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Odor, Color, and Turbidity Removal from Selected Industrial Wastewater Using an Electrocoagulation Process

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Abstract

Electrocoagulation (EC) is an efficient electrochemical method for treating water using electric charges to destabilize and coagulate pollutants. In this study, a bipolar electrocoagulation reactor with aluminum electrodes was used to treat selected industrial wastewater. Key parameters, including odor, turbidity, Color, and other physicochemical parameters, were analyzed to evaluate the performance of the reactor. Focusing on textile wastewater and two types of cassava wastewater, *fufu* and starch, this study assessed Odor and turbidity removal using aluminum electrodes. Textile wastewater was used to examine Color removal. The operational parameters—voltage (10V–40V), temperature (30°C–38°C), and operating time (15 minutes to 1 hour)—were systematically varied to optimize the performance. The reactor significantly improved turbidity and color removal, with moderate odor reduction. This study highlights the strong capability of the EC process in reducing turbidity using aluminum electrodes, despite challenges in Odor reduction. The electrocoagulation process effectively removed color, BOD, COD, TSS, and TDS from the wastewater. Voltage adjustments and electrolysis time are critical in optimizing pollutant removal and aligning with regulatory standards for industrial wastewater discharge. Despite its overall effectiveness, the challenges of achieving complete odor and BOD removal highlight areas for further research. This study highlights the potential of EC as a sustainable solution for industrial wastewater treatment.

Keywords*: Electrocoagulation, Textile Wastewater, Cassava Wastewater, Removal Efficiency, Wastewater Treatment.*

1. Introduction

Wastewater, the result of human, animal, and environmental activities, includes various sources and characteristics [1]. It is the water expended after use in different settings, including households, commercial centers, industrial centers, public organizations, and related bodies. Industrial, domestic, and agricultural activities contribute to the discharge of liquid and solid waste and contain physical, chemical, and biological pollutants. Wastewater produced by industrial centers commonly contains high levels of pollutants. The physicochemical and aesthetic qualities of water, which are vital for reuse, are severely polluted by pollutants, which require wastewater treatment.

Water quality is becoming an increasingly crucial problem today, particularly for countries in the third world and the world, due to increased pollution [2]. The global water crisis has emerged as the fourth leading societal issue [3]. The escalating scarcity of freshwater poses a significant threat to human health, the environment, and the global economy. Industrialization has substantially contributed to water pollution, which poses serious environmental and public health challenges [4], necessitating effective wastewater treatment methods to achieve the United Nations' Sustainable Development Goal of "Clean Water and Sanitation" by 2030.

Traditional wastewater treatment processes have proven to be inadequate for certain pollutants, prompting

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the exploration of advanced techniques. However, most advanced techniques are expensive to set up, therefore, prompting the need for cheap alternative treatment techniques to be explored. A host of very promising techniques based on electrochemical technology is being developed that do not require chemical additions. These methods include electrocoagulation, electroflotation, and electrooxidation. With electrocoagulation reaching a profitable commercialization level, it has emerged as a justifiable treatment method because of its simplicity, small footprint, effectiveness in handling large water volumes, reduced sludge production, and preserved alkalinity [5], [6], [7].

Electrocoagulation (EC) has emerged as an effective and eco-friendly technique for wastewater treatment and has gained attention for its potential to address the limitations of traditional methods. This treatment technique stands out for its simplicity, high efficiency, and minimal sludge production, requiring fewer chemicals compared to conventional treatments [7]. The fundamental process outlined by [8], and [9] involves the application of an electric field powered by direct current (DC) between electrodes submerged in the treatment solution. In this study, aluminum was used as the sacrificial electrode material in the EC unit. The anodic dissolution of aluminum results in the release of aluminum ions (Al^{3+}) into the solution (Eq. (1)). Simultaneously, hydroxide ions (OH^-) are generated at the cathode (Eq. (2)) and the reactions occurring at the electrodes (Eqs. (1) and (2)) produce Al^{3+} and OH^- ions, which subsequently interact to form various monomeric and polymeric species in the solution, resulting in complex precipitation processes, culminating in the formation of aluminum hydroxide $Al(OH)_3$ (Eq. (3)), as noted in [9] and [10]. The $Al(OH)_3$ formed exhibits sweep floc properties with an extensive surface area, a feature highlighted by [9],[11], enabling rapid adsorption of soluble pollutants within the EC reactor.

At the anode:

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^- \quad (1)$$

At the cathode:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (2)$$

Result:

$$Al^{3+}_{(aq)} + 2H_20_{(l)} \rightarrow Al(OH)_{3\,(s)} + 3H^+_{(aq)} \quad (3)$$

The major limitations of the EC process are the substantial consumption of anode material, electrode passivation, which reduces current and process efficiency, the requirement of an electrically conductive medium, and the fact that the generated sludge mostly contains various substances, including potentially harmful chemicals, requiring careful management [12].

