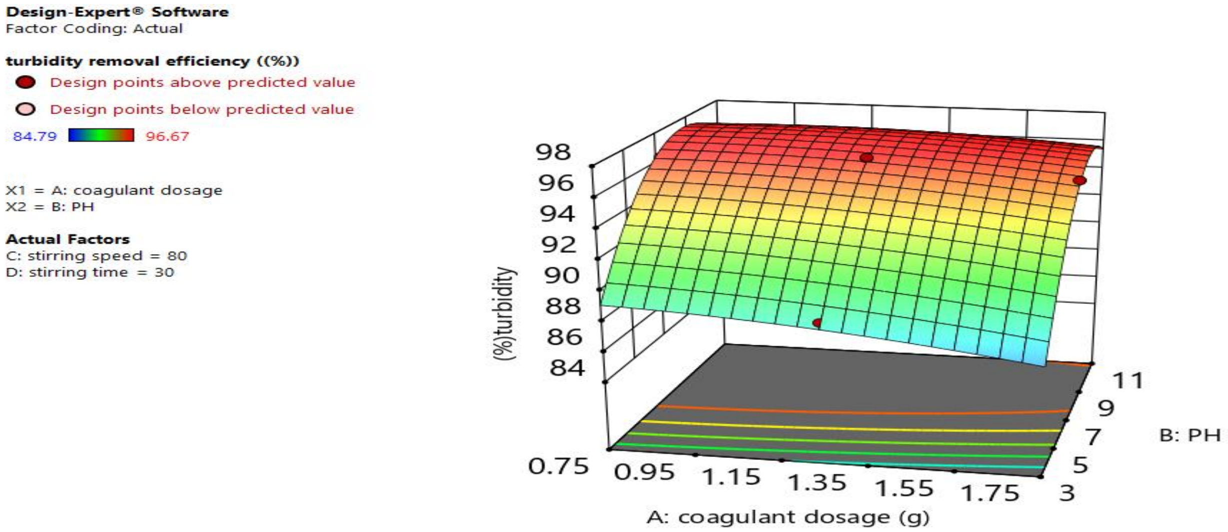


Figure 4. 43: 3D plot of the interaction effect of dose and pH on (%) of turbidity using aloe

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.43. The percent of turbidity removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively

4.3.25. Experimental variables effect for (%) of COD using aloe vera.

Table 4. 28:Model Summary Statistics on (%) of COD using aloe vera gel

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.24	0.6805	0.6224	0.5643	151.05	
2FI	2.58	0.6924	0.5002	0.1456	296.20	
Quadratic	**0.3322**	**0.9962**	**0.9917**	**0.9853**	**5.11**	**Suggested**
Cubic	0.4317	0.9978	0.9860	0.9109	30.89	Aliased

Table 4.28 shows that, the model summary statistics from The ANOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table4.29:ANOVA for (%) of COD using Aloe vera.
Response 3: COD removal efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	345.33	14	24.67	223.54	< 0.0001	Highly significant
A-coagulant dosage	0.7565	1	0.7565	6.86	0.0225	significant
B-PH	230.91	1	230.91	2092.61	< 0.0001	Highly significant
C-stirring speed	3.25	1	3.25	29.46	0.0002	significant
D-stirring time	0.9940	1	0.9940	9.01	0.0110	significant
AB	0.6281	1	0.6281	5.69	0.0344	significant
AC	0.6360	1	0.6360	5.76	0.0335	significant
AD	0.0105	1	0.0105	0.0952	0.7629	
BC	1.31	1	1.31	11.83	0.0049	significant
BD	0.5513	1	0.5513	5.00	0.0452	significant
CD	0.9950	1	0.9950	9.02	0.0110	significant
A^2	1.44	1	1.44	13.04	0.0036	significant
B^2	57.09	1	57.09	517.41	< 0.0001	Highly significant
C^2	0.3952	1	0.3952	3.58	0.0828	
D^2	0.6899	1	0.6899	6.25	0.0279	significant
Residual	1.32	12	0.1103			
Lack of Fit	0.7581	10	0.0758	0.2678	0.9385	not significant
Pure Error	0.5661	2	0.2830			
Cor Total	346.66	26				

The Model F-value of 223.54 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, AC, BC, BD, CD, A^2, B^2, D^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.27 implies the Lack of Fit is not significant relative to the pure error. There is an 93.85% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.26. Final equation in terms of coded factors for (%) removal of COD using aloe vera gel.

COD removal efficiency = $95.86+0.2050A+3.58B+0.4250C-0.2350D-0.1981AB+0.1994AC+0.0256AD-0.2856BC+0.1856BD-0.2494CD+0.7480A^2-4.71B^2-0.3920C^2+0.5180D^2$……………………………………………… ……………(4.13)

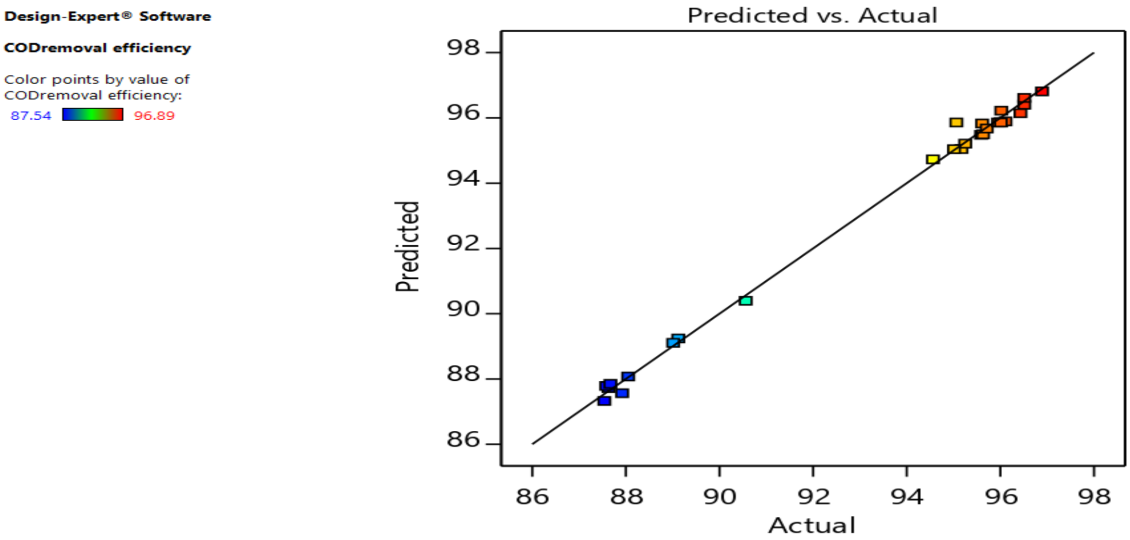


Figure 4.44:Predicted versus the actual value of response COD for aloe vera gel

As shown in figure 4.44 predicted versus the actual value of turbidity removal using moringa powder almost all the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental.

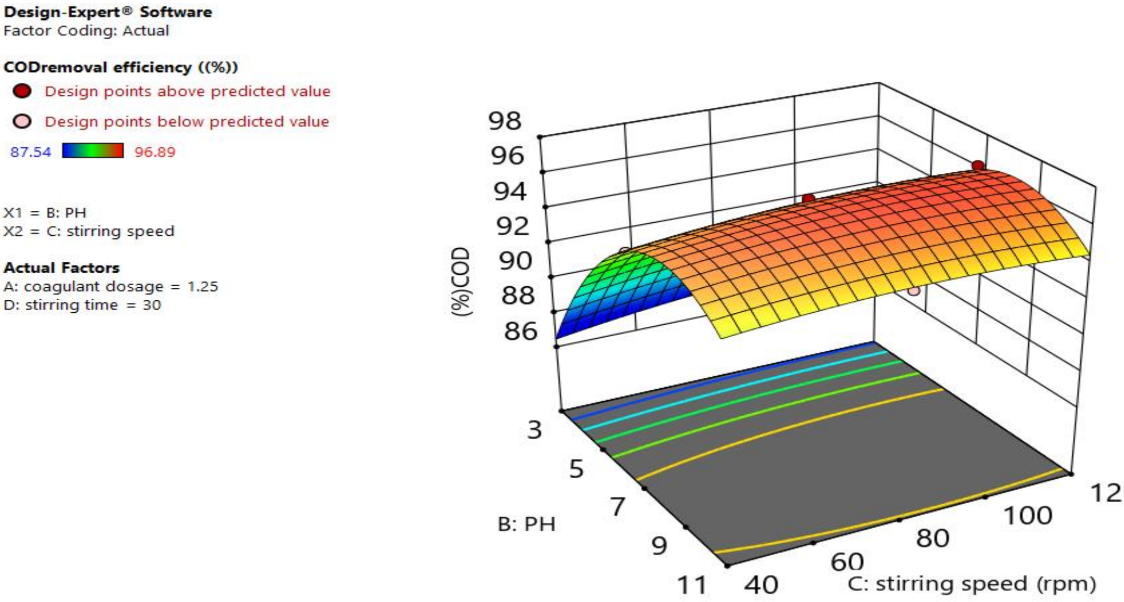


Figure 4. 45:3D plot of the interaction effect of dose and pH on (%) COD using aloe vera.

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.45. The percent of COD removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.27. Experimental variables effect for (%) of nitrate using aloe vera gel.

Table4.30: Model Summary Statistics for the (%) of nitrate using aloe vera gel

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	7.40	0.7033	0.6494	0.5893	1666.98	
2FI	8.55	0.7120	0.5320	0.0985	3659.10	
Quadratic	**1.22**	**0.9956**	**0.9905**	**0.9669**	**134.36**	**Suggested**
Cubic	1.00	0.9990	0.9935	0.8650	548.03	Aliased

Table 4.30 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table4.31: ANOVA for (%) of nitrate using aloe vera gel.
**Response 4: Nitrate removal efficiency **

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4040.99	14	288.64	195.16	< 0.0001	Highly significant
A-coagulant dosage	6.97	1	6.97	4.71	0.0507	
B-PH	2825.26	1	2825.26	1910.25	< 0.0001	Highly significant
C-stirring speed	8.58	1	8.58	5.80	0.0330	significant
D-stirring time	13.83	1	13.83	9.35	0.0099	significant
AB	15.07	1	15.07	10.19	0.0077	significant
AC	0.6440	1	0.6440	0.4354	0.5218	
AD	7.28	1	7.28	4.92	0.0466	significant
BC	1.35	1	1.35	0.9137	0.3580	
BD	6.11	1	6.11	4.13	0.0648	
CD	4.61	1	4.61	3.12	0.1028	
A^2	0.0599	1	0.0599	0.0405	0.8439	
B^2	464.32	1	464.32	313.94	< 0.0001	Highly significant
C^2	0.5622	1	0.5622	0.3801	0.5490	
D^2	0.0001	1	0.0001	0.0001	0.9924	
Residual	17.75	12	1.48			
Lack of Fit	15.98	10	1.60	1.81	0.4075	not significant
Pure Error	1.76	2	0.8821			
Cor Total	4058.74	26				

The Model F-value of 195.16 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, B, C, D, AB, AD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 1.81 implies the Lack of Fit is not significant relative to the pure error. There is an 40.75% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.28. Final Equation in Terms of Coded Factors for (%) of nitrate using aloe vera

Nitrate removal efficiency = $97.69--0.6222A+12.53B+0.6906C-0.8767D+0.9706AB-0.2006AC-0.6744AD-0.2906BC+0.6181BD+0.5369CD-0.1526A^2-13.44B^2-0.4676C^2+0.0074D^2$…. ……………………………………………………………(4.14)

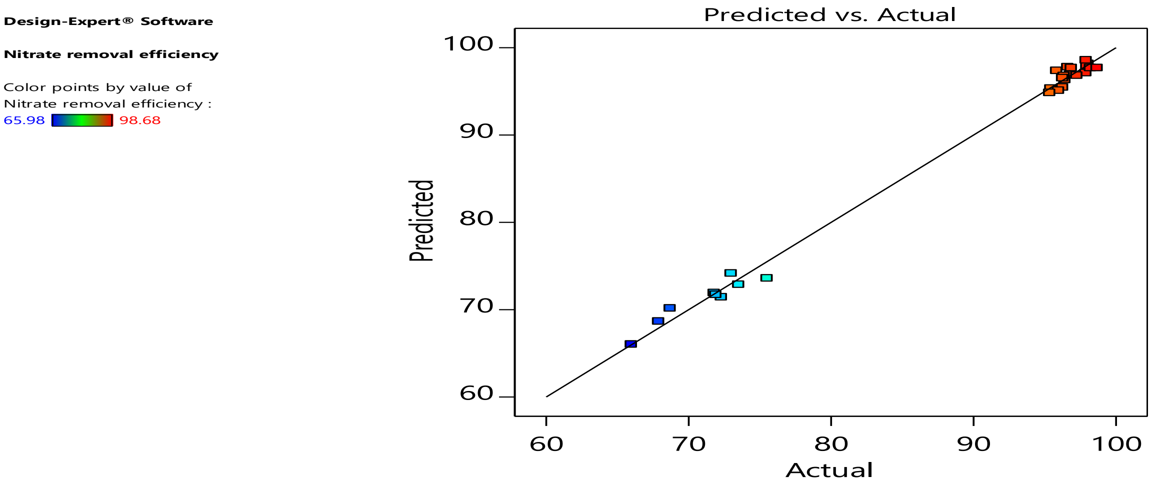


Figure 4. 46: Predicted versus the actual value of response nitrate for aloe vera gel

As shown in figure 4.46 predicted versus the actual value of nitrate removal using aloe vera. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

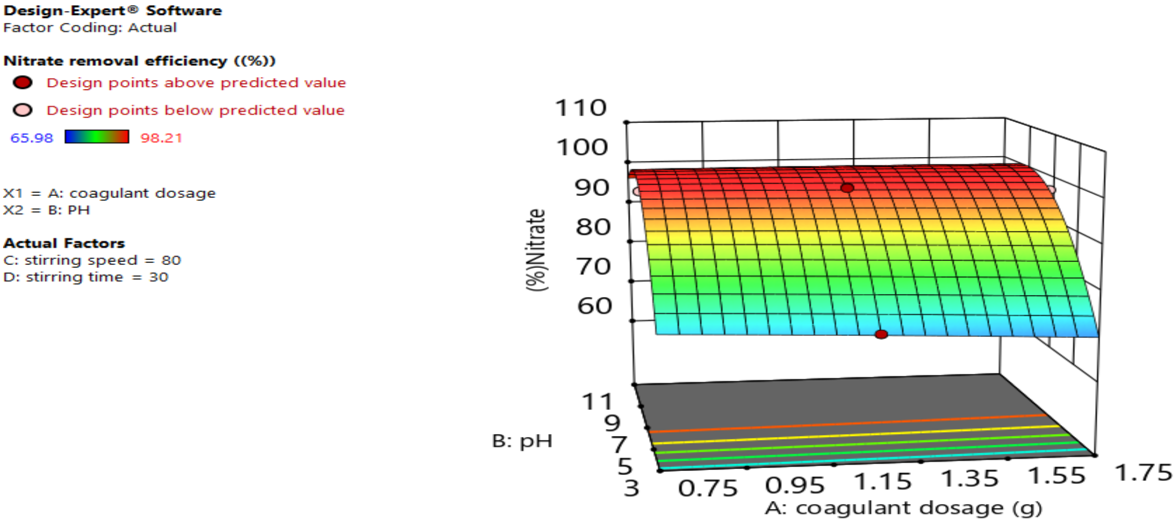


Figure4. 47: 3D plot of the interaction effect of dose and pH on (%) of nitrate using aloe vera.

