

COAGULATION-FLOCCULATION KINETICS AND OPTIMIZATION OF *CACTUS OPUNTIA* JUICE AS BIO- FLOCCULANT IN INDUSTRIAL WASTEWATER TREATMENT

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ABSTRACT

Cactus opuntia juice's effectiveness as a bio-flocculant in the treatment of industrial wastewater was optimized and analyzed using first order kinetic model. Wastewater from industrialization is constantly released into the environment, polluting it and eventually making it poisonous to living things. The ecology is constantly exposed to industrial effluents that include various metal derivatives, which have a major harmful effect. Numerous water-borne illnesses, including cholera, amoebic dysentery, giardiasis, diarrhoea, typhoid, and several neurological conditions, can be found in contaminated water. Consequently, wastewater treatment is crucial for human health. The kinetic model helps to understand the flocculation mechanism and predict the treatment efficiency. The result of the raw water and treated water with cactus opuntia juice have physico-chemical characteristics that reveal a control temperature of 23.4°C and a treatment temperature of 23.1°C. For the best dose outcome, the TDS rose from 96 mg/L for the control to 119 mg/L. The control's chemical oxygen demand (COD) of 115.3 mg/L dropped dramatically to 68.2 mg/L. The effluent included 38.2 mg/L of sodium, 4.24 mg/L of calcium, and 24.8 mg/L of magnesium. The optimal Cactus Opuntia Juice (COJ) dosage of 5.8% was found to minimize wastewater turbidity by 71%; nevertheless, the sodium adsorption ratio and Kelly's index rose from 10 to 16 and 1.3 to 2.4, respectively. The pH dropped to 7.3 from 8.3. Numerical optimization was used to optimize the water's characteristics, including turbidity, total dissolved solid (TDS), and COD. 5.8 mg/L of COJ, 60 minutes of contact time, 106 NTU for turbidity, 119 mg/L for TDS, and 68.2 mg/L for COD were the optimization results. The answers were checked and simulated. The validation result revealed a little discrepancy between the experiment and the prediction. The coagulant reduced TDS and COD and eliminated turbidity. It showed outstanding efficacy in treating wastewater, especially in terms of turbidity. This study suggests that more research is needed to develop useful technologies that eliminate turbidity and other harmful elements using various bio-coagulants.

Keywords: Kinetics of coagulation and flocculation, Cactus Opuntia, Optimization, Turbidity, Total Dissolved Solid

1. INTRODUCTION

In 2021, approximately 2.2 billion people lacked access to adequately managed drinking water facilities [1]. Many diseases prevalent in third-world countries are directly linked to poor drinking water quality. Every day, almost 4,000 people die from diseases attributable to inadequate water, sanitation, and hygiene [2]. As of 2020, an estimated 122 million individuals relied on surface water sources for their water supply [3-4]. Contaminated water contains various water-borne diseases like diarrhoea, typhoid, cholera, amoebic dysentery, giardiasis, and certain neurological disorders. Heavy metals like copper, chromium, lead, zinc, and cadmium, released into water bodies through various human activities, are noxious and harmful water pollutants. Therefore, wastewater treatment is essential for human well-being.

Drinking water is a basic human need and is essential for human health. These water sources can be polluted in various ways, such as through fertilizers from agricultural runoff and human and animal faeces.

Water treatment is essential for ensuring the safety and quality of surface water for human consumption and other uses. The limited availability of sufficient, uncontaminated, and safe water represents a significant global challenge. Water pollution occurs due to various chemical, physical, or biological contaminants dissolved in water, suspended in water, or deposited on the water bed. These contaminants cause deterioration of water quality, making it unfit for human use and necessitating treatment [5].

The United Nations Children's Fund [2] states that access to safe drinking water and sanitation are human rights to which we are all entitled. They are fundamental for human survival, dignity, economic development, and well-being. Without safe water and sanitation, people are likely to face a high risk of disease outbreaks.

Studies on drinking water samples from Jos South and Pankshin local government areas showed gradual contamination with E-coli, total coliforms, and some physicochemical parameters from various sources [6].

Water is treated mainly through two methods: chemical and natural. Coagulation-flocculation reduces dissolved substances, suspended matter, colloidal particles, non-settable particles, and coloring agents from wastewater effluent [5]. The effectiveness of natural coagulation as a wastewater treatment method is significantly affected by hydrogen ion concentration [7].

Muhammad *et al.* [8] revealed that natural coagulants are easily available, inexpensive, and have no side effects. They are a good alternative to commercially available coagulants and can be prepared locally to treat sewage water and rainwater before discharge into groundwater or for agricultural use.

Ojo [9] suggests that pawpaw seed powder is a more cost-effective and sustainable alternative to alum, as it achieves comparable water quality improvements. Abderrazzak *et al.* [10] revealed the effectiveness of natural bio-coagulants and bio-flocculants in treating textile wastewater through coagulation-flocculation. The study demonstrated the potential of bio-based agents in reducing turbidity and decolorization in textile wastewater.

Sankeeth and Asha [11] conducted tests on neem leaf powder as a coagulant, showing promising results in removing turbidity and other contaminants from water. The results imply an acidic range for neem leaf.

2. LITERATURE REVIEW

2.1 Water Quality Assessment in Nigeria

Many developing countries face a lack of access to clean drinking water at affordable prices. There is a need to develop low-cost and efficient water treatment alternatives that are feasible and sustainable [12]. Coagulation is a workable water treatment process for removing dissolved organic material and reducing colloidal particles. When large amounts of dissolved organic material are present, water may exhibit discoloration and have an unpleasant odour and taste [13]. Coagulation can reduce suspended particles and inorganic residues [14]. The coagulation process can also eliminate

some pathogens (i.e., viruses and bacteria) associated with the coagulated particles. The World Health Organization (WHO) reported that up to 84% of viruses and 87% of bacteria could be reduced by sedimentation and coagulation, although results varied considerably [15]. Ikhuriah and Onajite [16], evaluated the physicochemical properties and bacteriological quality of four (4) outdoor swimming pools in Ovia North East, Local Council of Edo State, Nigeria. Results of physicochemical analysis showed that water temperature (25.75 - 26.38°C), pH (3.78 - 6.1), electrical conductivity (37.5 - 72.5 mg/L), total dissolved solids (14.58 - 38.43mg/L), turbidity (0.75 - 4 NTU), dissolve oxygen (6.03 - 7.43 mg/L), residual chlorine (0.03 - 0.13mg/L), alkalinity(7 - 26.5 mg/L), hardness (6 - 36 mg/L), were within the World Health Organisation and Environmental Protection Agency stipulated maximum permissible limit for recreational waters except for pH and residual chlorine levels. The presence of pathogenic microorganisms in all the studied pools are total bacteria count (1 - 3 CFU/100mL), total coliform count (1 - 5 CFU/100 mL) and E. coli count (1 - 2 CFU/100 mL) predisposes the users of these facilities to microbial infection. The findings demonstrated that the swimming pools did not meet the required standards, particularly in terms of pH levels, residual chlorine, and microbial parameters. Waida *et al.* [17] evaluate the extent to which the water, soil and plants in parts of Plateau State are polluted through a factor known as pollution load index. The results revealed that, the contamination factor for heavy metals in Bassa, Jos South, Barkin Ladi, Mangu and Jos East have their values in trend with Cr (0.04) > As (0.013) > Pb (0.006) > Ni (0.005) > Cd (0.003) for water, Cr (75.2) > Pb (74.8) > Ni (43.6) > As (24.4) > Cd (3.58) for soil and Ni (5.4) > Pb (1.72) > Cr (0.71) > Cd (0.03) > As (0.028) for plant. It can therefore be concluded that the soil, water and plants in the study area are seriously polluted and call for serious concern and regulatory control.