The application of EC to wastewater treatment has gained significant traction over the last decade. Studies have demonstrated its ability to reduce turbidity, chemical oxygen demand (COD), and color in effluents from industries, such as textiles, pharmaceuticals, and food processing. For instance, a study by [7] integrated EC with a submerged membrane bioreactor (SMBR) to achieve over 99% color and turbidity removal under optimized conditions. Similarly, [13] highlighted the role of EC in enhancing nutrient removal and filterability in municipal wastewater. Despite these promising results, there remains a notable gap in the research focused on the specific treatment of cassava and textile wastewater. Several studies using electrochemical methods have been conducted [14], [15], [16], and studies using EC combined with other (pre/post) treatment methods have been conducted [17], [18], and [19]. Most studies addressing EC have not thoroughly examined how to effectively tackle issues such as odor removal from cassava wastewater or color removal from textile wastewater. Given that these industries generate large volumes of wastewater containing high levels of organic and inorganic chemicals, which are responsible for impacting odor, color, turbidity, chemical oxygen demand (COD), etc. [8],[20] which can significantly affect water quality, it is crucial to fill this knowledge gap.

Therefore, comprehensive studies are urgently needed to assess the efficiency of EC reactors for treating cassava and textile wastewater on a smaller scale. These studies will pave the way for potential large-scale applications, ultimately leading to improved wastewater management practices in these industries and better environmental protection.

Hence, this experimental study aimed to remove odor, color, and turbidity from the selected wastewater using a fabricated EC reactor with an aluminum electrode and to predict the efficiency of EC processes by analyzing key operational parameters. The specific objectives include the determination of the types of dye used and the quantity

produced per day, the determination of the operation of the cassava factory, the scale of the processing system, the quantity of waste produced per day, the characterization of physio-chemicals of selected wastewater streams, optimization of EC treatment processes, determination of EC reactor efficiency, and proposal of a safety management plan for the selected industrial wastewater.

This study hypothesizes that a fabricated EC designed based on modifications of Chen's foundational work on EC systems can significantly enhance the accuracy of predicting and optimizing the removal efficiencies of odor, color, and turbidity from industrial wastewater. Additionally, operational parameters such as current density, pH, and treatment time will have a statistically significant influence on the removal efficiency of odor, color, and turbidity.

This study offers several novel contributions to the field of wastewater treatment, addressing the simultaneous removal of multiple pollutants, offering a more holistic evaluation of EC's effectiveness of EC, ensuring practical applicability, and bridging the gap between theoretical predictions and real-world optimization of treatment parameters for industrial wastewater. Additionally, the specific contributions of this study include customized reactor design, parameter optimization, comparative analysis, and field applicability.

The proposed paper is organized into sections, starting with Section 2, which details the Materials and Methods, including study location, data collection, sampling techniques, and the EC reactor design, along with laboratory experiments, odor analysis methods, and experimental error assessment. Section 3 presents the Results and Discussion, focusing on the operations and waste generated from the investigated systems, the physicochemical characteristics of cassava and textile dye wastewater, and the impact of voltage on treatment efficiency compared to the Federal Ministry of Environment guidelines. Finally, Section 4 summarizes the key findings in the Conclusion and Recommendations, includes acknowledgments and a competing interest statement, and provides information on data accessibility, followed by the References section and Appendices with supplementary data tables.

2. Materials and Method

2.1. Study location

The study area is located within Ibadan, the capital of Oyo State. Ibadan is the third-largest city in Nigeria, following Lagos and Kano in terms of population. According to the annual population projection of 2016, the total population is 7,840,900, and over six million people live within a metropolitan area of 27,648 km^2 [21]. The cassava wastewater was collected from a processing site with geographical coordinates of 7° 31'47″ N, 3° 54'45" E, with an elevation of 75 m above sea level, approximately 250m from Akinyele LGA headquarters and textile and dye wastewater was collected from Adegbayi and Oyo State Cultural center processing sites with geographical coordinates 7°23'19" N, 3°59'17" E, and 7°24'10" N, 3°53'44" E, approximately 450m from Ife-Ibadan Expressway at Adegbayi for Adegbayi site, 450m from Oyo State Secretariate for Cultural center site.

2.2. Data collection

Qualitative and quantitative data were collected from the selected industries, focusing on environmental and sanitary conditions, waste generation quantity, waste disposal knowledge, and associated practices. Primary Stakeholder Discussion (PSD) was used to involve interactions with industry owners, workers, and community members. Sanitary Inspection (SI) assesses waste management practices at industrial processing sites. The data collected included operations, challenges, workforce details, waste volumes, and disposal methods.

2.3. Sampling

Standard methods in [22], guided sample collection, as clean, unused 25-liter containers were employed for laboratory sample collection. Containers were first washed with distilled water before washing them again at the site of collection with the wastewater to be collected, labeled with sample type, and collection details, and stored properly. Grab samples were taken in one-liter containers for raw wastewater quality assessment. The samples were preserved on ice and transported to the laboratory. All samples were analyzed using [22] to ensure accurate results.