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.47. The percent of nitrate removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.29. Experimental Variables Effect for (%) of phosphate using aloe vera.

Table 4.32: Model Summary Statistics for the (%) of $\mathbf{PO_4^{3-}}$ using aloe vera gel

Source	Std. Dev.	R²	Adjusted R²	Predicted R²	PRESS	
Linear	7.97	0.6761	0.6172	0.5473	1954.25	
2FI	9.07	0.6953	0.5049	0.0433	4129.88	
Quadratic	**1.62**	**0.9927**	**0.9842**	**0.9509**	**212.15**	**Suggested**
Cubic	0.7558	0.9995	0.9966	0.9522	206.30	Aliased

Table 4.32shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R², and the predicted R² is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R² is close to one, which is good.

Table 4. 33: ANOVA for (%) of phosphate using aloe vera gel.

Response 5: phosphate removal efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4285.38	14	306.10	116.51	< 0.0001	Highly significant
A-coagulant dosage	13.99	1	13.99	5.33	0.0396	significant
B-PH	2844.59	1	2844.59	1082.74	< 0.0001	Highly significant
C-stirring speed	39.46	1	39.46	15.02	0.0022	significant
D-stirring time	20.76	1	20.76	7.90	0.0157	significant
AB	4.80	1	4.80	1.83	0.2016	
AC	0.2025	1	0.2025	0.0771	0.7860	
AD	0.3969	1	0.3969	0.1511	0.7043	
BC	39.25	1	39.25	14.94	0.0022	significant
BD	20.84	1	20.84	7.93	0.0156	significant
CD	17.35	1	17.35	6.60	0.0246	significant
A²	0.5203	1	0.5203	0.1980	0.6642	
B²	498.60	1	498.60	189.78	< 0.0001	Highly significant
C²	3.46	1	3.46	1.32	0.2736	
D²	0.9263	1	0.9263	0.3526	0.5637	
Residual	31.53	12	2.63			
Lack of Fit	30.40	10	3.04	5.39	0.1664	not significant
Pure Error	1.13	2	0.5636			
Cor Total	4316.90	26				

The Model F-value of 116.51 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, D, BC, BD, CD, B² are significant model terms.

Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 5.39 implies the Lack of Fit is not significant relative to the pure error. There is a 16.64% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good so we want the model to fit.

4.3.30. Final equation in terms of coded factors for (%) removal of phosphate using aloe vera gel.

Phosphate removal efficiency =97.69-0.8817A+12.57B-1.48C-1.07D-0.5475AB+0.1125AC-0.1575AD+1.57BC+1.14BD+1.04CD-0.4498A^2-13.92B^2-1.16C^2+0.6002D^2…………………………………………………………………… (4.14)

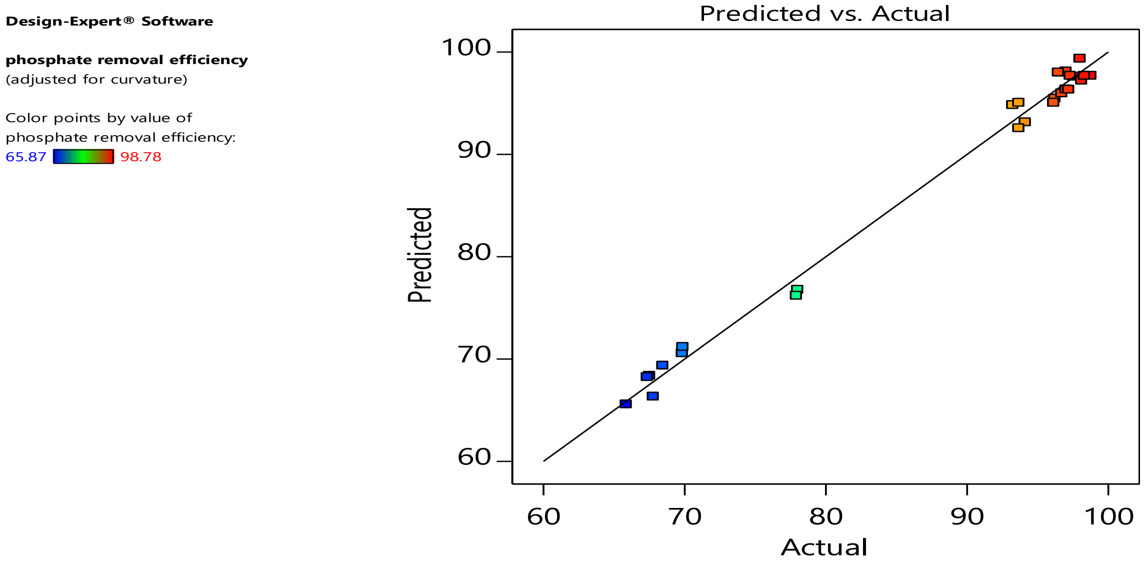


Figure 4.48:Predicted verses actual value of response PO_4^{3-} for aloe vera gel

As shown in figure 4.48 predicted verses actual value of phosphate removal using aloe vera gel. Hence, the points concentrated towards the diagonal line, about the mean indicate the is a close relation and agreement between the predicted and actual experimental value.

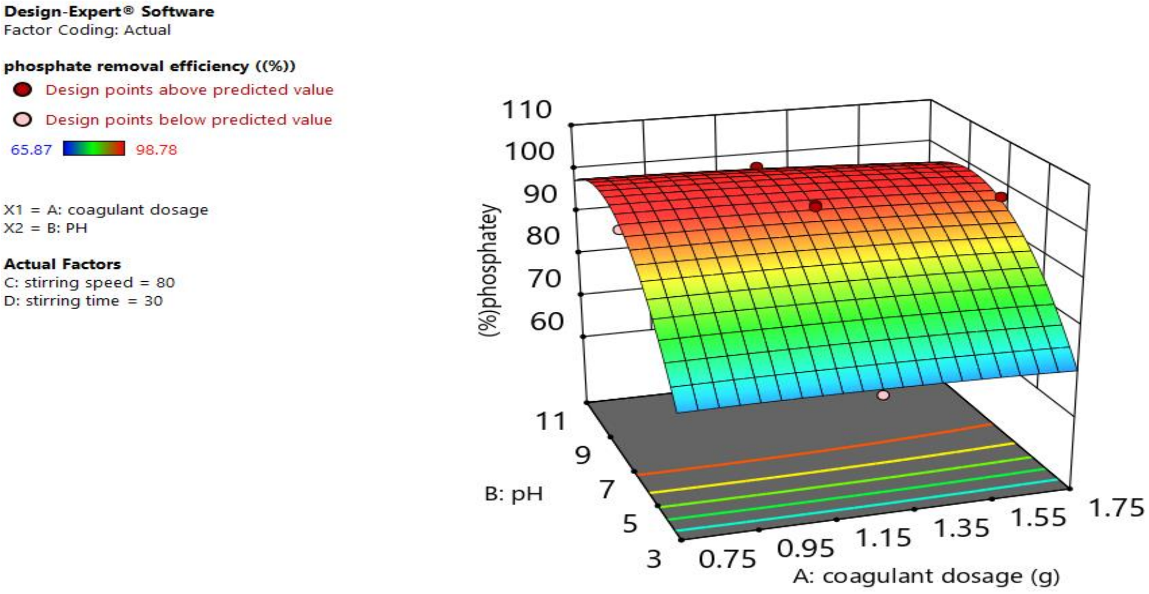


Figure 4. 49:3D plot of the interaction effect of dose and pH on (%) of PO_4^{3-} using aloe vera

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.49. The percent of phosphate removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

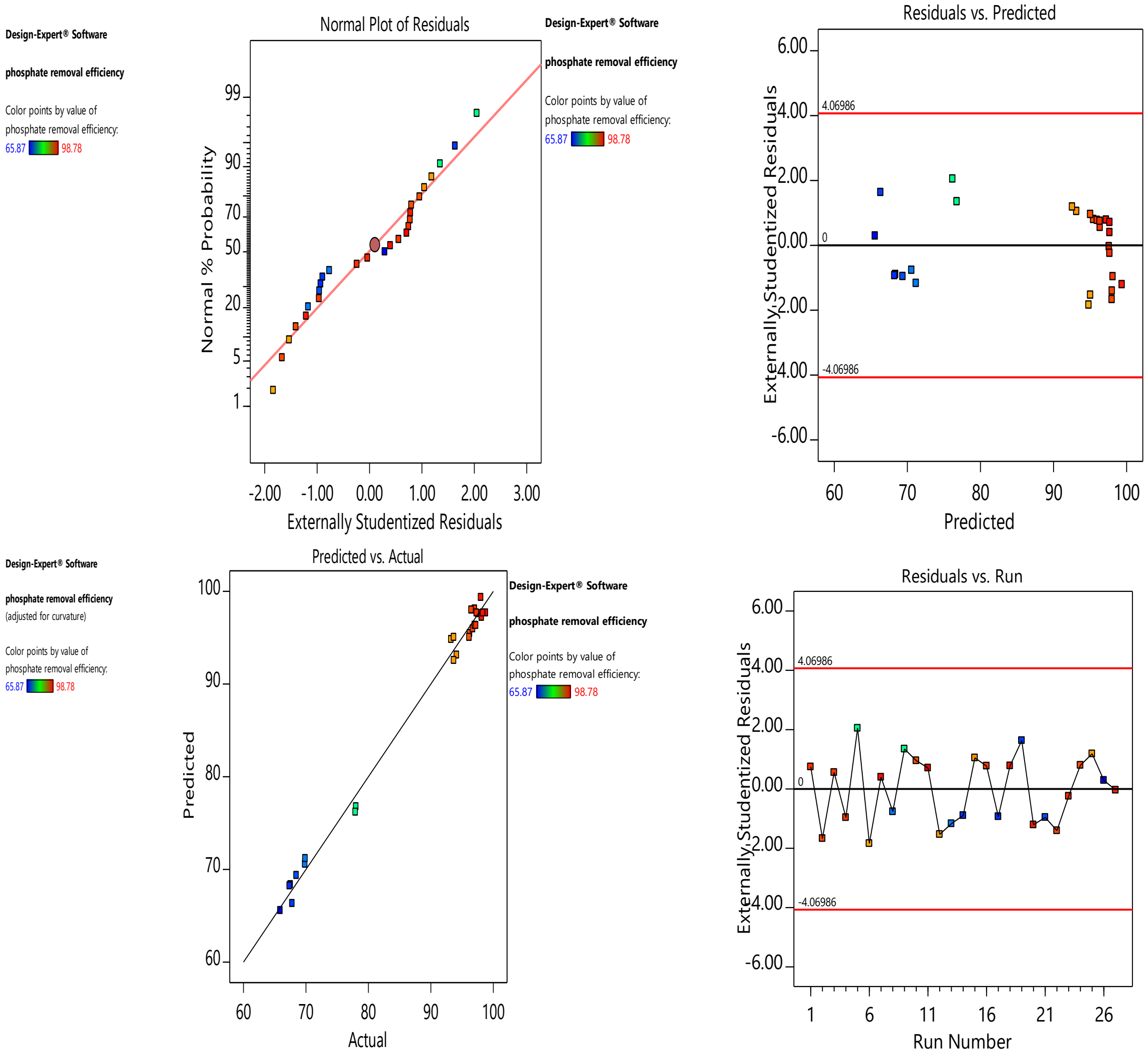


Figure 4. 50: Diagnostics graphs in terms of coded factors for (%) of $\boldsymbol{PO_4^{3-}}$ using aloe vera gel.