2.2 Natural Coagulants in Wastewater Treatment

Agricultural deposits and vegetable and fruit peels are the waste material that cannot be used anywhere. Hence, they can easily be used as low-cost adsorbents after pre-treatment [18].

Agricultural wastes are mainly composed of cellulose and lignin, due to which they possess versatile structure and chemical properties and can act as attractive alternative adsorbents. They exist in polymer chains with specific functional groups like alcohol, aldehyde, phenol, ketone, and carboxyl which help remove various contaminants from water [19].

A variety of agricultural wastes, i.e., orange peel, lemon peel, banana peel, wheat bran, rice husk, coconut, pulse seed coat, etc., have already been reported in wastewater treatment [20].

Agricultural waste materials are useful in natural as well as in modified form. In the natural system, the waste product is washed adequately, grounded, and sieved until it reaches the desired particle size and is later used as an adsorbent to purify water. The material is pre-treated into a modified form through different modification techniques [21]. An experimental study stated that the rice husk was dedicated by potassium carbonate and chemically activated to urea modified activated carbon to remove nitrate ions from wastewater [22].

Sugarcane bagasse is used in both natural and modified forms to remove chromium from wastewater [23]. Soybean hulls, rice straws, and rice bran are modified with citric acid and efficiently used for metal ion removal from wastewater, specifically copper ions [24].

Muhammad *et al.* [8] revealed that natural coagulants are easily available, cheap rates and have no side effects. Natural coagulants are a good alternative to commercially available natural coagulants. These can be prepared locally to treat sewage water and rainwater before discharge into groundwater or for use in agriculture purpose. Good natural coagulants are those that contain protein soluble properties and basicity. Some of the Alternative coagulants are chosen; Moringa seed, neem leaves, eggshells, orange peels, and banana peels. Different coagulants are used to reduce TDS and other dissolved impurities from an industrial outlet water sample .

Qandeel *et al.* [25] assessed the efficiency of powdered neem (*Azadirachta indica*) seeds in removing turbidity from water. Batch experiments determined the optimum coagulant dose, pH level, mixing time, and mixing speed to reduce turbidity from kaolin-based synthetic turbid water. Powdered neem seeds with a pore size of about 0.45 mm were prepared and used in water treatment under optimum conditions. Results showed that a coagulant dose of 3 g of neem seeds/L, 13.2 pH level, 60 mins mixing time at 80 rpm mixing speed could reduce turbidity levels to 35 NTU from 250 NTU (86% removal). Findings suggest that powdered neem seeds can be a potential substitute for conventional chemical coagulants for drinking water treatment.

Rakesh *et al.* [26] conducted a research using neem tree leaf and banana leaf powders as natural

coagulants for the treatment of dairy effluent. The jar test was used to determine the pH, turbidity, and metal ion content of the treated samples. The biocoagulants were experimented at a rate of 100 mg/L, 200 mg/L, and 300 mg/L at pH of 5, 6, and 7. The levels of turbidity, sodium (Na), potassium (K), calcium (Ca), barium (Ba), lithium (Li), and copper (Cu) were measured after the treatment process. Turbidity was reduced by 52%, and coagulants at 200 mg/L and 300 mg/L were more successful at removing metal ions from dairy effluent except in copper, where 100 mg/L was shown to be more effective. Neem tree leaf and banana leaf powders were efficient and cost-effective eco-friendly biocoagulants for the treatment of dairy effluent.

Sankeeth and Asha [11] conducted research to examine the several properties of neem leaf powder. This was done with varying dosages of 10, 20, 30, 40,50, and 60 g/L of neem leaf powder as a coagulant. The turbidity removal efficiency was found to be 49%, the removal efficiency of total hardness was found to be 34%, the removal efficiency of magnesium hardness was found to be 90%, the removal efficiency of calcium hardness was found to be 66%, The removal efficiency of chlorides was found to be 54% and removal efficiency of residual chlorine was found to be 35% post-treatment by natural coagulant neem leaf powder for hennagara lake water sample.

Ojo [9] comparatively evaluate the physicochemical properties of surface water treated by using alum and pawpaw seed powder using appropriate standard methods. Initial water quality parameters included turbidity of 27 NTU, pH of 7.9, total suspended solids (TSS) of 126.8 mg/L, total dissolved solids (TDS) of 267.2 mg/L, and hardness of 321 mg/L. Post-treatment with alum reduced these values to 9 NTU, pH 7.5, TSS 50 mg/L, TDS 135 mg/L, and hardness 95 mg/L. Pawpaw seed powder treatment resulted in reductions to 6 NTU, pH 7.6, TSS 60 mg/L, TDS 160 mg/L, and hardness 130 mg/L. The findings showed significant improvement in water clarity and quality for both treatments, with pawpaw seed powder demonstrating slightly superior turbidity reduction. Cost analysis revealed that alum treatment cost a total of 9000 NGN, whereas pawpaw seed powder treatment cost 5500 NGN due to lower procurement and transportation costs.

Abderrazzak *et al.* [10] revealed that the effectiveness of using natural bio-coagulants and bio-flocculants to treat textile wastewater through the coagulation-flocculation method and concluded that the bio-based agents have several advantages

over chemical agents, including biodegradability, natural abundance, low toxicity, and low cost.

Some of the common natural coagulants used for water purification are listed in Table 1.