2.4. Electrocoagulation reactor design

The EC reactor design, following Chen's method [9] was implemented in a laboratory setting. The EC reactor featured a stainless-steel plate tank that was insulated with foam and enclosed in a wooden box. The chamber contained a water inlet and outlet for the treated effluent. Nine aluminum anode and cathode plates were screwed onto a wooden frame for easy replacement. The Schematic design of the EC reactor is shown in (Figure 1), and the sectional design of the EC reactor is shown in (Figure A1 – A4).

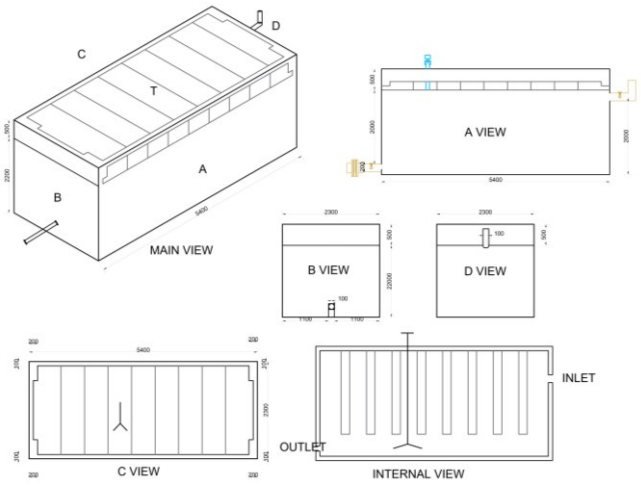

Figure 1. Schematic Design of the electrocoagulation reactor.

The EC reactor had external dimensions of length of 54 cm, breadth of 23 cm, height of 27 cm, and internal capacity of 20 liters. The inlet and outlet dimensions were 100 mm in diameter, which enhanced the functionality of the reactor. Nine aluminum anode and cathode plates, each with a height of 21 cm, length of 5 cm, breadth of 15 cm, and spacing of 6.35 cm, were utilized. These plates were screwed onto a wooden frame and allowed for convenient electrode replacement after corrosion. A DC power supply, using a Finbrok battery (5751 mf, 50 V), energized the EC unit. The electrode was arranged in a bipolar series configuration, with only the outer electrodes connected to the power source, thus simplifying reactor maintenance. Crocodile clips, a 1000 kohm rheostat for voltage regulation, and a digital voltmeter were integral components enclosed in a protective rectangular case.

The electrical setup facilitated precise voltage control during the EC. Crocodile clips, a rheostat, and a rectangular case housing a digital voltmeter were employed for effective electrical regulation.

2.5. Laboratory experiments

In this study, an experimental setup involving the batch mode was used. The EC setup began with of 20 L volume of wastewater introduced into the EC reactor via the inlet pipe. The reactor, equipped with aluminum electrodes, served as the core component for treatment. Once the wastewater was inside the reactor, a specified voltage was applied across the electrodes. The applied voltage can vary between 10V and 40V, depending on the desired treatment efficiency. The treatment time in the EC reactor was controlled and typically ranged from 15 minutes to 1 hour. The electrode polarity reversal after 30 min was used to prevent passivation. The temperature of the wastewater is also monitored, as EC generates heat due to the electrical current. As the electric current flows through the electrodes, the aluminum electrodes release ions that induce a series of electrochemical reactions that destabilize pollutants in the wastewater. This destabilization leads to the coagulation of contaminants, which are then agglomerated into larger particles, or flocs. These flocs are easily removed from the treated water through processes such as settling.

At the end of the treatment cycle, the treated wastewater is discharged through the outlet pipe. This treated effluent is then collected for further physicochemical analysis to assess the removal efficiency of the pollutants. Parameters such as pH, turbidity, TSS, TDS, BOD, COD, color, and odor are measured to evaluate the effectiveness of the EC treatment under specific conditions. The results guide any necessary adjustments in operational parameters, such as voltage, treatment time, and electrode configuration, to improve the removal efficiencies of the targeted pollutants.

The schematic diagram of the experimental setup is adapted from [23]. The setup is shown in (Figure 2).

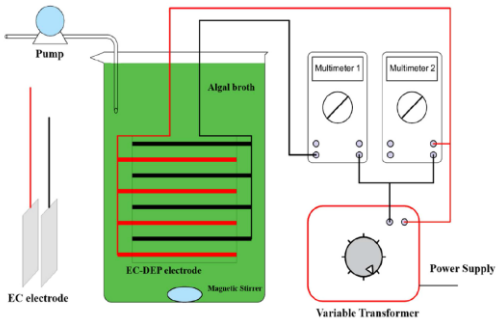

Figure 2. Schematic diagram of the electrocoagulation reactor setup (adapted from Warden [23]).

Figure 3 shows the graphical abstract diagram of the laboratory setup while Figure 4 shows the Laboratory experimental setup during operation at 30 V.

