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The Use of Chitosan as A Coagulant in Wastewater Treatment

David Emoefe Rockson-Itiveh[1*], Fabian Chidiebere Ozioko[1], Mabel Keke[1]

[1]Chemical Engineering Department, Delta State University of Science and Technology, Ozoro, Delta State, Nigeria

Email: *davidrockyle95@gmail.com, oziokofabian@yahoo.com, elohocute@yahoo.com*

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Abstract: In this study, the potential of chitosan as a coagulant for the treatment of wastewater was investigated. The effectiveness of chitosan was evaluated by measuring the removal efficiency of various pollutants, including turbidity, TSS, TDS, COD, BOD_5, nitrate, and phosphate. The experimental results showed that chitosan was effective in removing pollutants from wastewater, with the highest removal efficiency achieved at a dosage of 10g. The statistical analysis confirmed that there was a significant difference in the removal efficiency of chitosan at different dosages. This study tends to explore the use of bio-material such as chitosan as a sustainable and effective coagulant for wastewater treatment instead of the regular use of synthetic coagulants like alum and also highlights the need for further research to optimize the operating conditions and evaluate the economic feasibility of chitosan coagulation.
Keywords: Coagulation, Chitosan, Demineralization, flocculation, Wastewater.

INTRODUCTION

Wastewater treatment is a critical process that ensures the safe disposal and reuse of wastewater. In many countries, poor wastewater management and treatment can lead to environmental degradation and the spread of waterborne diseases. Wastewater treatment process involves several steps, including physical, chemical, and biological treatment, that remove pollutants and contaminants from the wastewater (WHO, 2018). One important aspect of wastewater treatment is the use of coagulants, which help to bind together fine particles and suspended solids, making them easier to remove. Traditional coagulants, such as aluminum and iron salts, have been used for decades but have several disadvantages including high costs, the production of toxic sludge and water pollution by metals, although they are easy to use, readily available and efficient (Eric et al., 2019).

In recent years, researchers have explored alternative coagulants in form of bio coagulants and bio flocculants due to their biological nature, biodegradability, affordability, eco-friendly and efficiency (Eric et al., 2019). One such alternative is chitosan, a biopolymer derived from chitin, a naturally occurring polysaccharide found in the exoskeletons of crustaceans. Chitosan has several unique properties that make it an attractive candidate for wastewater treatment, including its high positive charge density, which allows it to effectively bind with negatively charged particles and pollutants (Bhatnagar and Sillanpää, 2009).

Chitosan has been found to be effective in removing a wide range of pollutants from wastewater including heavy metals, dyes, and organic compounds (Saha et al., 2017). It has also been shown to be effective in the treatment of various types of wastewater, such as textile, dairy, and municipal wastewater (Nidheesh and Gandhimathi, 2012; Su et al., 2020; Zhao et al., 2019). Lee et al. (2018) demonstrated that chitosan was effective in removing up to 90% of the total suspended solids (TSS) and chemical oxygen demand (COD) from landfill leachate. Similarly, in a study by Zhao et al (2019), chitosan was found to be effective in removing 87% of the TSS and 77% of the COD from synthetic dye wastewater. Chik et al., 2023 investigated coagulation/flocculation with chitosan on the removal of turbidity from aquaculture wastewater using response surface methodology. They found out that chitosan was very effective in removing turbidity at a minimal dosage of about 1mg/L although, at a contact time of about 18.1 min.

* *Corresponding E-mail: davidrockyle95@gmail.com*
Corresponding Address: Chemical Engineering Department, Delta State University of Science and Technology Ozoro, Delta State, Nigeria.
Phone Number: +2348110096158

Chitosan, a natural biopolymer derived from chitin, has emerged as a promising alternative coagulant due to its unique properties. Due to its high performances, chitosan derivatives have been used as adsorption additives in several research investigations. Chitosan has a high positive charge density which enables it to effectively bind with negatively charged particles and pollutants in wastewater although, the solubility of chitosan is a major factor that limits its application (Suresh et al., 2022). Additionally, chitosan is biodegradable, non-toxic, and eco-friendly, making it an attractive option for use in wastewater treatment. In addition to its effectiveness in treating various types of wastewater, chitosan has also been shown to have advantages over traditional coagulants. For instance, chitosan can be produced from waste materials such as shrimp shells, crab shells, and fungal biomass, making it a cost-effective alternative to traditional coagulants (Suresh et al., 2022). Moreover, the use of chitosan in wastewater treatment can lead to the production of less sludge, which can reduce the environmental impact and cost of disposal (Nidheesh and Gandhimathi, 2012).