Table 1: List of Natural Coagulants in Water Treatment Process

Common name	Scientific name
Drumstick/horseradish tree	<i>Moringa oleifera</i>
Dolichos bean	<i>Dolichos lab</i>
Chumbera	<i>Opuntia ficus-indica</i>
Ivvy gourd	<i>Coccinia indica</i>
Chickpea	<i>Cicer arietinum</i>
Neem	<i>Azadirachta indica</i>
Barbados nut	<i>Jatropha curcas</i>
Mango	<i>Mangifera indica</i>
Cowpea	<i>Vigna unguiculata</i>
Corn	<i>Zea mays</i>
Kidney bean	<i>Phaseolus vulgaris</i>
Cactus	<i>Cactus latifolia</i>
Guar Bean	<i>Cyamopsis tetragonoloba</i>
Peas	<i>Pisum sativum</i>
Nirmali	<i>Strychnos potatorum</i>
Peanuts	<i>Arachis hypogaea</i>
Urad	<i>Vigna mungo</i>
Locust bean	<i>Parkia biglobosa</i>
Water hyacinth	<i>Eichhornia crassipes</i>

Source: Nargis and Bhupendra [27a]

2.3 Mechanism for Water Treatment

Amar *et al.* [27b] classified water treatment mechanism as charge neutralization mechanism and bridging mechanism as shown in Figure 1 to 2. The natural polymers act like polyelectrolytes and possess a number of charged and functional group in their structure viz., -OH, -COOH and -NH₂. In coagulation process coagulants involve bridging, neutralization of charge and sweep coagulation and compression of electrical double layer of charged colloidal particles.

Generally, constituents of bio-coagulants are carbohydrates, proteins and lipid macromolecules.

The polysaccharides and amino acid are main components of polymers which are used in wastewater treatment [27b]. When large amount of coagulants/flocculants are mixed into the wastewater, the coagulants are precipitated in the form of hydroxide, and the colloidal particles which are dissolved in water get swept up from the water and get trapped by the coagulant precipitate; this phenomenon is known as sweep coagulation/ flocculation. This process has tendency to remove the particles which are destabilized by neutralization of charge because it shows better aggregation rate with increased concentration of solids. This mechanism is helpful for the removal of much harmful compounds.

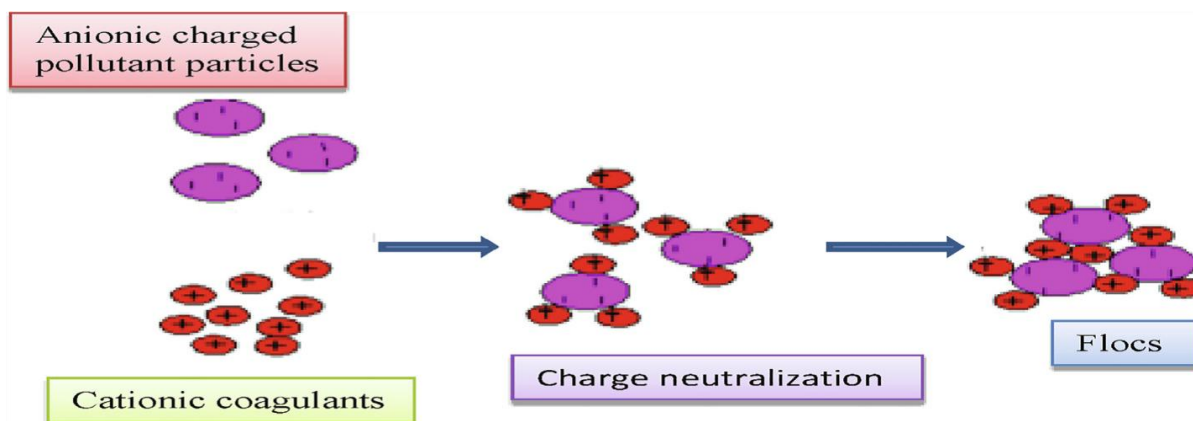


Figure 1. Charge Neutralization Mechanism-Source: Amar *et al.* [27b]

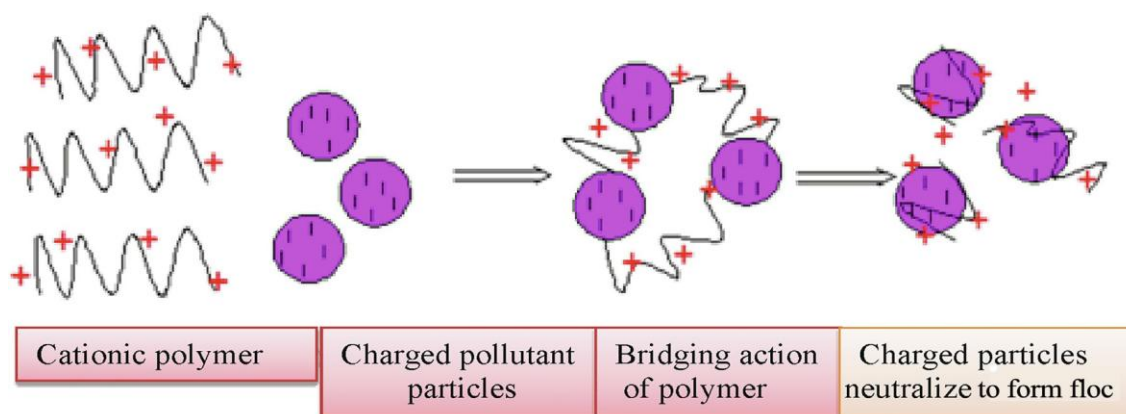


Figure 2: Bridging Mechanism-Source: Amar *et al.* [27b]

2.4 Cactus Plant as Natural Coagulant

Abderrazzak *et al.* [10] used natural bio-coagulants and bio-flocculants to treat textile wastewater through the coagulation-flocculation method. A bio-coagulant (holm oak acorn (HOA)) and a bio-flocculant (cactus juice) were used to investigate the capacity for turbidity removal and decolorization of textile wastewater. The UV spectrophotometer was used to characterize the discharges before and after treatment, and the chemical oxygen demand (COD) and biological oxygen demand (BOD5) levels were calculated. Box-Behnken design (BBD) coupled with response surface methodology (RSM) were utilized to optimize the process and reduce turbidity and decolorization in textile wastewater. The obtained results show that under the optimal conditions (0.5 g·L⁻¹ of HOA, 15 mL·L⁻¹ of cactus juice, and a pH of 7), decolorization and turbidity removal were achieved at 69% and 90%, respectively. This study demonstrates the potential of using bio-coagulants and bio-flocculants in the treatment of textile wastewater.

Mahir and Neema [28] revealed the effectiveness of removing turbidity in pond water with Cactus and watermelon seed coagulants was determined to be 78.58% and 94.18%, respectively. For both coagulants, the longer the settling time, the more turbidity was removed. The study indicates that watermelon and cactus pads can be used as coagulants to replace synthetic coagulants.

Ouafae *et al.* [29] used bio-coagulants to reduce pollution by coagulation-flocculation of wastewater from oil refining. The study shows an exciting contribution to the valuation of natural resources such as cacti in Morocco. Bio-coagulant is a novel biodegradable organic flocculant extracted from prickly pear juice. The results showed that the extract's optimal dosage varies between 10 and 40 mg/L, leading to removal yields ranging from 40 to 90%. Global data, based on the use of cactus juice as

a coagulant in coagulation-flocculation processes for the treatment of oil refinery wastewater, showed removal percentages between 86 and 99%, 62 and 76%, and 67 and 95% for turbidity, COD, and discoloration respectively.