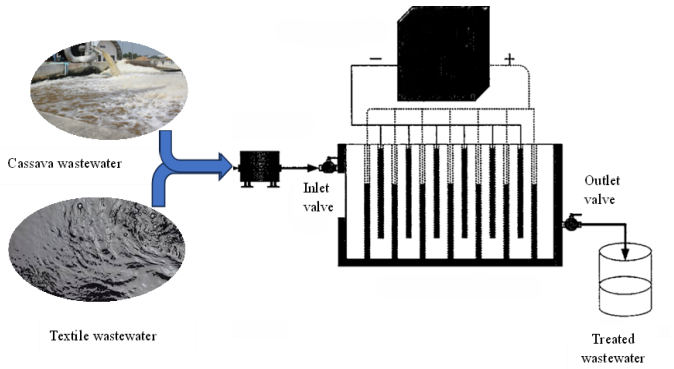

Figure 3. Graphical abstract diagram of the laboratory setup.

Figure 4. Laboratory experimental setup during operation at 30 V.

Samples of each stream were collected at 15-minute intervals of treatment time, labeled with treatment type and time. Samples collected were analyzed for Physiochemical parameters (TS, TDS, TSS, BOD, COD, Turbidity, Temperature, Electrical Conductivity, and pH), ensuring comprehensive wastewater treatment evaluation using [22], and analysis of Color using the UV-visible spectrophotometric—Single-Wavelength method at the laboratory. The turbidity of the wastewater samples was determined by the use of a spectrophotometer at a specified wavelength of 450 nm.

2.6. Odor analysis

Odor analysis was carried out in the laboratory using the triangular odor flask method (TOFM), where a sensory evaluation took place. For each sensory test, a panel of 6 members was assembled. Each panelist received 3 flasks: one containing a sample and two filled with odor-free water. They were instructed to identify the flask with the odor in a controlled environment free from any distractions. Upon correctly identifying the odorous flask, the odor was diluted with non-odorous water, and testing continued until it became impossible to distinguish the odorous flask. The testing began with a moderately diluted concentration to prevent olfactory fatigue. The odor index was calculated based on established methods.

The sensory tests conducted with the 6-panel members produced odor index results that fell within 10% of the population mean with a probability of 94%. When the results were recalculated using only 4-panel members, excluding the highest and lowest values, the probability of the results staying within a 10% range of the population mean dropped to 91%, indicating a high level of reliability. Additionally, to mitigate the effects of outliers, the maximum and minimum values were excluded from the analysis [24]. The probability distribution of the test result is shown in (Figure 5).

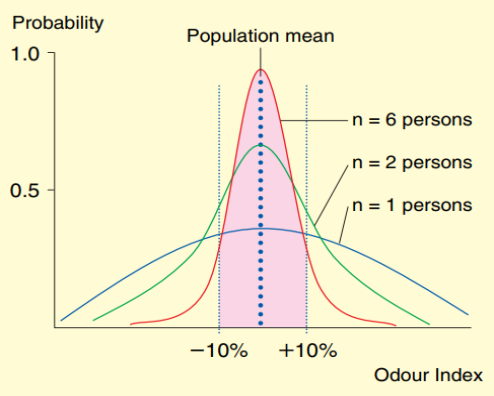

Figure 5. Probability distribution of the test results. (Adapted from Office of Odour, Noise and Vibration Environmental Management Bureau, Ministry of the Environment, Government of Japan. [24]).

2.7. Calculation of odor index

First, the threshold of each panel member was calculated as follows;

$$Xi = \frac{(logM1i + logM2i)}{2} \quad (4)$$

- Xi: Threshold of panel i (expressed as common logarithm)
- $M1i$: Maximum dilution rate at which the answer of panel i is correct.
- $M2i$: Minimum dilution rate at which the answer of panel i is incorrect or indistinct.

Then, calculation of the average threshold of the panel, which is the average of *Xi* excluding maximum and minimum values.

$$X = \frac{(X_1 + X_2 + \ldots + X_{n-2})}{X_{n-2}} \quad (5)$$

- *X*: Average threshold of panel (expressed as common logarithm)
- *n*: Number of panel members

The Odor index is calculated by multiplying X by the factor 10.

$$Y = 10X \quad (6)$$

- *Y*: Odor index

2.8. Efficiency of the system

The efficiency of the system is typically evaluated based on its ability to reduce key contaminants such as TSS, TDS, BOD, COD, turbidity, color concentration, and increase in clarity of the wastewater. Based on the uncertainties measured, the overall efficiency is subject to experimental error.

The equation for efficiency E is adapted from [8], [25], and [26] for the system to remove a contaminant, it is calculated as:

$$E\ (\%) = \frac{(C_{in} - C_{out})}{C_{in}} \times 100 \quad (7)$$

Where:

- C_{in} is the initial concentration of the contaminant. i.e. initial concentrations of each parameter before treatment.
- C_{out} is the final concentration after treatment. i.e. final concentrations of each parameter after treatment.