However, the effectiveness of chitosan as a coagulant in wastewater treatment is dependent on various factors such as pH, dosage, and the characteristics of the wastewater being treated. For instance, a study by Su et al. (2020) found that the optimal pH range for chitosan application was between 6.5 and 7.5, while the optimal dosage of chitosan was dependent on the initial concentration of the pollutant in the wastewater.

Overall, chitosan has demonstrated great potential as an alternative coagulant in wastewater treatment. Its unique properties, eco-friendliness, and effectiveness in removing a wide range of pollutants make it an attractive option for researchers and wastewater treatment facilities. However, further research is needed to fully understand its optimal conditions for application, as well as its economic feasibility in large-scale wastewater treatment operations.

This article is aim at accessing the potential of chitosan as a coagulant in wastewater treatment, specifically, we will describe the experimental methods used in our study to evaluate the effectiveness of chitosan and present the results of our experiments alongside with removal percentages

EXPERIMENTAL

Location of Sample Area

The Trans-Amadi abattoir is situated in Obio/Akpor Local Government Area in Port Harcourt metropolis of River State Nigeria. It is bounded by longitude 6.57ºE and latitude 4.57ºN of the equator. This abattoir is one of the largest in River state and its activities affects the Niger delta environment. The abattoir empties its water via drainage connected from it to the Woji- Oginigba community River into the Bonny River from which it streams into the Atlantic Ocean.

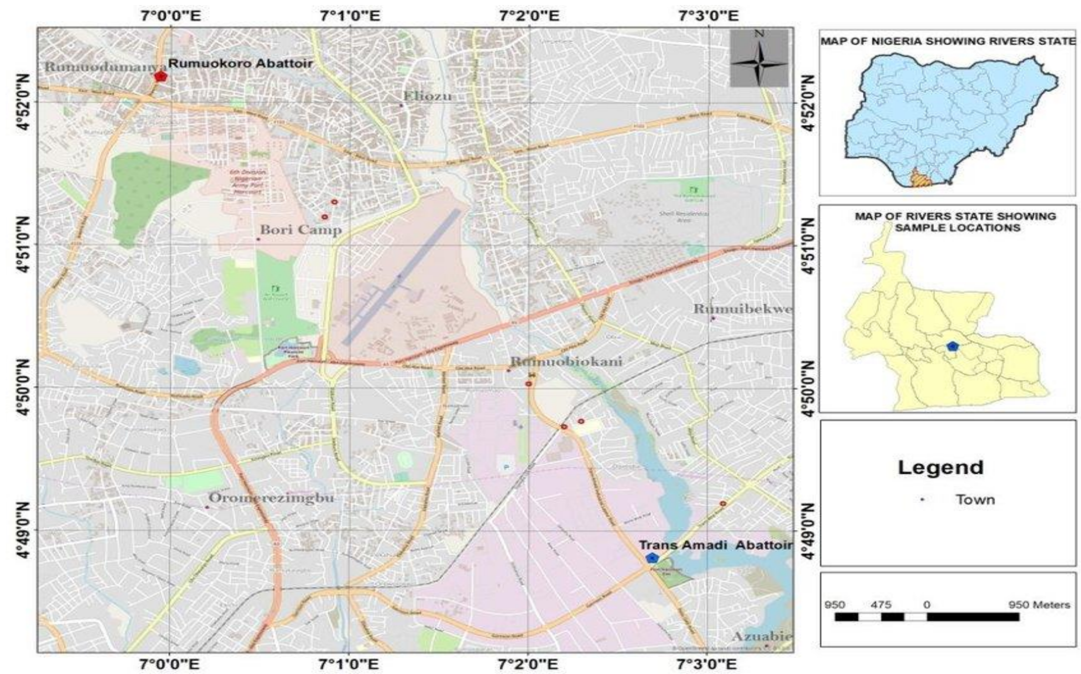

Figure 1. Map showing Sample Area

Materials

The materials and reagents utilized in this research were purchased from the University of PortHarcourt Chemical Engineering Shop and they are as follows: wastewater, Distilled water, Crab shell, Chitosan, Trioxonitrate (v) acid, Aluminium nitrate, Oxalic acid, Stock metal solution, Perchloric acid ($HClO_4$), Chlorine, Hydrochloric acid (HCL) and Sodium Hydroxide solution (NaOH).