The normal probability plot, as shown in figure 4.50 above, indicates that the residuals follow a normal distribution; in this experiment, the points in the plots fit to a straight line in the figure, indicating that the quadratic polynomial model satisfies the assumptions of analysis of variance (ANOVA), i.e., the error distribution is approximately normal. The residuals should be structureless if the model is correct and the assumptions are met; in particular, they should be unconnected to any other variable, including the expected response. Plotting the residuals against the fitted (predicted) values is a straightforward check. The assumption of constant variance is tested by plotting the residuals against the rising expected response values. The plot shows random scatter which justifying no need for an alteration to minimize personal error.

4.3.31. Experimental variables effect for (%) of color using a blended coagulant.

The coagulation and flocculation process using blended form of the three coagulants namely, AS, moringa and aloe vera also affects the color, turbidity, COD, nitrate and phosphate removal efficiency as the operating parameters vary. In this case the general trend of the process was the same with AS, moringa and aloe vera.

Table 4. 34:Model Summary Statistics for (%) of color using a blended coagulant

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	3.60	0.6761	0.6172	0.5540	391.97	
2FI	4.18	0.6819	0.4831	0.0005	878.44	
Quadratic	**0.9638**	**0.9873**	**0.9725**	**0.9326**	**59.26**	**Suggested**
Cubic	1.09	0.9946	0.9650	0.3333	585.97	Aliased

Table 4.34 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4.35: ANOVA for (%) of color using a blended coagulant

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	867.73	14	61.98	66.73	< 0.0001	Highly significant
A-coagulant dosage	4.87	1	4.87	5.24	0.0410	significant
B-PH	577.43	1	577.43	621.68	< 0.0001	Highly significant
C-stirring speed	5.23	1	5.23	5.63	0.0353	significant
D-stirring time	6.70	1	6.70	7.21	0.0198	significant
AB	1.29	1	1.29	1.39	0.2618	
AC	0.2756	1	0.2756	0.2967	0.5959	
AD	0.4970	1	0.4970	0.5351	0.4785	
BC	0.0196	1	0.0196	0.0211	0.8869	
BD	1.82	1	1.82	1.96	0.1866	
CD	1.19	1	1.19	1.28	0.2802	
A^2	0.1183	1	0.1183	0.1273	0.7274	
B^2	96.33	1	96.33	103.71	< 0.0001	Highly significant
C^2	3.86	1	3.86	4.16	0.0641	
D^2	0.1413	1	0.1413	0.1522	0.7033	
Residual	11.15	12	0.9288			
Lack of Fit	8.92	10	0.8915	0.7992	0.6726	not significant
Pure Error	2.23	2	1.12			
Cor Total	878.88	26				

The Model F-value of 66.73 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.80 implies the Lack of Fit is not significant relative to the pure error. There is an 67.26% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.32. Final equation in terms of coded factors for (%) of color using a blended coagulant

Color removal efficiency = $98.54+0.5200A+5.66B-0.5389C-0.6100D-0.2838AB-0.1313AC+0.3375AD-0.0350BC+0.3375BD-0.2725CD+0.2144A^2-6.12B^2-1.23C^2+0.2344D^2$……. ……………………………………………………………….(4.15)

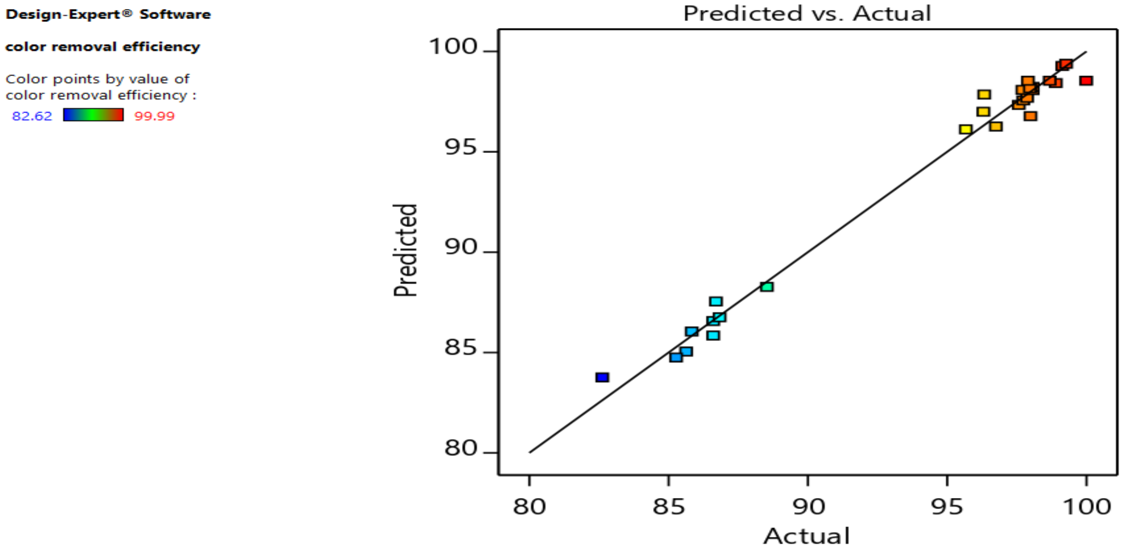


Figure 4.51: Predicted verses actual value of response for blend

As shown in figure 4.51, predicted versus the actual value of color removal using a blended form of coagulant. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value

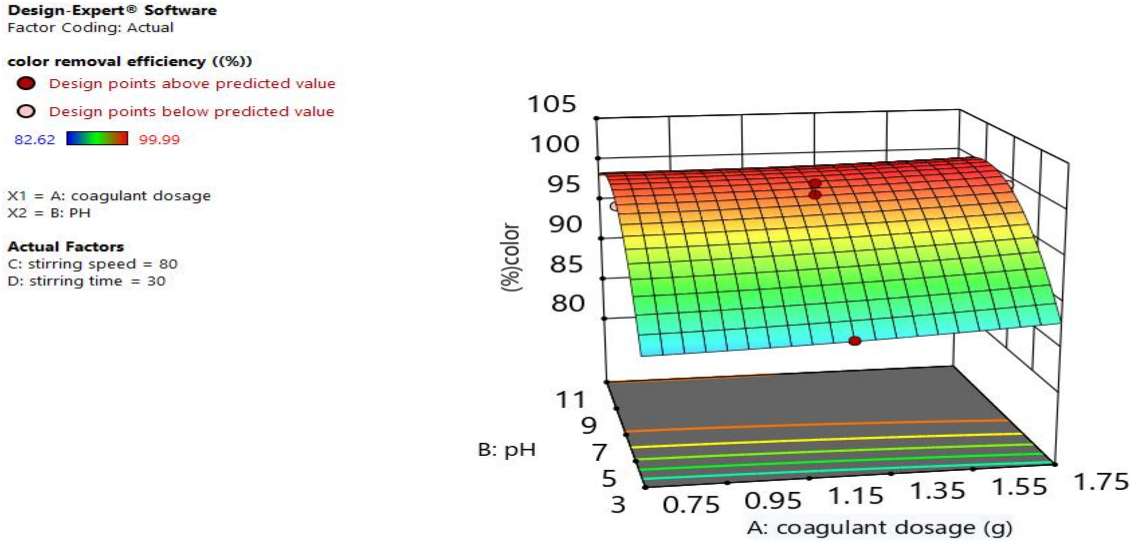


Figure 4.52: 3D plot of the interaction effect of dose and pH on (%) of color using a blended coagulant

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.52. The percent of color removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.33. Experimental variables effect for (%) of turbidity using a blended coagulant

Table 4.36:Model Summary Statistics on (%) of turbidity using a blended coagulant

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	3.38	0.6103	0.5394	0.4517	353.06	
2FI	3.82	0.6376	0.4111	-0.1952	769.61	
Quadratic	**1.44**	**0.9612**	**0.9159**	**0.7915**	**134.24**	**Suggested**
Cubic	1.21	0.9909	0.9407	0.0094	637.83	Aliased

Table 4.36 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table4. 37: ANOVA for (%) of turbidity using a blended coagulant
Response 2: turbidity removal efficiency

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	618.91	14	44.21	21.23	< 0.0001	Highly significant
A-coagulant dosage	16.67	1	16.67	8.00	0.0152	significant
B-PH	352.89	1	352.89	169.50	< 0.0001	Highly significant
C-stirring speed	10.40	1	10.40	4.99	0.0452	significant
D-stirring time	12.99	1	12.99	6.24	0.0280	significant
AB	1.55	1	1.55	0.7445	0.4051	
AC	11.16	1	11.16	5.36	0.0391	significant
AD	1.18	1	1.18	0.5655	0.4666	
BC	0.0676	1	0.0676	0.0325	0.8600	
BD	3.48	1	3.48	1.67	0.2205	
CD	0.1764	1	0.1764	0.0847	0.7760	
A^2	0.0393	1	0.0393	0.0189	0.8929	
B^2	51.23	1	51.23	24.61	0.0003	significant

C^2	4.78	1	4.78	2.30	0.1555	
D^2	0.5411	1	0.5411	0.2599	0.6194	
Residual	24.98	12	2.08			
Lack of Fit	22.64	10	2.26	1.93	0.3889	not significant
Pure Error	2.34	2	1.17			
Cor Total	643.90	26				

The Model F-value of 21.23 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AC, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 1.93 implies the Lack of Fit is not significant relative to the pure error. There is an 38.89% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.34. Final equation in terms of coded factors for (%) of turbidity using blended coagulant

Turbidity removal efficiency = $96.88-0.9622A+4.43B-0.7600C-0.8494D+0.3112AB-0.8350AC-0.2713AD+0.0650BC+0.4662BD-0.1050CD-0.1237A^2-4.46B^2-1.36C^2-0.1237D^2$………… …………………………………………………………………(4.16)

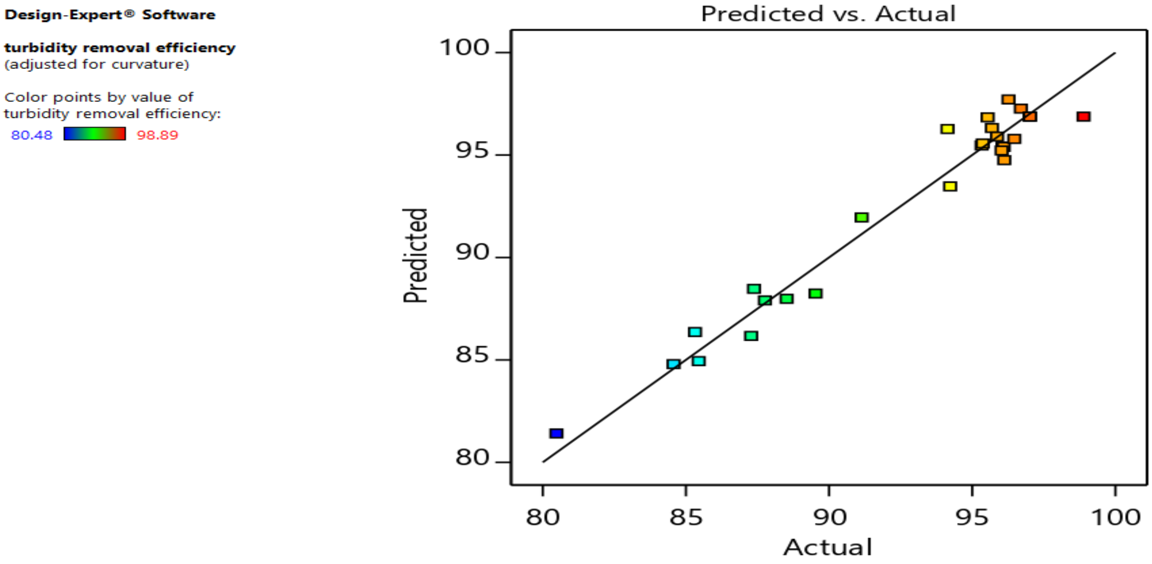


Figure 4. 53:Predicted versus the actual value of response for blended coagulant

As shown in figure 4.53 predicted versus the actual value of turbidity removal using a blended form of coagulants. Hence, the points concentrated towards the diagonal line, about the mean indicate a close relation and agreement between the predicted and actual experimental value. But points those further away from the diagonal line indicate some disagreement between the predicted and actual value. Generally, since most of the points close to the mean so there is a good agreement between the two values.