2.9. Uncertainty in efficiency for electrocoagulation reactor

Efficiency is a critical metric in evaluating the performance of a system, particularly in scientific and engineering applications. However, the reported efficiency of any system is inherently subject to uncertainties arising from a combination of factors, including instrumental limitations, environmental variability, human error, and methodological approximations. Understanding and quantifying these uncertainties is essential for interpreting results accurately, ensuring reproducibility, and providing a foundation for system optimization.

The efficiency uncertainty of a system arises from various sources, including instrumental limitations (precision, resolution, and calibration stability of instruments measuring C_{in} and C_{out}, for example, pH meters, thermocouples, and spectrophotometers can introduce errors), variability in system conditions (changes in ambient temperature, pressure, and humidity can affect measurements and system performance), human error (errors during sample collection, handling, preparation, or data recording can influence results), sampling variability (fluctuations in wastewater composition or other system inputs can cause inconsistencies), and methodological approximations (simplifications in calculation models, such as approximating odor index values or assuming linear relationships in certain parameters, can lead to deviations).

Each of these factors contributes to the total uncertainty, which must be quantified and reported to ensure the reliability of efficiency values.

The equation for U_{eff} is adapted from [27]. To calculate the uncertainty in efficiency (U_{eff}), the propagation of errors from C_{in} and C_{out} is performed.

$$U_{eff} = \sqrt{\left\{\frac{\partial \eta}{\partial C_{in}} U_{in}\right\}^2 + \left\{\frac{\partial \eta}{\partial C_{out}} U_{out}\right\}^2} \quad (8)$$

where:

- $\frac{\partial \eta}{\partial C_{in}} = -\frac{C_{out}}{C_{in}} \times 100$ (9)
- $\frac{\partial \eta}{\partial C_{out}} = \frac{1}{C_{in}} \times 100$ (10)

Here U_{in} and U_{out} are the uncertainties in inlet and outlet measurements, respectively. To get U_{in} and U_{out} for each parameter.

The formulas for U_{in} and U_{out} depend on the factors contributing to the measurement uncertainty as earlier stated specifically for each measured parameter.

$$U_{in} = \sqrt{\{U_{instrument,in}\}^2 + \{U_{method,in}\}^2 + \{U_{environment,in}\}^2 + \{U_{operator,in}\}^2} \quad (11)$$

$$U_{out} = \sqrt{\{U_{instrument,out}\}^2 + \{U_{method,out}\}^2 + \{U_{environment,out}\}^2 + \{U_{operator,out}\}^2} \quad (12)$$

Generally, uncertainty in current measurements is primarily attributed to fluctuations in the AC/DC power supply and any inaccuracy of the voltmeter reading, which may affect the stability of the readings. For pH and temperature (°C) measurements, errors are mainly due to the potential drift in the calibration of the pH meter and thermocouple, respectively. These instruments can experience shifts in accuracy over time, leading to deviations in the recorded values.

In the case of TSS and TDS, the precision of the balance used during sample weighing and the sampling technique itself contribute significantly to the uncertainty. Even minor deviations in sample collection or balance calibration can lead to considerable variation in results.

Turbidity is subject to uncertainty due to the potential noise interference in light scattering measurements. Variations in light intensity or scattering angle during the measurement process can introduce significant noise, thereby affecting the precision of the turbidity readings.

For BOD and COD measurements, the purity of the reagents used, potential mishandling of samples, and the incubation conditions during analysis can lead to errors in the measurement of oxygen demand, impacting the overall accuracy of the results. For color concentration measurements, the calibration of the instruments, the sample preparation process, and environmental factors such as light interference and temperature fluctuations during measurement also play a critical role in affecting the accuracy.

Uncertainty in odor parameter measurements can stem from panel sensory readings, variability in wastewater composition, subjectivity in olfactometry, sampling handling and timing, ambient temperature, contamination during electrocoagulation, and approximations in calculations like the odor index.

$U_{instrument}$ is derived from various instruments used to measure each parameter, $U_{enironment}$ involves quantifying the variability in system performance or measurement outcomes caused by external environmental factors. These factors can include temperature, humidity, pressure, and vibrations.

$U_{operator}$ is typically challenging to quantify precisely, as it depends on subjective factors such as skill, attention, and experience. However, it is possible to estimate the contribution of human error to uncertainty through various approaches. The key is to recognize that human error typically manifests as variability in measurements due to inconsistencies in performing tasks or interpreting data. The method used to analyze human error uncertainty is quantified using the Coefficient of Variation (CV) or Standard Deviation of the errors observed in repeated measurements. CV is used because of its usefulness especially when comparing the relative size of uncertainty to the mean value of the measurements. This is based on the assumption that any inconsistencies or errors introduced by the operator will cause some level of variation in the measurements.