It has been reported that cactus and watermelon seeds can reduce over 90% of the turbidity in raw water [30-31].

2.5 Kinetics of Coagulation-Flocculation

The kinetics of coagulation and flocculation in municipal water purification systems play a vital role in optimizing treatment performance. These processes involve complex, time-dependent interactions between destabilized particles, coagulants, and flocculants, ultimately leading to the formation of flocs that can be settled or filtered out. The rate of these interactions significantly impacts contaminant removal efficiency, chemical demand, and overall operational throughput of the treatment system [32]. Two widely used kinetic models describe coagulation-flocculation phenomena:

1. First-order model: $dC/dt = -k_1C$, which accurately represents early-stage coagulation with minimal particle interactions [33].

2. Second-order model: $dC/dt = -k_2C^2$, providing a more realistic depiction of later-stage coagulation dominated by particle collisions [34 – 35]. This model often yields higher correlation coefficients when analyzing experimental data [36 – 37].

The key parameters influencing coagulation-flocculation kinetics include:

(i) Coagulant dosage: critically affects charge neutralization and particle destabilization, with both underdosing and overdosing leading to poor treatment outcomes [38].

(ii) Mixing energy: significantly impacts coagulant dispersion and floc formation, requiring high intensity during initial coagulation and gentle mixing during flocculation [39 – 40].

3. MATERIALS AND METHODS

3.1 Materials and Equipments

The materials needed are Cactus pad and distilled water. The Equipments to be used in this study include the following: Laboratory Mill or Grinder, Weighing Balance, Beakers and Glassware, Stirrer or Magnetic Stirrer, pH Meter, Turbidimeter, Spectrophotometer, Microscope, Pipettes and Burettes: Precision measuring instruments for dispensing precise volumes of solutions during experiments.

3.2 Methods

3.2.1 Sample Collection from Study Area

The water samples were collected from the waste water at Grand Cereal Company Jos, Plateau State. Samples will be collected in 2-liter plastic containers and 200 cm³ reagent bottles properly cleansed with distilled deionized water prior to usage. Collection was carried out by careful immersion of the sample containers in the pond water and the containers were sealed with tight fitting corks and stoppers after collection, in order to avoid air bubbles. Samples were immediately transferred to a refrigerator (4°C) prior to analysis.

3.2.2 Physico-chemical Analysis

The samples collected were analyzed for pH, Turbidity, Total dissolved solids, COD, and Total hardness, Presence of sodium, calcium and magnesium.

3.2.2.1 Determination of pH

The pH of the water samples will be determined using the Hanna microprocessor pH meter. It was standardized with a buffer solution of pH range of 4-9.

3.2.2.2 Measurement of temperature

This test was carried out in-situ at the site of sample collection using a mobile thermometer. This was done by dipping the thermometer into the sample and recording the stable reading

3.2.2.3 Determination of turbidity

Turbidity was determined using a standardized Hanna H198703 Turbidimeter. The samples were poured into the measuring bottle and the surface of the bottle was wiped with silicon oil. The bottle was inserted into the Turbidimeter and the readings obtained.

3.2.2.4 Determination of total dissolved solids (TDS) by Gravimetric Method

A portion of water was filtered out and 10mL of the filtrate measured into a reweighed evaporating dish. Following the procedure for the determination of total solids above, the total dissolved solids content of the water was calculated using Equation 1.

$$\text{Total dissolved solids (mg/L)} = \frac{(W_2 - W_1) \text{mg} \times 1000}{\text{mL of Filtrate Used}} \quad \dots (1)$$

Where

W1 = initial weight of evaporating dish

W2 = Final weight of the dish (evaporating dish + residue).

3.2.3 Assessment by Water Quality Index

The quality of water used for drinking and irrigation purposes in this study was determined by weighted arithmetic water quality index, sodium adsorption ratio and Kelly's index method.

3.2.3.1 Sodium adsorption ratio assessment for irrigation water

The acceptable water for use in irrigation depends on some main components such as Na, Ca, Mg, etc in the water. The popular indices for water use in irrigation is sodium adsorption ratio (SAR). The SAR refers to sodium content (alkali risk), which has a significant indication to figure out whether irrigation water is suitable for usage (Shil *et al.*, 2019).

3.2.4 Preparation of cactus opuntia juice (COJ)

The cactus pads were rinsed with 10 ml of 60°C distilled water, precipitated with 15 ml of ethanol. Distilled water and ethanol were used in order to remove impurities and cut grinded to juice as shown in Plate 1.



PLATE I-III: Preparation of *Cactus Opuntia* Juice

3.2.6 Experimental design for Jar test

Central Composite Design (CCD) of design expert 13 software was adopted in the design of experimental combinations. It was also used to quantify the relationship between the controllable

input parameters and the obtained response surfaces. CCD was used to optimise the results of Turbidity, TDS, COD. The software was used to generate a mathematical model. Table 2 shows the factor level of mixture and Plate II shows the Jar Test.

Table 2: Factor and Factor Levels of Mixture

Name	Units	Low	Middle	High
CD	(mg/L)	4	6	8
C.T	(mins)	20	40	60

The responses are Turbidity, TDS, and COD

Where

CD = Coagulant dosage

C.T = Contact time

The agitation speed of 100 rpm



Plate IV: Jar Test

3.2.7 Kinetic modelling of *Cactus Opuntia* juice

The kinetic model helps to understand the flocculation mechanism and predict the treatment efficiency. The cactus juice bioflocculant works by bridging the suspended particles, forming larger flocs that can be easily removed. The kinetic model for cactus juice as a bioflocculant in wastewater treatment can be represented by the equation 2

$$\frac{dC}{dt} = -kC^n \quad \dots (2)$$

where

C is the concentration of suspended solids,

k is the flocculation rate constant, and

n is the order of the reaction.

The first-order and second-order kinetic models can be used to describe the flocculation process.

The kinetic model parameters (k and n)

can be determined experimentally by

conducting flocculation tests at different conditions.

(1) First-order model: $\ln(Ct/C0) = -kt \quad \dots (3)$

(2) Second-order model: $1/Ct = 1/C0 + kt \quad \dots (4)$

The percentage removal of turbidity is calculated by

$$\text{Removal (\%)} = (1 - C/C0) \times 100 \quad \dots (5)$$

Where: Ct = concentration at time t, Co = initial concentration, k = rate constant, t = time

4. RESULTS AND DISCUSSION

4.1 Properties of Raw Water

The results of physico-chemical quality of the raw water used in the study is presented in Table 3. The source of the raw water is prone to pollution from industrial effluent. The tested parameters were compared to permissible limits specified by NAFDAC.