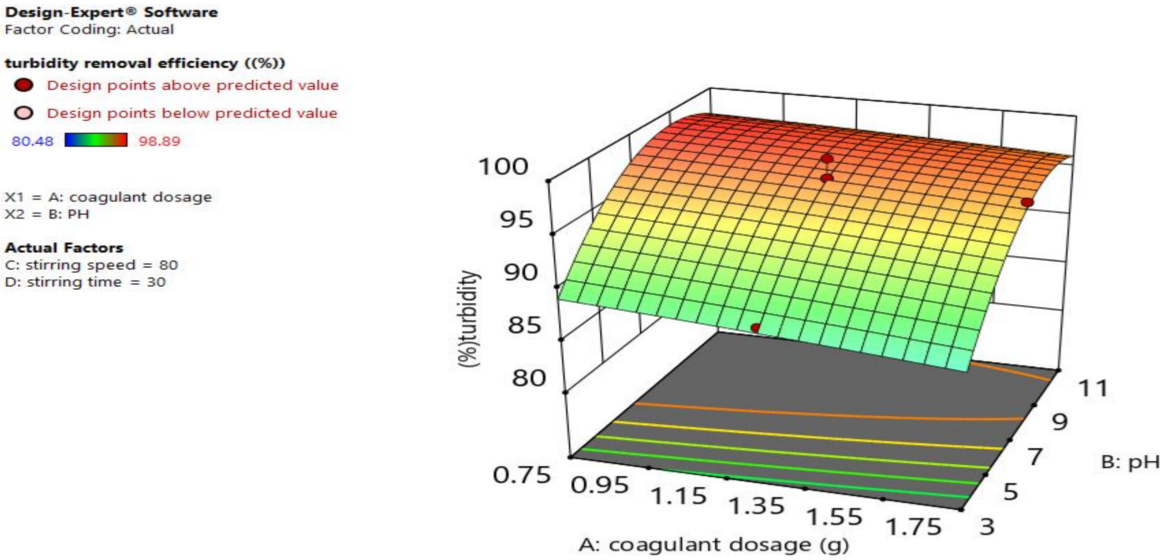


Figure 4.54: 3D plot of the interaction effect of dose and pH on (%) of turbidity using a blended

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.54. The percent of turbidity removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.35. Effect experimental variables (%) of COD using a blended coagulant

Table 4.38: Model Summary Statistics for (%) of COD using a blended coagulant

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	2.71	0.6543	0.5915	0.5314	218.58	
2FI	3.14	0.6624	0.4515	0.0588	438.99	
Quadratic	**0.7356**	**0.9861**	**0.9698**	**0.9471**	**24.66**	**Suggested**
Cubic	0.9942	0.9915	0.9449	0.8202	83.84	Aliased

Table 4.38 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4.39: ANOVA for (%) of COD using blended coagulant
Response 3: COD removal efficiency

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	459.93	14	32.85	60.71	< 0.0001	Highly significant
A-coagulant dosage	3.94	1	3.94	7.28	0.0194	significant

B-PH	296.30	1	296.30	547.58	< 0.0001	Highly significant
C-stirring speed	2.11	1	2.11	3.90	0.0719	
D-stirring time	2.85	1	2.85	5.26	0.0406	significant
AB	0.2093	1	0.2093	0.3868	0.5456	
AC	0.2328	1	0.2328	0.4302	0.5242	
AD	1.49	1	1.49	2.76	0.1224	
BC	1.61	1	1.61	2.97	0.1105	
BD	0.2280	1	0.2280	0.4214	0.5285	
CD	0.0105	1	0.0105	0.0194	0.8915	
A^2	0.0002	1	0.0002	0.0003	0.9861	
B^2	81.89	1	81.89	151.33	< 0.0001	Highly significant
C^2	2.53	1	2.53	4.68	0.0515	
D^2	0.0045	1	0.0045	0.0083	0.9288	
Residual	6.49	12	0.5411			
Lack of Fit	2.90	10	0.2898	0.1612	0.9823	not significant
Pure Error	3.60	2	1.80			
Cor Total	466.42	26				

The Model F-value of 60.71 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, D, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.16 implies the Lack of Fit is not significant relative to the pure error. There is an 98.23% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.36. Final equation in terms of coded factors for (%) of COD using a blended coagulant

COD removal efficiency = $97.08-0.4678A+4.06B-0.3422C0.3978D-0.1144AB+0.1206AC-0.3056AD+0.3169BC-0.1194BD+0.0256CD-0.0081A^2-5.64B^2+0.9919C^2+0.0419D^2$……………………………………………………………(4.17)

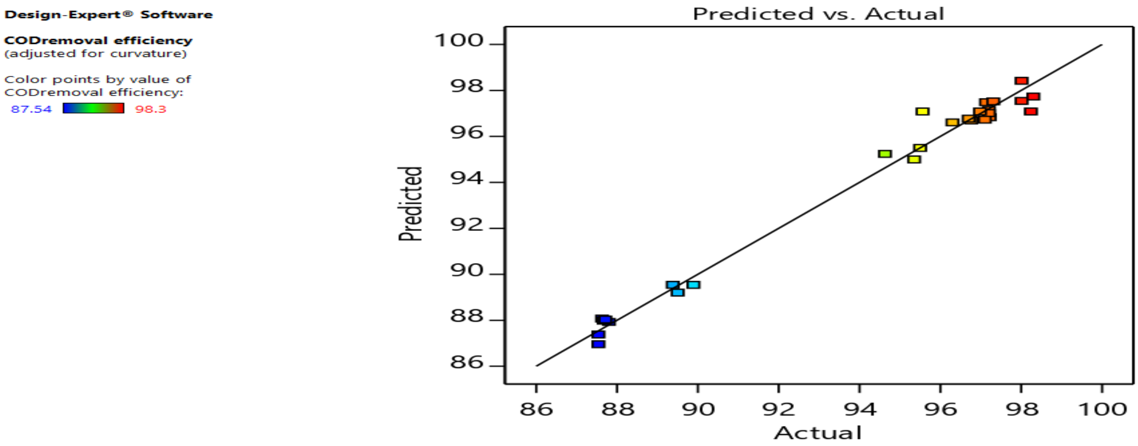


Figure 4. 55:Predicted versus the actual value of response for blended coagulant

As shown in figure 4.55, predicted versus the actual value of COD removal using a blended form of coagulants, the points are concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

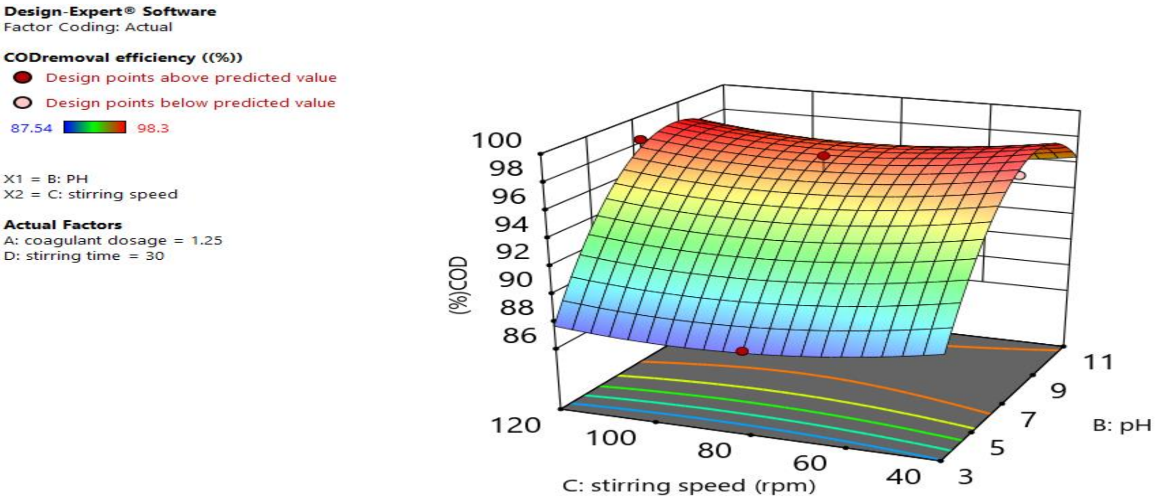


Figure 4.56: 3 D plot of the interaction effect of dose and pH on (%) of COD using a blended coagulant

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.56. The percent of COD removed using moringa is affected by pH and stirring speed. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.37. Experimental variables effect for (%) of nitrate using a blended coagulant

Table 4.40:Model Summary Statistics for (%) of nitrate using a blended coagulant

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	7.26	0.6487	0.5848	0.5065	1627.82	
2FI	8.42	0.6560	0.4410	-0.1722	3866.36	
Quadratic	**1.48**	**0.9920**	**0.9827**	**0.9483**	**170.51**	**Suggested**
Cubic	1.26	0.9981	0.9875	0.6689	1091.97	Aliased

Table 4 .40 shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4.41: ANOVA for (%) nitrate using a blended coagulant
**Response 4: Nitrate removal efficiency **

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3271.99	14	233.71	106.20	< 0.0001	Highly significant
A-coagulant dosage	34.39	1	34.39	15.63	0.0019	Significant
B-PH	2081.63	1	2081.63	945.87	< 0.0001	Highly significant
C-stirring speed	11.76	1	11.76	5.34	0.0394	Significant
D-stirring time	11.87	1	11.87	5.40	0.0386	Significant
AB	13.67	1	13.67	6.21	0.0283	Significant
AC	4.38	1	4.38	1.99	0.1838	
AD	0.1314	1	0.1314	0.0597	0.8111	
BC	1.10	1	1.10	0.4986	0.4936	
BD	4.74	1	4.74	2.15	0.1679	
CD	0.1661	1	0.1661	0.0755	0.7882	
A^2	2.41	1	2.41	1.09	0.3161	
B^2	274.01	1	274.01	124.51	< 0.0001	Highly significant
C^2	24.28	1	24.28	11.03	0.0061	Significant
D^2	0.4488	1	0.4488	0.2039	0.6596	
Residual	26.41	12	2.20			
Lack of Fit	24.42	10	2.44	2.46	0.3239	not significant
Pure Error	1.99	2	0.9942			
Cor Total	3298.40	26				

The Model F-value of 106.20 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 2.46 implies the Lack of Fit is not significant relative to the pure error. There is an 32.39% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.3.38. Final equation in terms of coded factors for (%) of nitrate using a blended coagulant

Nitrate removal efficiency = $96.26-1.38A+10.75B-0.8083C-0.8122D+0.9244AB-0.5231AC-0.0906AD+0.2619BC+0.5444BD+0.1019CD-0.9678A^2-10.32B^2-3.07C^2-0.4178D^2$……………………………………………………………………(4.18)

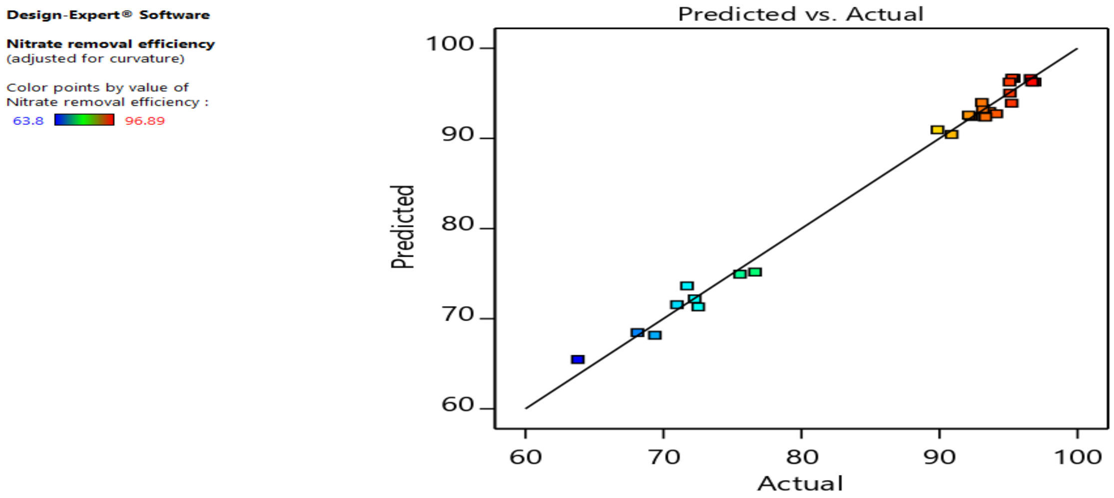


Figure 4. 57:Predicted verses actual value of response for blended coagulant (%) nitrate

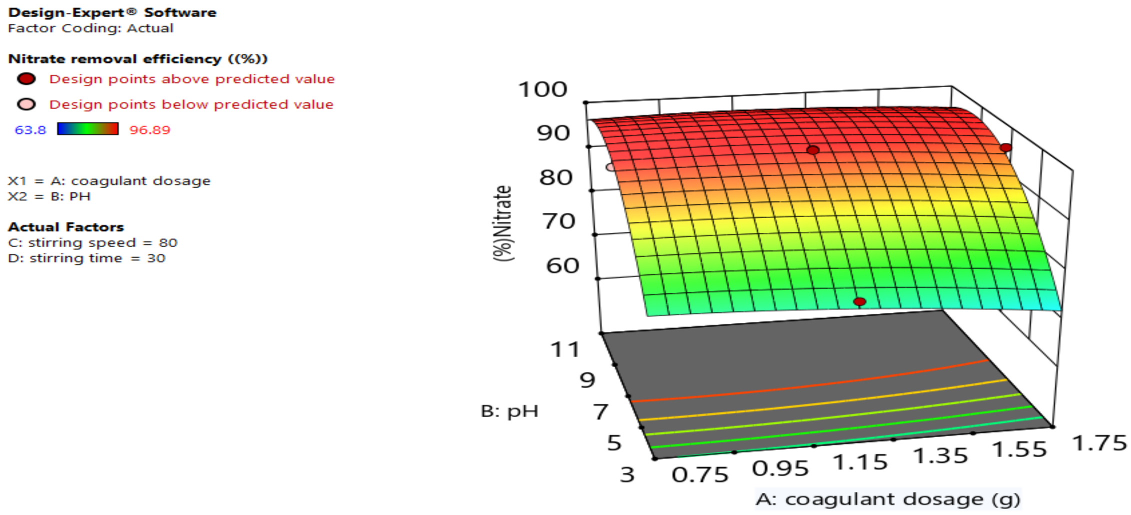


Figure 4.58: 3D plot of the interaction effect of dose and pH on (%) of nitrate using a blended coagulant

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.58. The percent of nitrate removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

4.3.39. Experimental variables effect for (%) of nitrate using a blended coagulant

Table4.42:Model Summary Statistics for (%) of phosphate using a blended coagulant

source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	8.38	0.6975	0.6425	0.5609	2242.96	
2FI	9.30	0.7289	0.5595	0.0539	4832.15	
Quadratic	**2.76**	**0.9821**	**0.9612**	**0.8732**	**647.83**	**Suggested**
Cubic	1.37	0.9985	0.9904	0.7789	1129.12	Aliased

Table 4.42shows that, the model summary statistics from Thea NOVA result show that the selected model, the quadratic model has been suggested for further study. And also, since the difference between the adjusted R^2, and the predicted R^2 is less than 0.2, there is a good agreement. Hence, quadratic model performance was good to predict the experimental data and R^2 is close to one, which is good.