U_{method} is uncertainty associated with each parameter as a result of method and sampling variability, this often occurs due to the natural variations or fluctuations that occur in measurements due to the inherent heterogeneity of the sample or reagent from which the sample or reagent is drawn. In many experiments, especially those involving wastewater different samples may yield slightly different results even if taken under similar conditions. To measure the uncertainty due to the method, we typically rely on statistical methods using the standard error of the mean (SEM).

$$CV = \frac{\sigma_{measurements}}{\mu_{mesurements}} \times 100 \quad (13)$$

where:

$$\mu = \frac{\sum(measurements)}{n} \quad (14)$$

and

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{n-1}} \quad (15)$$

- x_i is each individual reading.
- μ is the mean of the readings.
- n is the number of readings

$$SEM = \frac{\sigma}{\sqrt{n}} \quad (16)$$

3. Result and Discussion

3.1. Operations and major products

The textile dye processing plant prioritizes the production of four main products which are *Adire*, *Kampala, Batik, and Tie* and *Dye (Kampala).* Also, the cassava processing plant prioritizes the production of four main products which are *Garri, Fufu, Starch, and Elubo (Lafun)*. Fufu and garri emerge as the primary products, with elubo and starch produced on rare occasions. The most common type of dye used in textile and dye production is black. This is followed by other Colored dyes which are: orange, purple, yellow, and blue.

3.2. Scale of the processing system

The cassava plant employs 25 workers, including three males and 22 females, encompassing both daily and casual workers. On average, 15 workers are engaged daily, contributing to a processing capacity of one to two trucks weekly. The textile dye factories have a total of 8 workers, encompassing both daily and casual workers. The low number of workers is due to the incapacity of the industry to produce on a large scale.

3.3. Volume of solid and liquid waste produced

For each dye that is used, 20 liters of water are used to heat the dye and about 40 liters of water are used to wash the dyed material. The quantity of wastewater produced per day depends on the amount of dyeing order they receive. In festive seasons, orders are more as compared to normal work times when production is low. On average, the textile dye industries produce 20 pieces of 5 yards of cloth in two days while 100 pieces of 5 yards are during festive seasons. The quantity of wastewater produced on average is 600 liters per day. The quantity of wastewater for the cassava wastewater also varies for each cassava product. The processing plant generates a minimum of 3500 liters of liquid waste per day, this liquid waste tends to be doubled for days when fufu and starch production is dominant. Garri and elubo (lafun) production generates minimal liquid waste.

3.4. Solid and liquid waste disposal method employed

The cassava processing plant employs a sanitary waste disposal approach by repurposing waste generated at the cassava processing site. Solid waste is utilized as animal feed, and distributed to goat, ram, and pig breeders. Additionally, the cassava processing plant breeds livestock, which are fed using some of the solid waste. Any solid waste not suitable for livestock feed is appropriately disposed of. Liquid waste is directed to a designated land parcel used for growing grass intended for livestock feed that often flows into a nearby stream. The textile dye plant disposes their solid waste through the Oyo State government waste disposal truck, this truck takes the waste to the Oyo State dumpsite while the liquid waste is disposed of to a bare land that often flows into the nearby stream.

3.5. Physicochemical characteristics of wastewater

Figure 6, highlights the effectiveness of the EC in removing TSS and (Figure 7) highlights the effectiveness of the EC unit in removing TDS across various wastewater streams at different voltage levels.

In the fufu stream, TSS removal efficiencies were recorded at 74%, 76.6%, 78.4%, and 78.6% for voltages of 10V, 20V, 30V, and 40V, respectively. However, TDS removal showed a slight decline at the highest voltage, with 42.1%, 42%, 46.5%, and 43.36% efficiencies. This trend indicates a generally effective process, despite the minor drop in TDS at 40V. For the starch stream, the TSS removal efficiencies started at 58.27% and increased to 71.9% as the voltage rose from 10V to 40V.

In contrast, TDS removal efficiencies also increased, with values of 45%, 46.2%, 49.8%, and 51.3% at the corresponding voltages, showcasing a consistent improvement. The textile dye stream exhibited significant advancements in TSS removal, achieving efficiencies of 23.17%, 51.1%, 74.93%, and 75.9% as the voltage increased. Moreover, the TDS removal for this stream saw remarkable efficiency at higher voltages, reaching 99.8% highlighting the efficacy of the treatment method in this application.

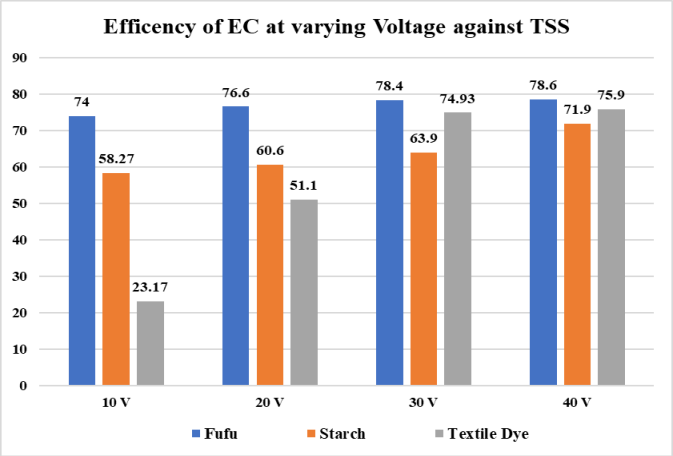

Figure 6. The Efficiency of EC at varying voltages against TSS.