Table 3: Properties of Raw Water

S/N	Parameter	Control sample	NAFDAC Maximum Allowed Limits
1	Temperature	23.4	--
2	pH	8.3	6.5-8.5
3	Colour (pt-co)	3462	--
4	Total Dissolved Solid mg/L	96	500
5	E/Conductivity (µs/cm)	130	1200
6	Turbidity for drinking water (NTU)	366	5
7	Sodium (Na) mg/L	38.2	52.5
8	Calcium (Ca) mg/L	4.24	75
9	Magnesium (Mg) mg/L	24.8	20
10	SAR	10	--
11	Kellys Index	1.3	--
12	COD mg/L	115.3	--

Table 3 shows the result of test conducted on raw water and compared to the NAFDAC standard. The pH value plays important role in the coagulation of both organic and inorganic particles/molecules. The pH result of raw water is 8.3 which is within NAFDAC allowable specified limit of 6.5 to 8.5. The result of the turbidity test conducted on the raw water showed 366 NTU which is significantly greater than 5 NTU for drinking water. It also shows that the industrial waste water at Grand Cereal Company Jos, Plateau State contains high level of suspended solids.

The value of COD for the raw water is 23.2 mg/L. EU sets a maximum allowable concentration of 125 mg/L for COD in surface water while No specific

guideline value for COD recommended by WHO and NAFDAC but recommends that drinking water should not contain substances that can cause harm to human health.

4.2 Evaluation of *Cactus Opuntia* Juice on Turbidity of Industrial Wastewater

The industrial wastewater was treated using *Cactus Opuntia* Juice. The effects of coagulant dosage and contact time on parameters such as turbidity, TDS and COD were investigated. The effect of COJ on turbidity of raw water at varied contact time is shown in Figure 3

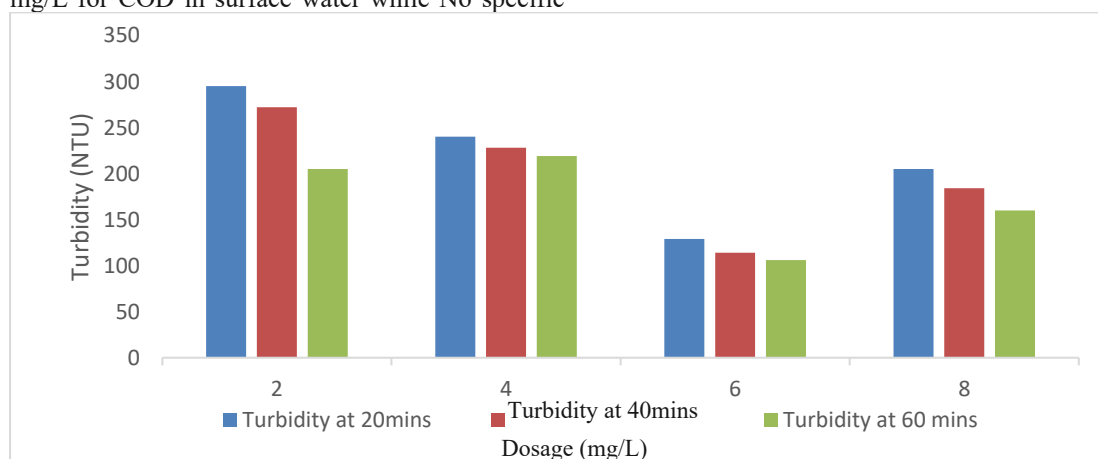


Figure 3: Turbidity Result with COJ Dosage

The amount of Turbidity reflects the level of clearness in wastewater at Grand Cereal Company Jos, Plateau State. According to WHO standard, the prescribed limit of Turbidity for drinking water, low risk crop and high-risk crop are 5 NTU, 100 NTU and 20 NTU respectively. From the result in Figure 3, the higher the dosage of *Cactus Opuntia* Juice, the lower the turbidity from 2 to 6 mg/L but high at 8 mg/L. Excessive coagulant addition will cause

higher increase in turbidity from 6 mg/L. The best turbidity reduction at 106 NTU was achieved with optimum dose of 6 mg/L COJ at 60 mins contact time. This result shows 71% turbidity removal from the raw water and the 106 NTU can only be used for low risk crops. Determination of optimum dose was done by the lab-scale Jar Test method. COJ was also used to treat waste water by Mahir and Neema (2024) and 78% of turbidity removal was achieved.

4.3 Influence of *Cactus Opuntia* Juice on TDS

The effect of *Cactus Opuntia* Juice on TDS of raw water at varied contact time is shown in Figure 4

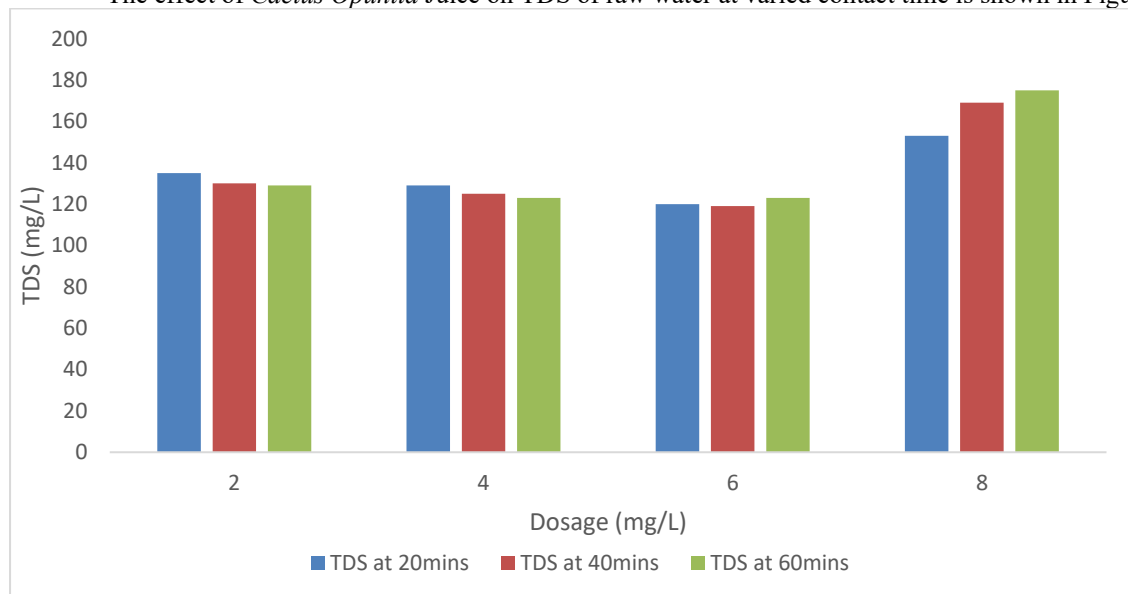


Figure 4: Effect of Coagulant Dosage and Contact Time on TDS

Influence of coagulant dosage and contact time on TDS is shown in Figure 4. The higher the coagulant dosage from 0.03 to 0.1mg/L, the higher the TDS but

after 0.1mg/L, there is visible reduction in the TDS. All the values of TDS are within the WHO and NAFDAC allowable specification.