Table 4.43:ANOVA for Quadratic model for (%) of phosphate using a blended coagulant

Response 5: phosphate removal efficiency

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	5016.24	14	358.30	47.03	< 0.0001	Highly significant
A-coagulant dosage	39.78	1	39.78	5.22	0.0413	Significant
B-PH	3414.96	1	3414.96	448.28	< 0.0001	Highly significant
C-stirring speed	69.23	1	69.23	9.09	0.0108	Significant
D-stirring time	38.43	1	38.43	5.04	0.0443	Significant
AB	37.52	1	37.52	4.92	0.0465	Significant
AC	18.88	1	18.88	2.48	0.1414	
AD	1.28	1	1.28	0.1676	0.6895	
BC	35.05	1	35.05	4.60	0.0531	
BD	66.83	1	66.83	8.77	0.0119	Significant
CD	1.01	1	1.01	0.1326	0.7221	
A^2	2.26	1	2.26	0.2966	0.5960	
B^2	365.51	1	365.51	47.98	< 0.0001	Highly significant
C^2	16.56	1	16.56	2.17	0.1662	
D^2	0.3471	1	0.3471	0.0456	0.8346	
Residual	91.41	12	7.62			
Lack of Fit	88.81	10	8.88	6.81	0.1348	not significant
Pure Error	2.61	2	1.30			
Cor Total	5107.66	26				

The Model F-value of 47.03 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, BD, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant The Lack of Fit F-value of 6.81 implies the Lack of Fit is not significant relative to the pure error. There is an 13.48% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good, so we want the model to fit.

4.8.10. Final equation in terms of coded factors for (%) of phosphate using a blended coagulant

Phosphate removal efficiency = $+95.99-1.49A+13.77B+1.96C-1.46D+1.53AB+1.09AC-0.2825AD-1.48BC+2.04BD+0.2512CD-0.9374A^2-11.92B^2-2.54C^2-0.3674D^2$………. (4.19)

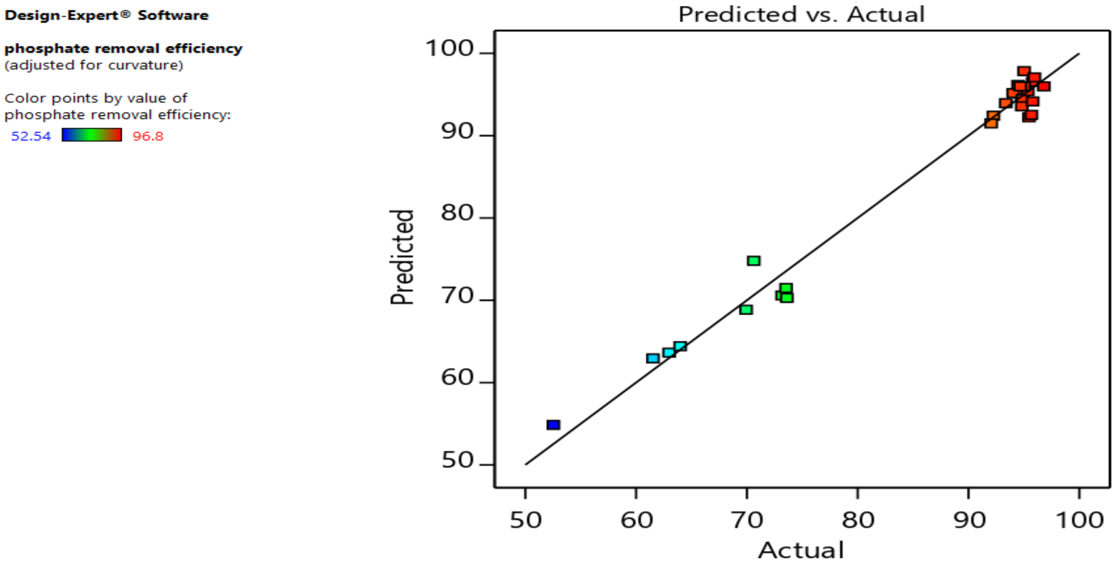


Figure 4.59: Predicted versus the actual value of $\boldsymbol{PO_4^{3-}}$ for blend

As shown in figure 4.59, predicted versus the actual value of phosphate removal using a blended form of coagulant. Hence, the points concentrated towards the diagonal line about the mean indicate a close relation and agreement between the predicted and actual experimental value.

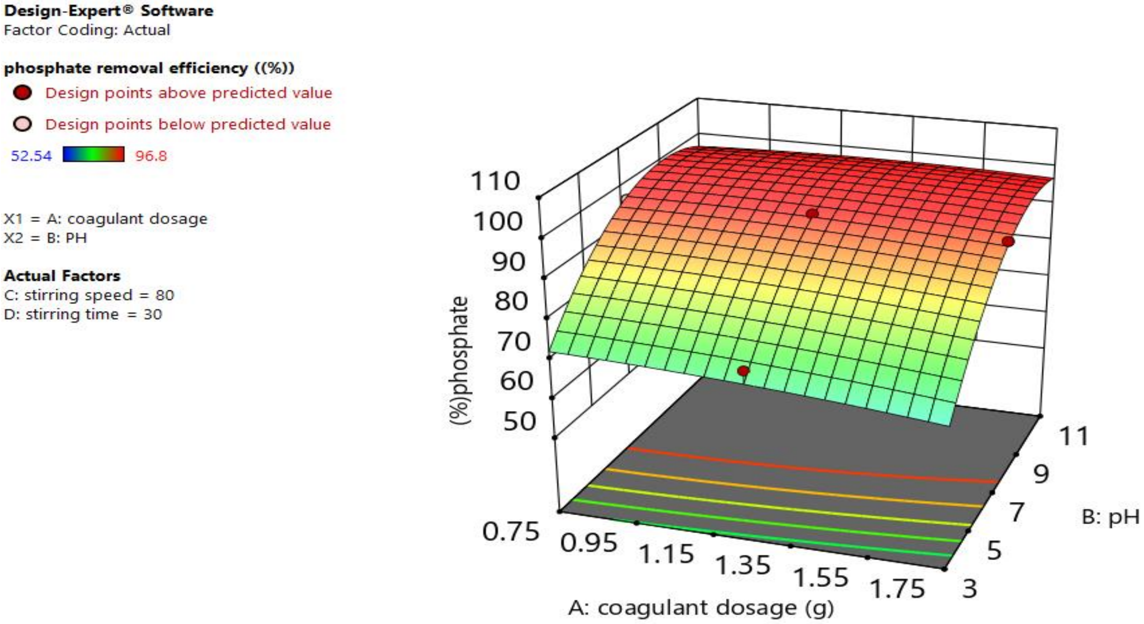


Figure 4. 60: 3D plot of the interaction effect of dose and pH on (%) of PO_4^{3-} using a blended coagulant

Interactions can be contour or 3D response surfaces impact as a result of the interactions of any two variables by holding the other value of the variable in the center, as shown in figure 4.60. The percent of phosphate removed using moringa is affected by pH and dosage. As a result, the removal efficiency is maximized when the dose and pH are moderate. The red and blue color on 3D surface indicates optimum and minimum point respectively.

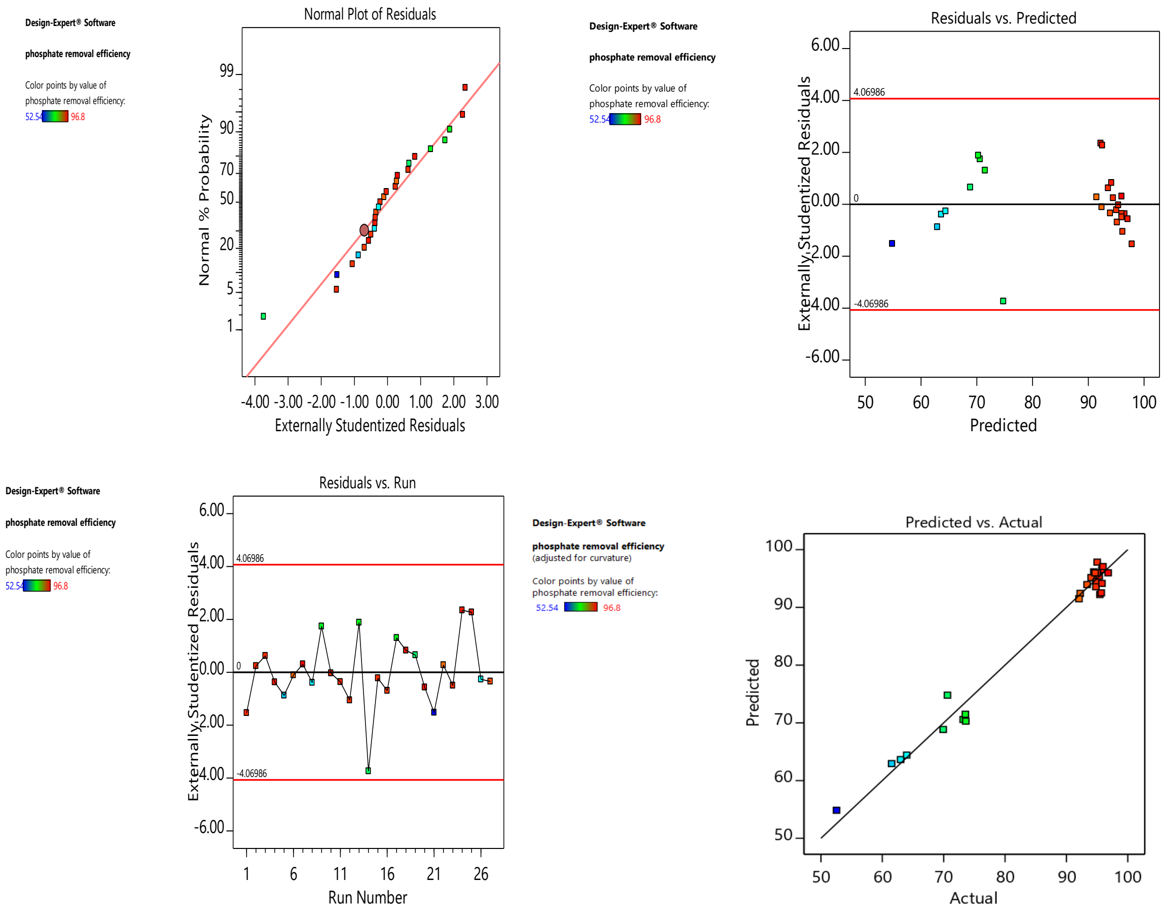


Figure 4. 61: Diagnostics graphs in terms of coded factors for (%) of PO_4^{3-}using blended coagulant

The normal probability plot, as shown in figure 4.61 above, indicates that the residuals follow a normal distribution; in this experiment, the points in the plots fit to a straight line in the figure, indicating that the quadratic polynomial model satisfies the assumptions of analysis of variance (ANOVA), i.e., the error distribution is approximately normal. The residuals should be structureless if the model is correct and the assumptions are met; in particular, they should be unconnected to any other variable, including the expected response. Plotting the residuals against the fitted (predicted) values is a straightforward check. The assumption of constant variance is tested by plotting the residuals against the rising expected response values. The plot shows random scatter which justifying no need for an alteration to minimize personal error.

4 .4 Optimization

Process optimization is the discipline of adjusting a process to optimize (make the best or most effective use of) a specified set of parameters while not violating any constraints. The most common objectives are to reduce costs while increasing throughput and, or efficiency. The best solution chosen based on the parameters by compromising percentage removal, economy, and energy carrying. The primary goals of RSM are to determine the optimal control variable settings that result in a maximum (or minimum) response over a specific region of interest, R (Khannous *et al.*, 2011). This requires having a ‘good’ fitting model that provides an adequate representation of the mean response because such a model is utilized the value of the optimum. Optimization techniques used in RSM depend on the nature of the fitted model. Optimization study of the experimental results performed by keeping responses within desired ranges by using responses surface methodology. And also, in this study, the responses, color, turbidity, COD, NO_3 , and PO_4^{3}-removal targeted to the maximum, and other design parameters kept in a range.

Therefore, in this investigation with the color, turbidity, COD, $NO_{3,}$ and PO_4^{3}-removal as the response for both coagulants, the response surfaces (3D) of the quadratic model with one variable kept at a central level and the other two varying within the experimental ranges are respectively shown in Figures above. The prominent trough in the response surfaces indicates that the optimal conditions were precisely located inside the design boundary. The results showed that four factors considered in this study to contribute an essential role of the removal efficiency of color, turbidity, COD nitrate, and phosphate. According to the experimentally analyzed result, the optimum conditions and responses obtained from the numerical optimization system for coagulant dosage, pH, agitation speed, and agitation time and their respective responses (color, turbidity, COD, NO_3 and PO_4^{3}- removal efficiencies) are listed out below in table 4.44. Even if all coagulants are best, the more effective result was found using the blended form of coagulant for coffee effluent treatment.