Equipment and Apparatus

The apparatus and equipment used are those from the University of PortHarcourt Chemical Engineering Laboratory and they are as follows: Retort stand, 250 ml beaker, 300ml BOD bottles, Filter paper, stop watch, Open end 500ml measuring cylinder, Magnetic stirrer, Electronic weighing balance, Flocculator, Electric drier, 250ml Conical flask, Thermometer, pH meter (indicator), Pipette, Turbidometre, Atomic Adsorption Spectrophotometer (AAS), DO meter, Sample bottles, Volumetric flask and Test tube.

Material Preparation

A. Sampling of wastewater

Wastewater samples were collected from Trans Amadi slaughterhouse within the early hours of the day from three (3) designated points (immediately by the cow butcher point, goat butcher point, and at about 50metre away from the goat slaughter point where significant amount of the wastewater from the Cow slaughter has blended with that from the goat slaughter before entering into the River).

B. Processing of chitosan from chitin

Chitin extraction

The chitosan substance was extracted using the exoskeleton of a crab. After the crab was cooked, the chitin was separated from the proteinaceous substance. The chitin was then heated to around 60 oC, dried, and finally crushed.

Figure 2. Crab Shell

Demineralization of chitin

Crab shell fragments were demineralized for 24 hours using 5% hydrochloric acid (HCL). It was then rinsed with distilled water to get rid of the acid and the fleshy part, dried at 60 degrees Celsius, and then again cleaned and dried.

Deproteinization

With the use of a 5% sodium hydroxide solution (NaOH), the demineralized shell's deproteinization was accomplished. The combination was heated to 70oC and given 48 hours to come into contact. Additionally, the mixture was rinsed with distilled water to get rid of the base before being dried at 60 degrees Celsius.

Deacetylation

During the deacetylation process, which turns chitin into chitosan, the acetyl group is removed from chitin. Chitin is dissolved in 60% NaoH solution and heated to roughly 60°C for two hours during deacetylation. After a second round of cleaning with distilled water, the chitosan is dried at 60°C and then packaged in a bottle.

Experimental Procedure for Abattoir Wastewater Treatments

Screening

The wastewater from the abattoir was first screened using screen with a diameter of 90mm to eliminate grit, small stones, gravel, animal bones, skin and other contaminants.

Coagulation and flocculation

The chitosan that had been prepared served as the coagulant. Sample A (wastewater received from point 1) was filtered to eliminate big materials in suspension and measured into three distinct 500 ml measuring cylinders with dosages of 2.5g, 5g, and 10g of chitosan added, respectively. The steps were repeated for samples B and C. The chitosan-containing effluent is then stirred for about 5 minutes and left to stand for around 48 hours. The samples were filtered once they had settled, and their physiochemical features were examined.