4.4 Influence of *Cactus Opuntia* Juice on COD

The effect of *Cactus Opuntia* Juice on COD of raw water at varied contact time is shown in Figure 5

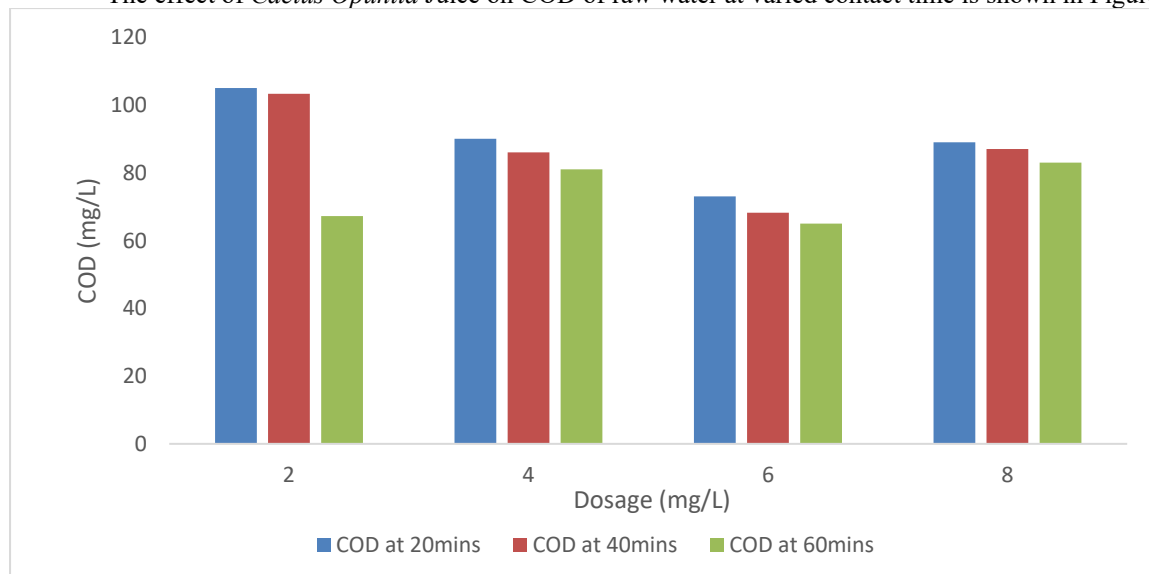


Figure 5: Effect of Coagulant Dosage and Contact Time on COD

Influence of coagulant dosage and contact time on COD is shows a decrease with increase in coagulant dosage from 2 to 6%. Further increase in coagulant dosage from 6 mg/L, the higher the COD. All the

values at different dosage and contact time are within EU maximum allowable concentration of 125 mg/L for COD in surface water.

4.5 Analysis and Modelling of Responses by CCD

Optimization strategies delve into refining treatment parameters such as dosage and contact time for

Cactus Opuntia Juice using central composite design as shown in Table 4.

Table 4: Factors and Responses by CCD

Run	Factor 1 A: Dosage mg/L	Factor 2 B: Contact time mins	Response 1 Turbidity NTU	Response 2 TDS mg/L	Response 3 COD mg/L
1	6	60	106	123	65
2	4	20	240	126	90
3	8	60	160	175	83
4	6	20	129	120	73
5	6	40	114	119	78
6	4	40	228	125	86
7	8	20	205	153	89
8	6	40	114	119	68.2
9	6	40	114	119	68.2
10	4	60	219	123	81
11	6	40	114	119	68.2
12	6	40	114	119	68.2
13	8	40	184	169	87

4.5.1 Turbidity

The ANOVA and Fit statistics for Turbidity is presented in Tables 5 and 6.

Table 5: ANOVA for Turbidity

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	31401.22	5	6280.24	981.69	< 0.0001
A-Dosage	3174.00	1	3174.00	496.14	< 0.0001
B-Contact time	1320.17	1	1320.17	206.36	< 0.0001
AB	144.00	1	144.00	22.51	0.0021
A ²	22525.98	1	22525.98	3521.13	< 0.0001
B ²	9.05	1	9.05	1.41	0.2730
Residual	44.78	7	6.40		
Lack of Fit	44.78	3	14.93		
Pure Error	0.0000	4	0.0000		
Cor Total	31446.00	12			

The Model F-value of 981.69 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, AB, A² are

significant model terms. Values greater than 0.1 indicate the model terms are not significant.

Table 6: Fit Statistics for Turbidity

Parameters	Values
Std. Dev.	2.53
Mean	157.00
C.V. %	1.61
R ²	0.9986
Adjusted R ²	0.9976
Predicted R ²	0.9864
Adeq Precision	79.7155

It is seen from the analysis of variance result, R^2 is 0.9986 showing that the correlation between the actual and predicted values is very good and the regression model coincides with the test data. The Predicted R^2 of 0.9864 is in reasonable agreement with the Adjusted R^2 of 0.9976; i.e. the difference is less than 0.2. Adeq Precision measures the signal to

noise ratio. A ratio of 79.72 indicates adequate signal. Any ratio greater than 4 is desirable. The model equation for turbidity is shown in Equation 6 and the actual and predicted values are presented in Table 13. The effect of contact time and coagulant dosage on turbidity of raw water is presented in Figure 6.

$$\text{Turbidity} = 997 - 276.4A - 0.204B - 0.15AB + 22.6A^2 + 0.005B^2 \quad \dots (6)$$

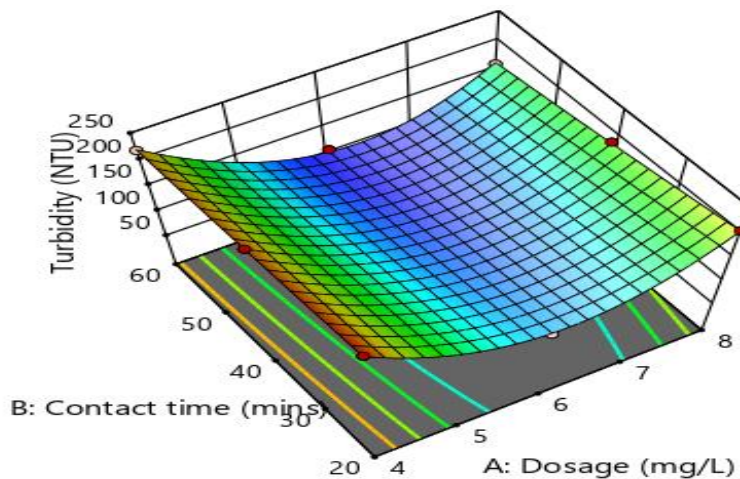


Figure 6: Response Surface Graph Showing the Effect of C.T and CD on Turbidity

4.5.2 Total dissolved solid by CCD

The result of the analysis of variance for TDS is presented in Table

7.