Table 4. 44: Optimum conditions from numerical optimization both process factors and responses

coagulants	Process factors (optimum values)				Respective responses				
	Dose (g)	pH	Stirring speed (rpm)	Stirring time (min)	Color (%)	Turbidity (%)	COD (%)	NO_3 (%)	PO_4^{3-} (%)
AS	0.98	8.76	76.67	21.69	99.19	97.52	97.43	99.44	99.36
Moringa	0.82	8.6	73.68	28.00	98.53	98.37	98.00	98.22	99.88
Aloe vera	1.65	8.94	70.96	32.64	98.87	96.74	96.94	99.99	99.26
Blended	0.75	8.76	80.73	19.23	99.99	98.70	98.41	99.12	99.63

4.4.1. Validation of the model

To validate this prediction, an experiment carried out, and the results computed with the prediction; as a result, the model was deemed accurate and reliable for predicting the percentage removal of raw wet coffee processing effluent wastewater using wet AS stem, moringa powder, aloe vera gel, and a blended form of the three coagulants mentioned above as coagulants. Based on the second-order models, numerical optimization carried out to maximize the removal efficiency using the response optimizer in Design expert®11.1.0.1.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Wet AS stem, moringa powder, aloe-vera gel and blended form of (wet AS stem, moringa powder, and aloe vera gel) were used for the treatment of raw wet coffee processing wastewater to remove color, turbidity, COD, NO_3, and PO_4^{3-}. This, study concluded that the treatment of coffee processing wastewater before disposal is vital to ensure the safety of our environment. Coagulation, applied in this study, represents a powerful treatment method for pollutants of coffee processing wastewater.

Thus, different types of experiments undertaken to address each of the four specific objectives of the study. The initial character of the coffee processing wastewater sample showed temperature 26.89 ^{O}C-pH -4.75, color – 3.00 Abs, turbidity- 145 NTU, COD – 7603.2mg/l, NO_3 – 20.21 mg/l, PO_4^{3-} – 9.10 mg/l. This shows that, the coffee processing wastewater was highly polluted, with suspended solid, color, organic and inorganic pollutant and acidic in pH.

The coagulation experiment proved coagulant dose, pH, stirring speed, and mixing time were essential design parameters for the removal of color, turbidity, COD, NO_3, and PO_4^{3-} from coffee processing wastewater using wet AS stem, moringa powder and, aloe-vera gel and blended form of (wet AS stem, moringa powder and, aloe-vera gel) as a coagulant.

The optimum conditions using blended coagulant for process factors and respective responses obtained from numerical optimization was 0.750g, 8.76, 80.73rpm, 19.23min, 99.99%, 98.70%, 98.41%, 99.12% and 99.63%.

The experimentally analyzed results were incorporated into the optimization process using CCD to verify the results. As a result, the experimental results were very close to what the model predicted.

Therefore, from this study, it can be concluded that, the removal efficiency of wet AS stem, moringa powder and aloe vera gel individually and the blended coagulant were outstanding in treating wet coffee processing wastewater to remove color, turbidity, COD, NO_3, and PO_4^{3-}. It can also be concluded that blended coagulant was the most effective in potential removal, for color, turbidity, COD, NO_3, and PO_4^{3-} than the three coagulants namely, acanthus sennii, moringa, and aloe vera.

5.2. Recommendations

Based on the finding of the current study, showed throughout the experimental processes as well as from optimized values and also the condition of design parameters on respective responses for this study, the following recommendations recommended:

- ✓ It is preferable to investigate the removal efficiency of the blended coagulant on coffee processing wastewater by varying other operational variables such as blending ratio and blending type, particularly blending the two most effective coagulants instead of blending three coagulants. On the other hand, it is preferable to investigate the efficiencies of coagulants by varying settling time, and temperature in detail to improve the removal efficiency of the system.
- ✓ Wet coffee processing effluent should meet the permissible limits of WHO guidelines before discharging to water bodies and environment.
- ✓ It is better to study the other responses like total suspended solids and BOD,
- ✓ It is better to determine whether the seed, root, and leaf of the AS plant are adequate for water and wastewater treatment. Due to its availability, it is better to test the efficiency of this plant for surface water treatment in a small household, particularly in the rural areas where the treatment plant not found. In addition, it should be checked the effectiveness of this plant in dry or powder form instead of using it in a wet form to use it for a long time.
- ✓ It is critical to raise awareness among farmers to plant and engage in AS, moringa, and aloe vera development throughout the countries, as well as to create markets for local people to sell the plant.
- ✓ The government should also focus on planting and utilizing these plants.
- ✓ Even if slugs' natural coagulants are biodegradable, further study is essential to confirm the proper management and reuse of thus coagulants sludge.

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APPENDIXES

Appendix A: Photographic Representation of laboratory works while determining the coagulants removal efficiencies of color, turbidity, COD, NO_3 and PO_4^{3-}

Appendix B: Raw water characteristics

Characteristics	Unit	Value
pH	_	4.75
Temperature	OC	26.89
Color	ABS	3.00
Turbidity	NTU	145
COD	mg/l	7603.2
Nitrate	mg/L	20.21
phosphate	mg/L	9.10

Appendix C: Experimental design matric and response based on the experimental run value color, turbidity, COD, nitrate and phosphate removal (%) for acanthus sennii stem based on central composite design (CCD).

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3	Response 4	Response 5
Run	coagulant dosage	PH	stirring speed	stirring time	color removal	turbidity removal	COD removal	Nitrate removal	phosphate removal
Unit	g	-	rpm	minute	(%)	(%)	(%)	(%)	(%)
1	1.25	11	80	30	96.25	95.46	95.57	94.69	95.79
2	0.75	11	120	45	95.75	95.35	96.2	94.06	93.59
3	1.75	7	80	30	96.76	96.42	95.51	97.81	95.8
4	0.75	7	80	30	98.01	97.03	96.06	98.34	96.86
5	1.75	3	40	15	84.56	88.99	87.58	77.78	69.65
6	1.75	11	40	15	96.43	95.76	95.74	92.88	96.13
7	1.25	7	80	30	98.41	97.5	96.48	98.36	97.02
8	0.75	3	40	45	83.67	88.74	87.63	69.98	71.25
9	0.75	3	40	15	84.93	89.75	88.45	72.02	65.98
10	1.25	7	120	30	97.98	95.59	96.76	93.98	96.5
11	1.25	7	80	30	98.35	96.38	96.44	97.36	97.53
12	1.75	11	120	45	96.23	94.78	94.9	91.26	96.76
13	1.25	3	80	30	85.3	90.16	87.75	75.33	68.11
14	0.75	3	120	15	86.73	89.65	88.68	72.43	63.99
15	1.75	11	120	15	96.87	95.88	95.57	93.43	96.25
16	0.75	11	40	45	95.87	96.04	94.98	95.9	96.04
17	1.75	3	120	15	84.37	88.65	88.06	83.55	66.98
18	1.25	7	80	45	98.23	95.77	96.38	95.52	96.79
19	0.75	3	120	45	85.83	88.56	88.34	70.98	67.33
20	1.25	7	80	15	97.61	96.35	96.42	96.38	96.91
21	1.75	3	40	45	83.49	87.92	87.58	71.36	70.34
22	1.25	7	40	30	96.98	96.32	96.42	95.34	96.74
23	1.25	7	80	30	97.4	96.34	97.39	98.37	96.37
24	0.75	11	120	15	97.03	95.55	97.13	96.02	96.02
25	1.75	11	40	45	95.89	95.75	95.36	90.71	96.87
26	1.75	3	120	45	83.32	86.82	87.54	78.64	68.99
27	0.75	11	40	15	95.93	95.85	95.56	92.98	94.26

Appendix C: Experimental design matric and response based on the experimental run value color, turbidity, COD, nitrate and phosphate removal (%) for moringa powder based on central composite design (CCD).

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3	Response 4	Response 5
Run	coagulant dosage	PH	stirring speed	stirring time	color removal	turbidity removal	COD removal	Nitrate removal	Phosphate removal
Unit	g	-	rpm	minute	(%)	(%)	(%)	(%)	(%)
1	1.25	11	80	30	94.53	96.5	96.55	94.08	97.5
2	0.75	11	120	45	95.81	96.19	96.51	94.07	97.92
3	1.75	7	80	30	97.1	96.91	96.89	95.51	96.82
4	0.75	7	80	30	96.73	97.21	96.82	95.63	97.81
5	1.75	3	40	15	84.63	90.12	87.67	79.74	82.85
6	1.75	11	40	15	97.23	96.29	96.2	92.69	98.12
7	1.25	7	80	30	97.52	97.3	96.98	97.1	98.12
8	0.75	3	40	45	88.47	89.27	87.63	72.08	63.09
9	0.75	3	40	15	89.07	90.16	88.43	80.68	71.53
10	1.25	7	120	30	97.36	96.04	97.01	95.69	95.48
11	1.25	7	80	30	96.63	97.13	96.81	97.83	95.92
12	1.75	11	120	45	93.67	95.84	96.3	93.43	97.46
13	1.25	3	80	30	85.47	88.78	88.34	78.64	65.43
14	0.75	3	120	15	84.91	88.47	88.43	84.96	73.95
15	1.75	11	120	15	97.01	95.67	96.84	91.24	96.69
16	0.75	11	40	45	92.21	96.57	96.68	92.26	97.57
17	1.75	3	120	15	80.57	89.09	88.38	77.55	71.53
18	1.25	7	80	45	96.07	95.1	96.81	97.01	96.14
19	0.75	3	120	45	83.77	89.1	88.47	82.54	56.38
20	1.25	7	80	15	96.32	97	96.93	95.61	96.36
21	1.75	3	40	45	84.37	87.28	87.58	76.45	79.19
22	1.25	7	40	30	97.4	97.03	96.67	96.71	96.69
23	1.25	7	80	30	96.54	98.12	97.25	96.11	95.87
24	0.75	11	120	15	97.82	95.86	96.63	95.71	98.23
25	1.75	11	40	45	95.77	96.17	94.8	91.79	98.78
26	1.75	3	120	45	83.33	84.81	87.54	78.64	62.47
27	0.75	11	40	15	97.53	96.53	96.43	96.43	96.83

Appendix D: Experimental design matric and response based on the experimental run value color, turbidity, COD, nitrate and phosphate removal (%) for aloe vera gel based on central composite design (CCD).

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1		Response 2	Response 3	Response 4	Response 5
Run	coagulant dosage	PH	stirring speed	stirring time	color removal		turbidity removal	COD removal	Nitrate removal	phosphate removal
Unit	g	-	rpm	minute	(%)		(%)	(%)	(%)	(%)
1	1.25	11	80	30	97.57		95.42	94.56	96.36	97.2
2	0.75	11	120	45	96.62		94.56	95.25	95.84	96.52
3	1.75	7	80	30	97.62		95.67	96.89	96.81	97.01
4	0.75	7	80	30	98.12		96.21	96.51	98.04	97.02
5	1.75	3	40	15	86.7		87.81	88.05	72.3	77.92
6	1.75	11	40	15	96.57		94.44	95.17	96.62	93.24
7	1.25	7	80	30	98.67		96.67	96.01	98.68	98.31
8	0.75	3	40	45	85.43		88.78	87.54	68.71	69.84
9	0.75	3	40	15	86.5		89.63	87.63	73.52	78.01
10	1.25	7	120	30	98.5		96.62	96.11	97.96	96.14
11	1.25	7	80	30	98.23		96.21	95.95	98.21	98.78
12	1.75	11	120	45	96.43		94.48	95.71	96.42	93.67
13	1.25	3	80	30	87.6		88.71	87.92	71.92	69.88
14	0.75	3	120	15	88.87		89.99	89.12	72.99	67.52
15	1.75	11	120	15	96.97		95.01	96.02	97.89	94.13
16	0.75	11	40	45	95.99		94.98	95.61	95.97	96.71
17	1.75	3	120	15	86.1		85.12	90.56	71.8	67.36
18	1.25	7	80	45	97.53		96.31	96.43	97.26	98.12
19	0.75	3	120	45	87.81		86.78	87.67	75.51	67.79
20	1.25	7	80	15	98.32		96.6	96.51	97.91	98.01
21	1.75	3	40	45	84.9		86.96	87.58	65.98	68.46
22	1.25	7	40	30	97		95.06	95.01	96.26	96.47
23	1.25	7	80	30	97.5		96.61	95.06	96.87	97.31
24	0.75	11	120	15	97.13		96.24	96.01	96.26	96.23
25	1.75	11	40	45	96.24		96.4	95.63	95.35	93.67
26	1.75	3	120	45	83.5		84.79	89.01	67.9	65.87
27	0.75	11	40	15	96.33		96.53	95.59	95.43	97.56

Appendix E: Experimental design matric and response based on the experimental run value color, turbidity, COD, nitrate and phosphate removal (%) for blend form of the three-coagulant based on central composite design (CCD).