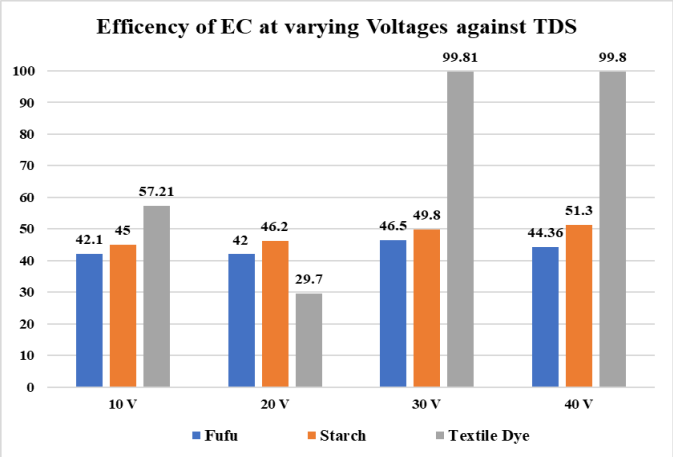

Figure 7. The Efficiency of EC at varying voltages against TSS.

In terms of results for biochemical oxygen demand (BOD) Figure 8, chemical oxygen demand (COD) Figure 9, and dissolved oxygen (DO) Figure 10 removal, across various wastewater streams at different voltage levels, the fufu stream displayed BOD efficiencies of 16.3%, 17.3%, 21.0%, and 26.3%, DO removal efficiency of 38.5%, 44%, 65.1%, 72.3% across the same voltage range, while COD removal efficiencies remained fairly consistent, recorded at 42.1%, 42%, 46.5%, and 43.36%. In the starch stream, BOD and DO removal improved from 47.8% to 54.6% for BOD and 84.1% to 95.2% for DO indicating effective treatment, while COD efficiencies increased from 45% to 51.3%. The textile dye stream showed dramatic increases in BOD removal, peaking at 82.9% and maintaining high efficiencies, with COD removal efficiencies significantly rising from 15.34% at 10V to 82.88% at 40V.

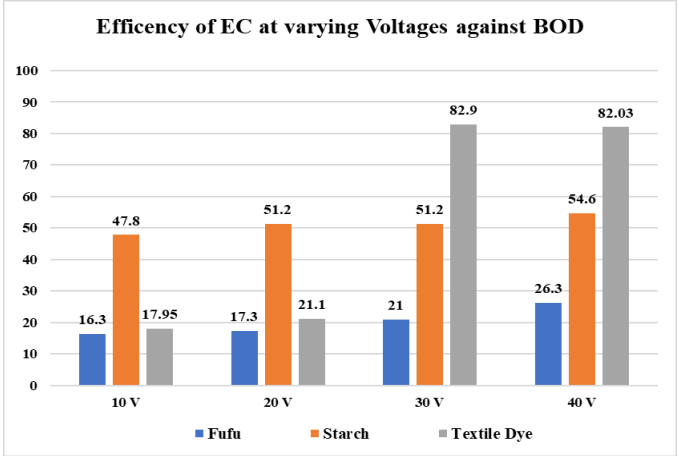

Figure 8. The Efficiency of EC at varying voltages against BOD.

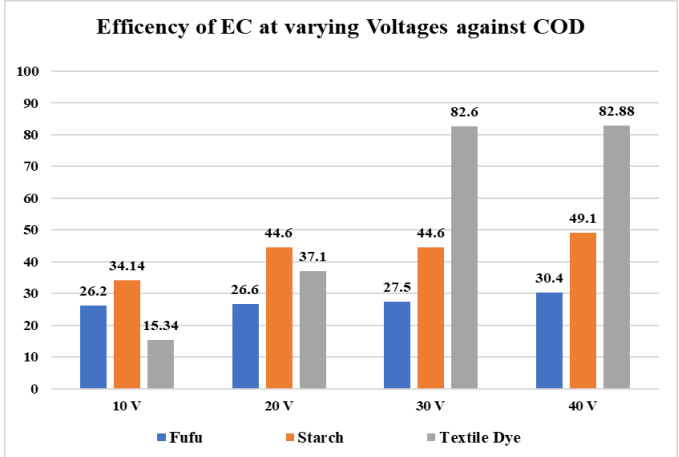

Figure 9. The Efficiency of EC at varying voltages against COD.