Table 7: ANOVA for TDS

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	4851.39	5	970.28	170.47	< 0.0001
A-Dosage	2521.50	1	2521.50	443.01	< 0.0001
B-Contact time	80.67	1	80.67	14.17	0.0070
AB	156.25	1	156.25	27.45	0.0012
A ²	1791.07	1	1791.07	314.68	< 0.0001
B ²	0.0033	1	0.0033	0.0006	0.9815
Residual	39.84	7	5.69		
Lack of Fit	39.84	3	13.28		
Pure Error	0.0000	4	0.0000		
Cor Total	4891.23	12			

The Model F-value of 170.47 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, AB, A² are

significant model terms. Values greater than 0.1 indicate the model terms are not significant. The Fit statistic for TDS is shown in Table 8.

Table 8: Fit Statistics for TDS

Parameter	Value
Std. Dev.	2.39
Mean	131.46
C.V. %	1.81
R ²	0.9919
Adjusted R ²	0.9860
Predicted R ²	0.9301
Adeq Precision	36.7408

The Predicted R^2 of 0.9860 is in reasonable agreement with the Adjusted R^2 of 0.9860; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 36.7408 indicates an adequate signal. The model equation for TDS is shown in Equation 7

$$TDS = 317 - 72.4A - 0.75B + 0.156AB + 6.37A^2 - 8.62e - 05 * B^2 \dots (7)$$

The response surface graph on the effect of contact time and coagulant dosage on TDS of raw water is presented in Figure 7.

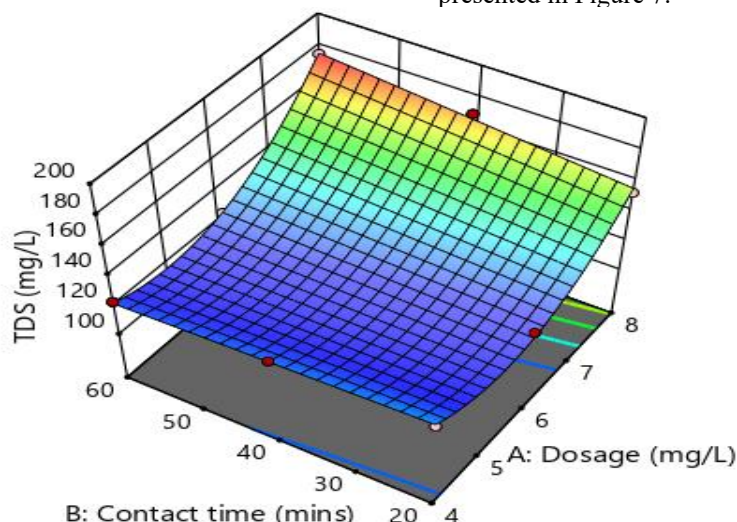


Figure 7: Response Surface Graph Showing the Effect of C.T and CD on TDS

4.5.3 COD result

The ANOVA and Fit statistics results of COD are presented in Tables 9 and 10.

Table 9: ANOVA for COD

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	938.53	5	187.71	17.04	0.0009
A-Dosage	0.6667	1	0.6667	0.0605	0.8127
B-Contact time	88.17	1	88.17	8.00	0.0254
AB	2.25	1	2.25	0.2042	0.6650
A ²	755.39	1	755.39	68.57	< 0.0001
B ²	2.56	1	2.56	0.2321	0.6447
Residual	77.11	7	11.02	0.0049	0.9994
Lack of Fit	0.2826	3	0.0942		
Pure Error	76.83	4	19.21		
Cor Total	1015.65	12			

The Model F-value of 17.04 implies the model is significant. P-values less than 0.05 indicate model terms are significant. In this case B, A² are

significant model terms. Values greater than 0.1 indicate the model terms are not significant.

Table 10: Fit Statistics for COD

Parameter	Value
Std. Dev.	3.32
Mean	77.29
C.V. %	4.29
R ²	0.9241
Adjusted R ²	0.8698
Predicted R ²	0.8871
Adeq Precision	10.9191

The Predicted R² of 0.8871 is in reasonable agreement with the Adjusted R² of 0.8698. The difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 10.92 indicates an adequate signal. This model can be used to navigate the design

$$COD = 226 - 50.2A - 0.112B + 0.019AB + 4.13A^2 - 0.0024B^2 \quad \dots (8)$$

space. The model equation for COD is shown in Equation 8 and the actual and predicted values are presented in Table 21. The response surface graph on the effect of contact time and coagulant dosage on COD of raw water is presented in Figure 8.

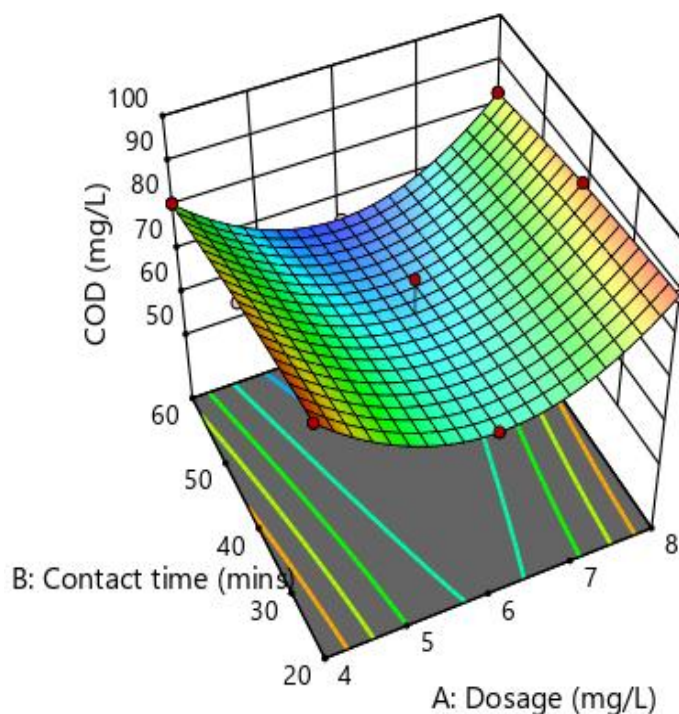


Figure 8: Effect of Contact time and Coagulant Dosage on COD

4.6 Comparison between Control and Optimum Dosage

The comparison of results from analysis carried out on raw water and water treated by optimum dose