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3	Response 4	Response 5
Run	coagulant dosage	B:PH	stirring speed	stirring time	color removal	turbidity removal	COD removal	Nitrate removal	phosphate removal
	g	-	rpm	minute	(%)	(%)	(%)	(%)	(%)
1	1.25	11	80	30	97.7	95.54	95.5	95.26	95.02
2	0.75	11	120	45	96.75	95.33	96.7	92.12	94.87
3	1.75	7	80	30	99.13	96.47	96.3	95.23	94.81
4	0.75	7	80	30	98.07	96.27	98.01	95.38	95.79
5	1.75	3	40	15	88.53	87.76	89.5	70.98	61.52
6	1.75	11	40	15	98.9	95.69	96.76	93.14	92.25
7	1.25	7	80	30	99.99	97.02	98.24	96.71	96.8
8	0.75	3	40	45	85.63	85.32	89.38	72.26	62.99
9	0.75	3	40	15	85.83	89.53	89.89	75.55	73.18
10	1.25	7	120	30	97.99	96.12	98.3	93.33	95.35
11	1.25	7	80	30	98.68	98.89	96.98	95.08	95.02
12	1.75	11	120	45	95.67	91.14	94.63	90.88	94.47
13	1.25	3	80	30	86.83	88.52	87.54	76.64	73.61
14	0.75	3	120	15	86.6	87.38	87.8	71.71	70.62
15	1.75	11	120	15	97.73	94.23	97.22	89.86	94.69
16	0.75	11	40	45	97.87	96.1	97.2	92.26	94.03
17	1.75	3	120	15	86.7	84.57	87.63	69.38	73.54
18	1.25	7	80	45	97.97	95.37	97.1	95.11	95.79
19	0.75	3	120	45	82.62	87.28	87.71	72.52	69.93
20	1.25	7	80	15	99.27	96.7	97.31	96.6	95.95
21	1.75	3	40	45	86.6	85.45	87.67	68.12	52.54
22	1.25	7	40	30	96.33	94.14	98.01	93.07	92.05
23	1.25	7	80	30	97.9	97.01	95.56	96.89	94.67
24	0.75	11	120	15	96.3	95.87	97.2	94.12	95.46
25	1.75	11	40	45	98.07	96.03	95.35	93.27	95.68
26	1.75	3	120	45	85.27	80.48	87.54	63.8	63.98
27	0.75	11	40	15	97.57	96.06	97.13	93.62	93.37

Appendix G: Experimental runs and results after treatment including pH after TT

Experiment: 1 System: Jar test Coagulant type: AS stem Date:29/6/2013(05/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed = 80	0.11	6.58	2.44	1.07	0.38	8.55
PH = 11	Settling time = 45						
Stirring time = 30	Temp. (^{o}C) = 22.5						

Experiment: 2 System: Jar test Coagulant type: AS stem Date: (06/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed =120	0.13	6.74	2.59	1.20	0.58	8.48
PH = 11	Settling time = 45						
Stirring time =45	Temp. (^{o}C) = 24						

Experiment: 3 System: Jar test Coagulant type: AS stemDate:1/7/2013(07/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed = 80	0.10	5.19	2.42	0.44	0.38	6.78
PH = 7	Settling time = 45						
Stirring time = 30	Temp. (^{o}C) = 22.9						

Experiment: 4 System: Jar test Coagulant type: AS stemDate:2/7/2013(08/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed = 80	0.06	4.31	2.55	0.34	0.27	6.59
PH = 7	Settling time = 45						
Stirring time =30	Temp. (^{o}C) = 24.1						

Experiment: 5 System: Jar test Coagulant type: AS stem Date: (09/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed = 40	0.46	15.96	0.54	4.49	2.76	3.31
PH = 3	Settling time = 45						

Stirring time =15	Temp. (^{o}C) = 23.2						

Experiment: 6 System: Jar test Coagulant type: AS stemDate:4/7/2013(10/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 1.75	Stirring speed = 40	0.11	6.15	2.48	1.44	0.35	8.49
PH = 11	Settling time = 45						
Stirring time =15	Temp. (^{o}C) = 23.2						

Experiment: 7 System: Jar test Coagulant type: AS stemDate:5/7/2013(11/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) =1.25	Stirring speed = 80	0.05	3.63	2.65	0.33	0.29	6.53
PH = 7	Settling time = 45						
Stirring time = 30	Temp. (^{o}C) = 24.2						

Experiment: 8 System: Jar test Coagulant type: AS stemDate:6/7/2013(12/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) =0.75	Stirring speed = 40	0.49	16.33	0.55	6.07	2.62	3.21
PH = 3	Settling time = 45						
Stirring time = 45	Temp. ((^{o}C) = 24.3						

Experiment: 9 System: Jar test Coagulant type: AS stemDate:7/7/2013(13/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) =0.75	Stirring speed = 40	0.45	14.86	0.75	5.65	3.10	3.17
PH = 3	Settling time = 45						
Stirring time = 15	Temp. (^{o}C) = 24.3						

Experiment: 10 System: Jar test Coagulant type: AS stemDate:8/7/2013(14/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.25	Stirring speed = 120	0.05	6.39	2.72	1.22	0.28	6.49
PH = 7	Settling time = 45						
Stirring time = 30	Temp. (^{o}C) = 22.2						

Experiment: 11 System: Jar test Coagulant type: AS stemDate:9/7/2013(15/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.25	Stirring speed = 80	0.05	5.25	2.64	0.53	0.22	6.57
PH = 7	Settling time = 45						
Stirring time = 30	Temp. (^{o}C) = 24.2						

Experiment: 12 System: Jar test Coagulant type: AS stem Date:10/7/2013(16/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.75	Stirring speed = 120	0.09	5.97	2.44	1.33	0.34	8.48
PH = 11	Settling time = 45						
Stirring time = 45	Temp. (^{o}C) = 24.3						

Experiment: 13 System: Jar test Coagulant type: AS stem Date:11/7/2013(17/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.25	Stirring speed = 80	0.44	14.27	0.58	4.99	2.90	3.24
PH = 3	Settling time = 45						
Stirring time = 45	Temp. ((^{o}C) = 25.1						

Experiment: 14 System: Jar test Coagulant type: AS stem Date:12/7/2013(18/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =0.75	Stirring speed = 120	0.40	15.01	0.80	5.57	3.28	3.19
PH = 3	Settling time = 45						
Stirring time = 15	Temp. ($^{o}{}_{C}$) = 24.9						

Experiment: 15 System: Jar test Coagulant type: AS stem Date:13/7/2013(19/3/2021)
Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.75	Stirring speed = 120	0.09	5.97	2.44	1.33	0.34	8.51
PH = 11	Settling time = 45						
Stirring time = 15	Temp. ($^{o}{}_{C}$) = 24.3						

Experiment: 16 System: Jar test Coagulant type: AS stem Date:14/7/2013(20/3/2021)
Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =0.75	Stirring speed = 40	0.12	5.74	2.30	0.83	0.36	8.89
PH = 11	Settling time = 45						
Stirring time = 45	Temp. ($^{o}{}_{C}$) = 25.4						

Experiment: 17 System: Jar test Coagulant type: AS stem Date:15/7/2013(21/3/2021)
Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.75	Stirring speed = 120	0.47	16.46	0.65	3.32	3.00	3.18
PH = 3	Settling time = 45						
Stirring time = 15	Temp. ($^{o}{}_{C}$) = 25.2						

Experiment: 18 System: Jar test Coagulant type: AS stem Date:16/7/2013(22/3/2021)
Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.25	Stirring speed = 80	0.05	6.13	2.65	0.91	0.29	6.71
PH = 7	Settling time = 45						
Stirring time = 15	Temp. (^{o}C) = 24.2						

Experiment: 19 System: Jar test Coagulant type: AS stem Date:17/7/2013(23/3/2021)
Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.43	16.59	0.72	5.86	2.97	3.25
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.9						

Experiment: 20 System: Jar test Coagulant type: AS stem Date:18/7/2013(24/3/2021)
Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3} (mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.07	5.29	2.64	0.73	0.28	6.56
PH = 7	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24.2						

Experiment: 21 System: Jar test Coagulant type: AS stem Date:19/7/2013(25/3/2021)
Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.50	17.52	0.54	5.79	2.70	3.16
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 23.2						

Experiment: 22 System: Jar test Coagulant type: AS stem Date:20/7/2013(26/3/2021)
Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3}-(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 40	0.09	5.34	2.64	0.94	0.30	6.54
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 25.8						

Experiment: 23 System: Jar test Coagulant type: AS stem Date:21/7/2013(27/3/2021)
Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3}-(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.08	5.31	2.87	0.33	0.33	6.56
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 25.8						

Experiment: 24 System: Jar test Coagulant type: AS stem Date:22/7/2013(28/3/2021)
Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3}-(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.09	6.45	2.81	0.80	0.36	8.78
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24						

Experiment: 25 System: Jar test Coagulant type: AS stem Date:23/7/2013(29/3/2021)
Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3}-(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.12	6.16	2.39	1.88	0.28	8.45
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 23.2						

Experiment: 26 System: Jar test Coagulant type: AS stem Date:24/7/2013(30/3/2021)
Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.50	19.11	0.53	4.32	2.82	3.59
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (${}^{o}{}_{C}$) = 25.2						

Experiment: 27System: Jar test Coagulant type: AS stem Date:25/7/2013(31/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.12	6.02	2.44	1.42	0.52	8.59
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (O_c) = 25.4						

Appendix G: Experimental results for moringa powder usage of coagulation and flocculation process for coffee processing wastewater effluent.

Experiment: 1 System: Jar test Coagulant type: Moringa powder

Date:29/6/2013(05/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.16	5.08	2.67	1.20	0.22	8.45
PH = 11	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (${}^{o}{}_{C}$) = 22.2						

Experiment: 2 System: Jar test Coagulant type: Moringa powder

Date:30/6/2013(06/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.13	5.52	2.66	1.20	0.19	8.68
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (${}^{o}{}_{C}$) = 24						

Experiment: 3 System: Jar test Coagulant type: Moringa powder

Date:1/7/2013(07/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 80	0.09	4.48	2.75	0.91	0.47	6.59
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 22.9						

Experiment: 4 System: Jar test Coagulant type: powder Date:2/7/2013(08/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 80	0.10	4.05	2.73	0.88	0.20	6.78
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 24.1						

Experiment: 5 System: Jar test Coagulant type: Moringa powder Date:3/7/2013(09/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.46	14.33	0.56	4.09	1.56	3.29
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 23.2						

Experiment:6 System: Jar test Coagulant type: Moringa powder Date:4/7/2013(10/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.08	5.38	2.59	1.48	0.17	8.78
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 23.2						

Experiment:7 System: Jar test Coagulant type: Moringa powder Date:5/7/2013(11/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.13	4.26	2.72	0.80	0.22	6.29
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 224.2						

Experiment:8 System: Jar test Coagulant type: Moringa powder
Date:6/7/2013(12/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.35	15.56	0.55	5.64	3.36	3.18
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.3						

Experiment:9 System: Jar test Coagulant type: Moringa powder
Date:7/7/2013(13/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.33	14.27	0.74	3.90	2.59	3.38
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24.3						

Experiment:10 System: Jar test Coagulant type: Moringa powder
Date:8/7/2013(14/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 120	0.07	5.74	2.78	0.87	0.41	6.62
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 22.2						

Experiment:11 System: Jar test Coagulant type: Moringa powder
Date:9/7/2013(15/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.13	4.16	2.73	0.44	0.37	6.54
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 24.2						

Experiment:12 System: Jar test Coagulant type: Moringa powder
Date:10/7/2013(16/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.19	6.03	2.61	1.33	0.23	8.62
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.3						

Experiment:13 System: Jar test Coagulant type: Moringa powder
Date:11/7/2013(17/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.44	16.27	0.72	16.27	4.32	3.34
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 25.1						

Experiment:14 System: Jar test Coagulant type: Moringa powder
Date:12/7/2013(18/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.45	16.72	0.74	3.04	2.37	3.23
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24.9						

Experiment:15 System: Jar test Coagulant type: Moringa powder
Date:13/7/2013(19/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.09	6.28	2.74	1.77	0.30	8.91
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24.3						

Experiment:16 System: Jar test Coagulant type: Moringa powder
Date:14/7/2013(20/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =0.75	Stirring speed(rpm) = 40	0.23	4.97	2.70	1.56	0.22	8.56
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 25.4						

Experiment:17 System: Jar test Coagulant type: Moringa powder
Date:15/7/2013(21/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.75	Stirring speed(rpm) = 40	0.58	15.82	0.73	4.54	2.59	3.22
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 25.2						

Experiment:18 System: Jar test Coagulant type: Moringa powder
Date:16/7/2013(22/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) =1.25	Stirring speed(rpm) = 80	0.12	7.11	2.73	0.58	0.35	6.71
PH = 7	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.2						

Experiment:19 System: Jar test Coagulant type: Moringa powder
Date:17/7/2013(23/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.49	15.81	0.75	3.53	3.97	3.15
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.9						

Experiment:20 System: Jar test Coagulant type: Moringa powder
Date:18/7/2013(24/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.11	4.35	2.76	0.89	0.33	6.49
PH = 7	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24.2						

Experiment:21 System: Jar test Coagulant type: Moringa powder
Date:19/7/2013(25/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.47	18.44	0.54	4.76	1.89	3.19
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 23.2						

Experiment:22 System: Jar test Coagulant type: Moringa powder
Date:20/7/2013(26/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 40	0.03	4.31	2.80	0.66	0.30	6.52
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 25.8						

Experiment:23 System: Jar test Coagulant type: Moringa powder
Date:21/7/2013(27/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.10	2.73	2.84	0.79	0.38	6.57
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 24.2						

Experiment:24 System: Jar test Coagulant type: Moringa powder
Date:22/7/2013(28/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.07	6.00	2.69	0.87	0.16	8.56
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24						

Experiment:25 System: Jar test Coagulant type: Moringa powder
Date:23/7/2013(29/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.13	5.55	2.25	1.66	0.11	8.46
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 23.2						

Experiment:26 System: Jar test Coagulant type: Moringa powder
Date:24/7/2013(30/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.50	22.03	0.53	4.32	3.42	3.13
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 25.2						

Experiment:27 System: Jar test Coagulant type: Moringa powder
Date:25/7/2013(31/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.07	5.03	2.64	0.72	0.29	8.45
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. ($^{o}{}_{C}$) = 25.4						

Appendix H: Experimental results for Aloe vera gel usage of coagulation and flocculation process for coffee processing wastewater effluent.