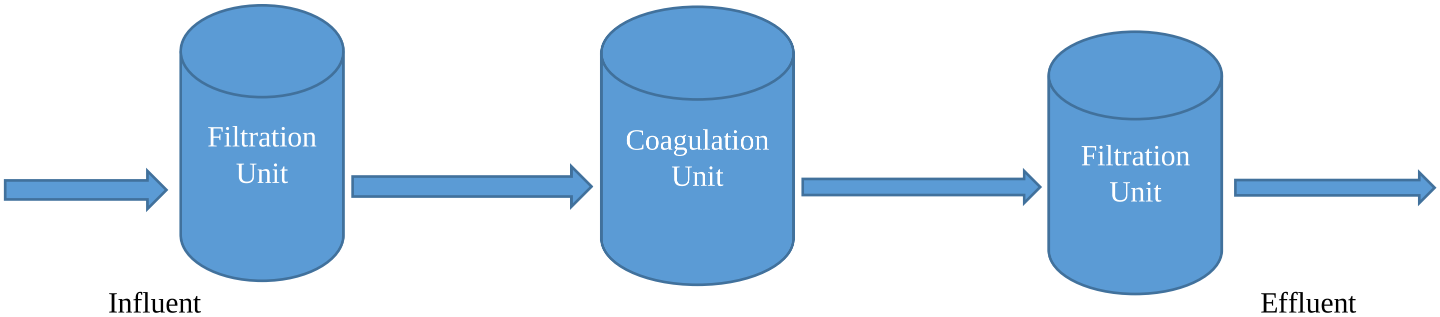

Figure 3. Process Flow Diagram

RESULTS AND DISCUSSION

PHYSICOCHEMICAL PARAMETERS OF ABATTOIR WASTEWATER BEFORE TREATMENT

The results of the physicochemical parameters of sampled wastewater obtained from Trans-Amadi slaughter house in Rivers State Nigeria is displayed in Table 1. The result revealed parameters with range; SAMPLE pH 5.99±0.01 to 6.02±0.01, TDS (mg/l) 1720±1.73 to 3420±1.16, TSS (mg/l) 1563±1.73 to 3174±2.31, DO (mg/l) 4.43±0.01 to 5.74±0.02, BOD5 (mg/l) 198.27±0.01 to 283.52±0.01, COD (mg/l) 845.03±0.02 to 1416.13±0.02, Nitrate (mg/l) 17.46±0.02 to 19.24±0.02, PO_4(mg/l) 24.71±0.01 to 26.70±0.12, P (mg/l) 8.06±0.01 to 8.71±0.01, Total coliform 30±0.58 to 70±0.12, E.coli 22±1.16 to 51±0.58. with average maximal levels seen in the samples in the order; sample 2 > sample 1 > sample

Table 1. Characteristics of wastewater before treatment

Parameter	Sample 1	Sample 2	Sample 3	WHO, 2006	FEPA
pH	5.99	6.02	5.99	6.0-9.0	6.0-9.
Temperature	32	32	34	< 40	<40
TDS (mg/l)	1720	3420	2260	1500	2,000
TSS (mg/l)	1563	3174	2043	60.0	30.0
DO (mg/l)	5.74	4.43	4.91	>1.0	N/A
BOD5 (mg/l)	198.27	283.52	249.16	60.0	50.0
COD (mg/l)	845.03	1416.13	1305.64	150.0	NA
Nitrate (mg/l)	17.46	19.24	18.63	45.0	20.0
Phosphate(mg/l)	26.70	24.71	25.52	15	5.0

Wastewater Characteristics after coagulation/flocculation treatment

The results of the physicochemical parameters of sampled wastewater obtained from notable slaughter house in Rivers State Nigeria after coagulation and flocculation treatment with variable mass (2.5g, 5g, 10g) of chitosan (as the coagulant) is as shown in Table 2. The result revealed that 10g of chitosan proved to be more effective as it gave minimal turbidity (NTU) 0.04±0.01, 0.39±0.06, 0.02±0.01, TSS (mg/l) 42.30±0.17, 48.40±0.23, 32.20±0.00 and TDS (mg/l) 41.00±0.58, 48.00±0.58, 31.40±0.12 levels in samples 1,2 and 3 respectively. The experimental setup of the treatment standing for a time period is given in Figure 3 below.

Figure 4. Influence of Chitosan coagulant

Table 2. Wastewater Characteristics after coagulation/flocculation treatment

SAMPLE	Treatment level	Turbidity (NTU)	TSS (mg/l)	TDS (mg/l)	DO (mg/l)
SAMPLE 1	2.5g	0.31±0.00[a]	53.1±0.06 [a]	52.80±0.17 [a]	5.0±0.12 [a]
	5g	0.12±0.01[a]	46.9±0.06 [a]	46.60±0.12 [a]	3.1±0.12 [a]
	10g	0.04±0.01[a]	42.30±0.17 [a]	41.00±0.58 [a]	1.0±0.17 [a]
SAMPLE 2	2.5g	1.29±0.01[a]	71.40±0.12 [a]	69.60±0.23 [a]	2.1±0.03[c]
	5g	0.58±0.02 [a]	57.90±0.23 [a]	56.40±0.06 [a]	1.0±0.01 [a]
	10g	0.39±0.06[b]	48.40±0.23 [a]	48.00±0.58 [a]	0.2±0.01[a]
SAMPLE 3	2.5g	0.25±0.03[c]	48.80 ±0.06 [a]	48.60±0.17 [a]	2.30±0.23 [a]
	5g	0.06±0.01 [a]	37.50±0.12 [a]	37.20±0.12 [a]	1.2±0.06 [a]
	10g	0.02±0.01[a]	32.20±0.00 [a]	31.40±0.12 [a]	0.9±0.58 [a]

Values represents Mean±SEM. Mean in the same column with same superscript alphabets are significantly different at $p<0.05$. Sample 1= wastewater from slaughter house, Sample 2 = wastewater from 5meters away from the slaughter, Sample 3 = wastewater from the river bank