(6mg/L) of *Cactus Opuntia* Juice is tabulated in Table 11

Table 11: Comparison of Control and Optimum Dosage

S/N	Parameter	Control sample	Optimum Dosage
1	Temperature	23.4	23.1
2	pH	8.3	7.3
3	Colour (pt-co)	3462	1822
4	Total Dissolved Solid mg/L	96	119
5	E/Conductivity (µs/cm)	130	248
6	Turbidity NTU	366	106
7	Sodium(Na) mg/L	38.2	52.5
8	Calcium(Ca) mg/L	4.24	1.12
9	Magnesium(Mg) mg/L	24.8	20.6
10	SAR	10	16
11	Kellys Index	1.3	2.4
12	COD mg/L	115.3	68.2

4.7 Optimization by Numerical Method

The automatic optimization function of Design-Expert software version 13 indicates that the optimal

values of the factors and responses are presented in Figure 9.

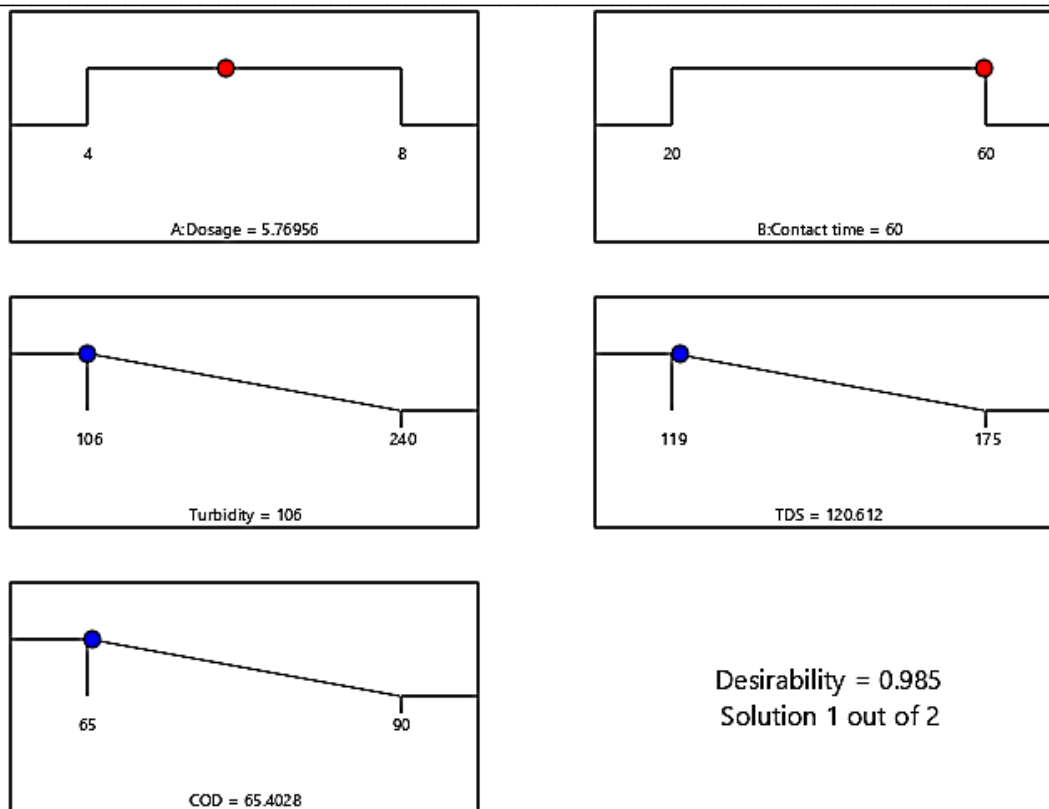


Figure 9: Ramp Plot Showing the Optimal Values for Factors and Responses

4.8 Kinetic Modelling of *Cactus Opuntia* in Waste Water Treatment

After using First Order Kinetic Model, the result of the reaction rate is presented in Table 12.

Table 12: Percentage Removal and Reaction Rate of *Cactus Opuntia* in Wastewater Treatment

Factor 1 A: Dosage mg/L	Factor 2 B: Contact time mins	Response 1 Turbidity NTU	Percentage Removal %	Reaction Rate K (per mins)
Control	0	366	-	-
6	60	106	71	0.021
4	20	240	34	0.021
8	60	160	56	0.014
6	20	129	67	0.056
6	40	114	69	0.029
4	40	228	38	0.012
8	20	205	44	0.029
6	40	114	69	0.029
6	40	114	69	0.029
4	60	219	40	0.009
6	40	114	69	0.029
6	40	114	69	0.029
8	40	184	50	0.017

From the result in Table 12, it was revealed that 6 mg/L of *cactus opuntia* at 60 mins contact time has the highest percentage removal of turbidity in wastewater but 6 mg/L at 20 mins contact time has the fastest reaction rate ($k = 0.056$) with 67% removal of turbidity.

5 Conclusion and Recommendations

Based on the findings of this study, the following conclusions were drawn;

- (i) The physico-chemical parameters of raw water and treated water with *Cactus Opuntia* Juice shows temperature of 23.4°C for control and 23.1°C for optimum dosage of COJ. TDS of 96 mg/L for control increased to 119 mg/L for the optimum dosage result. COD of 115.3 mg/L reduced significantly to 68.2 mg/L for control. Sodium, calcium and magnesium contents in the wastewater were 38.2 mg/L, 4.24 mg/L and 24.8 mg/L respectively.
- (ii) The optimum dose of 5.8% of COJ was determined which reduced the turbidity of wastewater by 71% but both sodium adsorption ratio and Kelly's index obtained were increased from 10 to 16 and 1.3 to 2.4 respectively. The pH reduced from 8.3 to 7.3.
- (iii) The properties of water such as turbidity, TDS and COD were optimized using numerical optimization. The optimization result showed 5.8 mg/L of COJ, 60 minutes' contact time, 106 NTU for turbidity, 119 mg/L for TDS and finally 68.2 mg/L for COD
- (iv) From the first order kinetic analysis, it was revealed that 6 mg/L of cactus opuntia at 60 mins contact time has the highest percentage removal of turbidity in wastewater but 6 mg/L at 20 mins contact time has the fastest reaction rate ($k = 0.056$) with 67 % removal of turbidity.

5.3 Recommendations

This research has indicated the limits in which *Cactus Opuntia* Juice can be used to treat industrial wastewater. Further research is recommended in order to broaden its use.

- i. This study recommends the use of 6 mg/L of *Cactus Opuntia* Juice at 20 mins contact time for purification of wastewater.
- ii. Further research should be carried out to evaluate the effects of more bio-coagulants juice for water treatment.

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