Experiment: 1 System: Jar test Coagulant type: aloe vera, Date:29/6/2013(05/3/2021)

Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.07	6.64	2.20	0.74	0.22	9.14
PH = 11	Settling time(min) = 45						
Stirring time(min)= 30	Temp. ($^{o}{}_{C}$) = 22.2						

Experiment: 2 System: Jar test Coagulant type: aloe vera, Date:30/6/2013(07/3/2021)

Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.10	7.89	2.36	0.84	0.32	9.31
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. ($^{o}{}_{C}$) = 24						

Experiment: 3 System: Jar test Coagulant type: aloe vera gel, Date:1/7/2013(08/3/2021)

Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 80	0.07	6.28	2.75	0.64	0.23	6.61
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. ($^{o}{}_{C}$) = 22.9						

Experiment: 4 System: Jar test Coagulant type: aloe vera gel, powder Date:2/7/2013(09/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 80	0.06	5.50	2.66	0.40	0.27	6.56
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp (^{o}C) = 24.1						

Experiment: 5 System: Jar test Coagulant type: aloe vera gel, powder Date:3/7/2013(10/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.40	17.68	0.65	5.60	2.01	3.57
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 23.2						

Experiment: 6 System: Jar test Coagulant type: aloe vera gel, Date:4/7/2013(11/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.10	8.06	2.34	0.68	0.62	9.08
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 23.2						

Experiment: 7 System: Jar test Coagulant type: aloe vera gel, Date:5/7/2013(12/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.04		2.68	4.99	0.27	6.52
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp (^{o}C) = 24.2						

Experiment: 8 System: Jar test Coagulant type: aloe vera gel, Date:6/7/2013(13/3/2021)
Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.44	16.27	0.53	6.32	2.74	3.65
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.3						

Experiment: 9 System: Jar test Coagulant type: aloe vera gel, Date:6/7/2013(14/3/2021)
Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.41	15.04	0.55	5.35	2.00	3.34
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24.3						

Experiment: 10 System: Jar test Coagulant type: aloe vera gel, Date:7/7/2013(15/3/2021)
Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 120	0.05	4.90	2.57	0.41	0.35	6.53
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 22.2						

Experiment: 11 System: Jar test Coagulant type: aloe vera gel, Date:8/7/2013(16/3/2021)
Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.05	5.50	2.53	0.36	0.11	6.64
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^{o}C) = 24.2						

Experiment: 12 System: Jar test Coagulant type: aloe vera gel, Date:9/7/2013(17/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.11	8.00	2.47	0.72	0.58	9.56
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (°C) = 24.3						

Experiment: 13 System: Jar test Coagulant type: aloe vera gel, Date:10/7/2013(18/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.37	16.37	0.62	5.67	2.74	3.21
PH = 3	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (°C) = 25.1						

Experiment: 14 System: Jar test Coagulant type: aloe vera gel, Date:11/7/2013(19/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.33	14.51	0.90	5.46	2.96	3.45
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp (°C) = 25.1						

Experiment: 15 System: Jar test Coagulant type: aloe vera gel, Date:11/7/2013(20/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.09	7.24	2.54	0.43	0.53	9.12
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (°C) = 24.3						

Experiment: 16 System: Jar test Coagulant type: aloe vera gel, Date:12/7/2013(21/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.12	7.28	2.45	0.81	0.30	9.06
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 25.4						

Experiment: 17 System: Jar test Coagulant type: aloe vera gel, Date:13/7/2013(22/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.42	21.58	1.25	5.70	2.97	3.52
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 25.2						

Experiment: 18 System: Jar test Coagulant type: aloe vera gel, Date:14/7/2013(23/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.07	5.35	2.69	0.55	0.17	6.59
PH = 7	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.2						

Experiment: 19 System: Jar test Coagulant type: aloe vera gel, Date:15/7/2013(24/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.05	19.17	2.66	4.95	2.93	3.21
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.9						

Experiment: 20 System: Jar test Coagulant type: aloe vera gel, Date:16/7/2013(25/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.05	4.16	2.66	0.42	0.18	3.56
PH = 7	Settling time(min) = 45						
Stirring time(min)= 15	Temp (^{o}C) = 24.2						

Experiment: 21 System: Jar test Coagulant type: aloe vera gel,
Date:17/7/2013(26/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage (g) = 1.75	Stirring speed(rpm) = 40	0.45	18.91	0.54	6.88	2.87	3.63
PH = 3	Settling time(min) = 45						
Stirring time (min)= 45	Temp. (^{o}C) = 23.2						

Experiment: 22 System: Jar test Coagulant type: aloe vera gel,
Date:18/7/2013(27/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g/) = 1.25	Stirring speed(rpm) = 40	0.09	7.16	2.30	0.76	0.32	6.57
PH = 7	Settling time(min) = 45						
Stirring time (min)= 30	Temp. (^{o}C) = 25.8						

Experiment: 23 System: Jar test Coagulant type: aloe vera gel,
Date:19/7/2013(28/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.08	4.92	2.32	0.63	0.15	6.61
PH = 7	Settling time(min) = 45						
Stirring time (min)= 30	Temp. (^{o}C) = 24.2						

Experiment: 24 System: Jar test Coagulant type: aloe vera gel,
Date:20/7/2013(29/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.09	5.45	2.54	0.76	0.34	9.42
PH = 11	Settling time(min) = 45						
Stirring time (min)= 15	Temp. (^{o}C) = 24						

Experiment: 25 System: Jar test Coagulant type: aloe vera gel,
Date:21/7/2013(30/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.11	5.22	2.45	0.94	0.58	9.34
PH = 11	Settling time(min) = 45						
Stirring time (min)= 45	Temp. (^{o}C) = 23.2						

Experiment: 26 System: Jar test Coagulant type: aloe vera gel,
Date:22/7/2013(30/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.50	22.05	0.88	6.49	3.11	3.65
PH = 3	Settling time(min) = 45						
Stirring time (min)= 45	Temp. (^{o}C) = 25.2						

Experiment: 27 System: Jar test Coagulant type: aloe vera gel,
Date:23/7/2013(31/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.11	5.03	2.44	0.92	0.22	9.03
PH = 11	Settling time(min) = 45						
Stirring time (min)= 15	Temp. (^{o}C) = 25.4						

Appendix I: Experimental results for blended form of the three-coagulant usage of coagulation and flocculation process for coffee processing wastewater effluent.

Experiment: 1 System: Jar test Coagulant type: blended form of the three-coagulant
Date:29/6/2013(05/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.01	0.96	6.467	0.96	0.45	8.96
PH = 11	Settling time(min) = 45						
Stirring time(min)=30	Temp. ($^{o}{}_{C}$) = 22.2						

Experiment: 2 System: Jar test Coagulant type: blended form of the three coagulant
Date:30/6/2013(06/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.10	6.78	2.71	1.59	0.47	8.87
PH = 11	Settling time(min) = 45						
Stirring time (min)= 45	Temp. ($^{o}{}_{C}$) = 24						

Experiment: 3 System: Jar test Coagulant type: blended form of the three coagulant
Date:1/7/2013(07/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 80	0.03	5.12	2.61	0.96	0.47	6.55
PH =7	Settling time(min) = 45						
Stirring time (min)= 30	Temp. ($^{o}{}_{C}$) = 22.9						

Experiment: 4 System: Jar test Coagulant type: blended form of the three coagulant
Date:2/7/2013(08/3/2021) Day Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	$NO_3(mg/l)$	$PO_4^{3-}(mg/l)$	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 80	0.06	5.41	3.02	0.93	0.38	6.49
PH =7	Settling time(min) = 45						
Stirring time (min)= 30	Temp. ($^{o}{}_{C}$) = 24.1						

Experiment: 5 System: Jar test Coagulant type: blended form of the three coagulant
Date:3/7/2013(09/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.34	17.75	1.00	5.86	3.50	3.12
PH =3	Settling time(min) = 45						
Stirring time (min)= 15	Temp. (O_c) = 23.2						

Experiment: 6 System: Jar test Coagulant type: blended form of the three coagulant
Date:4/7/2013(10/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.03	6.25	2.72	1.39	0.71	8.92
PH =11	Settling time(min) = 45						
Stirring time (min)= 15	Temp. ($^{o}{}_{C}$) = 23.2						

Experiment: 7 System: Jar test Coagulant type: blended form of the three coagulant
Date:5/7/2013(11/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.06	4.32	2.44	0.66	0.29	6.51
PH =7	Settling time(min) = 45						
Stirring time (min)= 30	Temp. ($^{o}{}_{C}$) = 24.2						

Experiment: 8 System: Jar test Coagulant type: blended form of the three coagulant
Date:6/7/2013(12/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.43	21.29	0.97	5.61	3.37	3.41
PH =3	Settling time(min) = 45						
Stirring time (min)= 45	Temp. ($^{o}{}_{C}$) = 24.3						

Experiment: 9 System: Jar test Coagulant type: blended form of the three coagulant
Date:7/7/2013(13/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.43	15.18	1.09	4.94	2.44	3.24
PH =3	Settling time(min) = 45						
Stirring time (min)= 15	Temp. (^{o}C) = 24.3						

Experiment: 10 System: Jar test Coagulant type: blended form of the three coagulant Date:8/7/2013(14/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 120	0.06	5.63	2.78	1.35	0.42	6.53
PH =7	Settling time(min) = 45						
Stirring time (min)= 30	Temp. (^{o}C) = 22.2						

Experiment: 11 System: Jar test Coagulant type: blended form of the three coagulant Date:9/7/2013(15/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 120	0.06	5.63	2.78	1.35	0.42	6.23
PH =7	Settling time(min) = 45						
Stirring time (min)= 30	Temp. (^{o}C) = 24.2						

Experiment: 12 System: Jar test Coagulant type: blended form of the three coagulant Date:10/7/2013(16/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.13	12.85	2.21	1.84	0.50	8.99
PH = 11	Settling time(min) = 45						
Stirring time (min)= 45	Temp. (^{o}C) = 24.3						

Experiment: 13 System: Jar test Coagulant type: blended form of the three coagulant Date:11/7/2013(17/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.40	16.65	0.53	4.72	2.40	3.23
PH = 3	Settling time(min) = 45						
Stirring time (min)= 30	Temp. ($^{o}{}_{C}$) = 25.1						

Experiment: 14 System: Jar test Coagulant type: blended form of the three coagulant Date:15/7/2013(18/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.40	18.30	0.59	5.72	2.67	3.43
PH = 3	Settling time(min) = 45						
Stirring time (min)= 15	Temp. ($^{o}{}_{C}$) = 24.9						

Experiment: 15 System: Jar test Coagulant type: blended form of the three coagulant Date:13/7/2013(19/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.07	8.37	2.83	2.05	0.48	8.86
PH = 11	Settling time(min) = 45						
Stirring time (min)= 15	Temp. ($^{o}{}_{C}$) = 24.3						

Experiment: 16 System: Jar test Coagulant type: blended form of the three coagulant Date:14/7/2013(20/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.06	5.66	2.82	1.56	0.54	8.83
PH = 11	Settling time(min) = 45						
Stirring time (min)= 45	Temp. ($^{o}{}_{C}$) = 25.4						

Experiment: 17 System: Jar test Coagulant type: blended form of the three coagulant Date:15/7/2013(21/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.40	22.37	0.55	6.19	2.41	3.32
PH = 3	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 25.4						

Experiment: 18 System: Jar test Coagulant type: blended form of the three coagulant
Date:16/7/2013(22/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.06		2.80	6.71	0.99	6.19
PH = 7	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.2						

Experiment: 19 System: Jar test Coagulant type: blended form of the three coagulant
Date:17/7/2013(23/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.52	18.44	0.57	5.55	2.74	3.45
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 24.9						

Experiment: 20 System: Jar test Coagulant type: blended form of the three coagulant
Date:18/7/2013(24/3/2021) Day: Sunday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.02	4.79	2.85	0.63	0.37	6.12
PH = 7	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 24.2						

Experiment: 21 System: Jar test Coagulant type: blended form of the three coagulant
Date:19/7/2013(25/3/2021) Day: Monday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.40	21.10	0.56	6.44	4.32	3.22
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^oC) = 23.2						

Experiment: 22 System: Jar test Coagulant type: blended form of the three coagulant Date:20/7/2013(26/3/2021) Day: Tuesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 40	0.11	8.50	3.02	1.40	0.72	6.13
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^oC) = 25.8						

Experiment: 23 System: Jar test Coagulant type: blended form of the three coagulant Date:21/7/2013(27/3/2021) Day: Wednesday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.25	Stirring speed(rpm) = 80	0.001	4.34	3.07	0.63	0.49	6.35
PH = 7	Settling time(min) = 45						
Stirring time(min)= 30	Temp. (^oC) = 24.2						

Experiment: 24 System: Jar test Coagulant type: blended form of the three coagulant Date:22/7/2013(28/3/2021) Day: Thursday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 120	0.11	5.99	2.82	1.19	0.41	8.89
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^oC) = 24						

Experiment: 25 System: Jar test Coagulant type: blended form of the three coagulant Date:23/7/2013(29/3/2021) Day: Friday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 40	0.06	5.76	2.39	1.36	0.39	8.91
PH = 11	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 23.2						

Experiment: 26 System: Jar test Coagulant type: blended form of the three coagulant
Date:24/7/2013(30/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 1.75	Stirring speed(rpm) = 120	0.44	28.30	0.53	7.32	3.28	3.25
PH = 3	Settling time(min) = 45						
Stirring time(min)= 45	Temp. (^{o}C) = 25.2						

Experiment: 27 System: Jar test Coagulant type: blended form of the three coagulant
Date:25/7/2013(31/3/2021) Day: Saturday

Coffee processing effluent treatment							
Design parameters		ABS	NTU	FAS	NO_3(mg/l)	PO_4^{3-}(mg/l)	PH after treatment
Dosage(g) = 0.75	Stirring speed(rpm) = 40	0.07	5.71	2.81	1.29	0.60	8.79
PH = 11	Settling time(min) = 45						
Stirring time(min)= 15	Temp. (^{o}C) = 25.4						