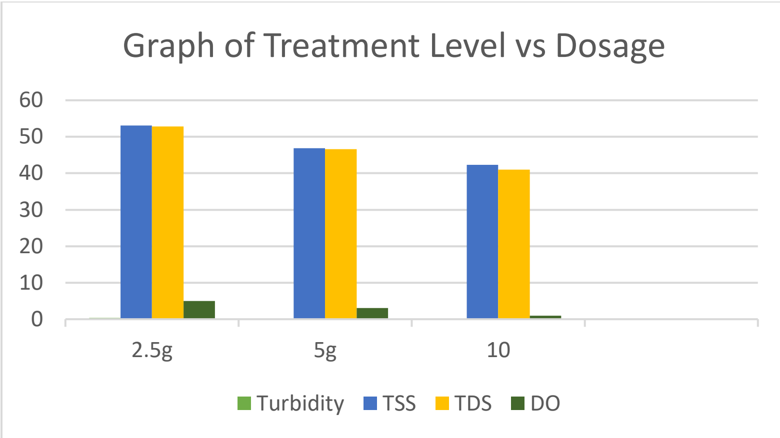

Figure 5. Graph of Treatment Level against Chitosan Dosage for Sample 1

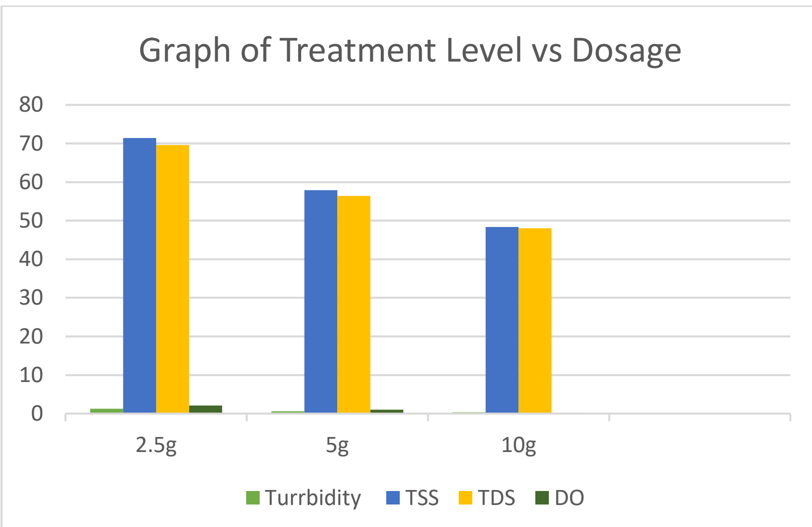

Figure 6. Graph of Treatment Level against Chitosan Dosage for Sample 2

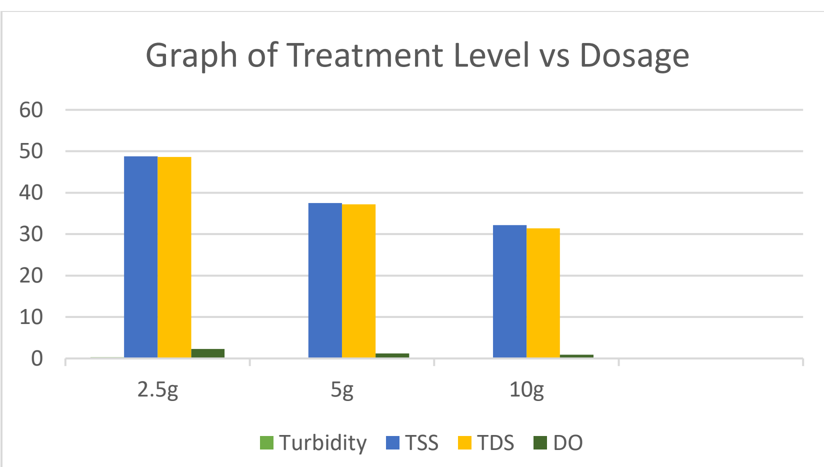

Figure 7. Graph of Treatment Level against Chitosan Dosage for Sample 1

At a dosage of 2.5 g, the turbidity was reduced to 0.31 NTU, TSS was reduced to 53.1 mg/l, TDS was reduced to 52.80 mg/l and DO was reduced to 5.0mg/l across sample 1 as shown in the graph in Figure

4 above. At a dosage of 5 g, the turbidity was further reduced to 0.12 NTU, TSS was reduced to 46.9 mg/l, TDS was reduced to 46.60 mg/l and DO was reduced to 3.1 mg/l. At a dosage of 10 g, the turbidity was brought down to 0.04 NTU, TSS reduced to 42.30 mg/l, TDS was reduced to 41.0 mg/l and DO was further reduced to 1.0. From the foregoing, these reductions from the coagulation treatment fall within the acceptable discharge limit as given by World Health Organization (WHO) and the Federal Environmental Protection Agency (FEPA). The most effective dosage of chitosan was found to be 10 g across sample 1,2 and 3 as shown from the graphs above.

It is worth noting that the removal efficiency of chitosan can vary depending on the characteristics of the wastewater sample and the dosage used (Hao et al., 2021). However, these results suggest that chitosan can be an effective coagulant for reducing the levels of turbidity, TSS, and TDS in wastewater.

In order to further optimize the use of chitosan as a coagulant, it may be beneficial to explore the effect of varying factors such as pH, initial pollutant concentration, and contact time on the removal efficiency of chitosan. This can help to identify the most effective conditions for chitosan treatment of wastewater samples. Before treatment, the wastewater sample had a TDS level of 1720 mg/l and a TSS level of 1563 mg/l. However, after treatment with chitosan, the TDS and TSS levels were reduced to 41.00 mg/l and 42.30 mg/l, respectively, at the most effective dosage of 10 g. This represents a significant reduction in the levels of these pollutants, indicating that chitosan was able to effectively coagulate and remove them from the wastewater sample.

Similarly, the levels of other pollutants, such as turbidity, BOD_5, COD, nitrate, and phosphate was greatly influenced by the coagulation process. When the coagulants are added to wastewater, they neutralize the electrical charges on suspended particles, allowing them to come together and form larger, more easily removed floc. As these flocs settle out of the water, they take with them a significant amount of the organic matter responsible for BOD and COD.

Overall, these results suggest that chitosan can be an effective coagulant for the treatment of wastewater, particularly in the removal of organic matter and other pollutants that contribute to poor water quality. The results of the experiment demonstrate that chitosan is an effective coagulant for reducing the levels of pollutants in wastewater. The addition of chitosan to the wastewater sample resulted in a significant reduction in the levels of TDS, TSS, turbidity, BOD5, COD, nitrate, and phosphate. The most effective dosage of chitosan was found to be 10 g, which resulted in the greatest reduction in pollutant levels across all parameters tested. This suggests that the effectiveness of chitosan as a coagulant is dosage-dependent, and that increasing the dosage can lead to greater pollutant removal. The effectiveness of chitosan as a coagulant can be attributed to its unique chemical and physical properties, including its cationic nature, high molecular weight, and ability to form insoluble complexes with negatively charged pollutants. These properties make chitosan an effective coagulant for removing a wide range of pollutants from wastewater, including organic matter and heavy metals. The reduction in TDS and TSS levels in the wastewater sample after treatment with chitosan was significant, indicating that chitosan was able to effectively coagulate and remove these pollutants. The reduction in turbidity was also substantial, which suggests that chitosan can improve water clarity. The reduction in BOD_5, COD, nitrate, and phosphate levels also indicates that chitosan was effective in removing organic matter and other pollutants from the wastewater sample. These pollutants are a major concern in wastewater treatment because they contribute to the eutrophication of water bodies and can have negative impacts on aquatic ecosystems.

CONCLUSION

In conclusion, this study investigated the effectiveness of chitosan as a coagulant for the treatment of wastewater. From this process, it was observed that the inherent particle type, the particle concentration, the turbidity, the pH, the alkalinity, the chitosan concentration and the nature of the organic matter present in the wastewater all determines the level of coagulation and treatment. The results demonstrated that chitosan can effectively remove pollutants from wastewater, including turbidity, TSS, and TDS. The highest removal efficiency was achieved at a dosage of 10g. Furthermore, the statistical analysis showed that there was a significant difference in the removal efficiency of chitosan at different dosages. The results also showed that chitosan coagulation was effective in reducing COD, BOD_5, nitrate, and phosphate. Overall, this study provides important insights into the potential use of chitosan as a coagulant for the treatment of wastewater. However, there are some limitations to the study that must be addressed in future research. For example, the study was conducted using a specific wastewater sample, and the optimal dosage and operating conditions for chitosan coagulation may differ depending on the characteristics of the wastewater.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions
Conceptualization: Rockson-Itiveh D.E, Investigation: Rockson-Itiveh D.E, Material and Methodology: Rockson-Itiveh D.E, Ozioko F.C.; Supervision: Rockson-Itiveh D.E, Mabel keke; Writing-Original Draft:Rockson-Itiveh D.E, Mabel Keke; Writing-review & Editing: Rockson-Itiveh D.E, Ozioko F.C; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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