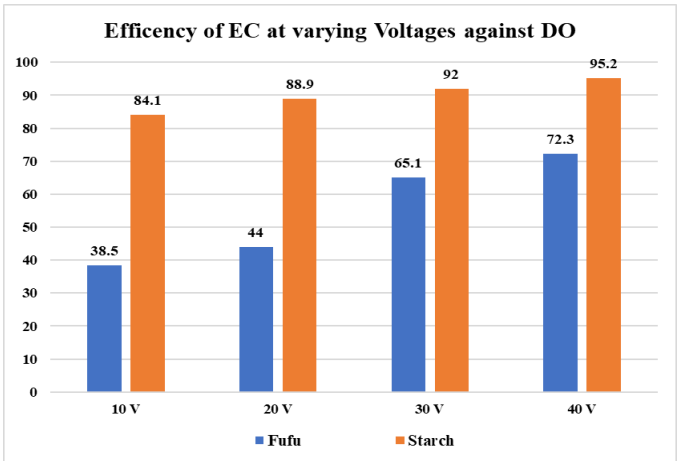

Figure 10. The Efficiency of EC at varying voltages against DO.

Overall, these results indicate that the EC treatment system effectively reduces TSS and TDS concentrations, as well as BOD, COD, and DO levels, with performance generally improving as voltage increases across all examined wastewater streams.

3.6. Turbidity characteristics of cassava wastewater

The efficiency of EC in removing turbidity across various wastewater streams at different voltage levels is presented in (Figure 11). The figure shows that the turbidity concentration of cassava wastewater streams significantly decreases. The system achieved 26.2%, 56.7%, 57%, and 84.4% efficiency for the fufu stream at 10 V, 20 V, 30 V, and 40 V, respectively. The starch stream achieved 30%, 40.8%, 44.5%, and 75% efficiency at the same voltages. The results align with [25] who reported that EC is an excellent technique for turbidity removal, owing to the ability of coagulants to aggregate and remove particulate matter efficiently. Similarly, EC's ability to remove suspended solids that often cause wastewater turbidity is likely to be removed through coagulation and flocculation processes where aluminum ions neutralize particles and help them aggregate into larger, settleable flocs. The effectiveness of this process at high voltages can be attributed to the increased charge density, which enhances particle destabilization and subsequent removal. This result suggests that EC is a suitable method for reducing turbidity in industrial wastewater, particularly in cassava processing.

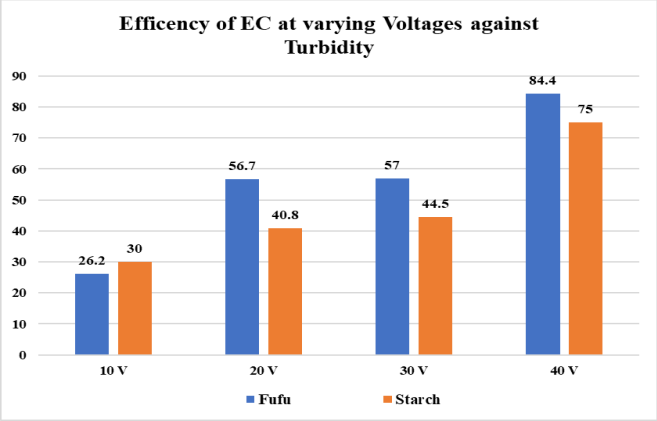

Figure 11. The efficiency of EC at varying voltages against Odor, Color, and Purity.

3.7. Odor characteristics of cassava wastewater

The results for the efficiency of EC in removing odor, color, and purity across various wastewater streams at different voltage levels are shown in (Figure 12). The study shows that EC was less effective at removing odor from both fufu and starch wastewater, with only a slight improvement across different voltage levels. However, the EC treatment exhibited a consistent increase in odor removal across varying voltages. Despite the increase in voltage (from 10 V to 40 V), the odor removal efficiency remained low. This is evident from the odor thresholds around 39, which were only marginally reduced at 30 V and 40 V treatments.

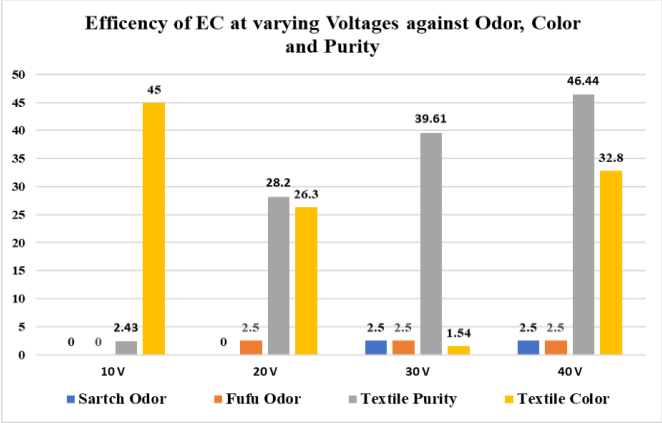

Figure 12. The efficiency of EC at varying voltages against Odor, Color, and Purity.

The limited efficiency can be attributed to logarithmic odor threshold calculations, and the complex nature of organic compounds causing odor in cassava wastewater, suggesting the need for additional treatment steps, such as biological methods or odor-absorbing media, to achieve better results, and treating the wastewater streams at exponential levels for each sample treatment. The details of odor characteristics of each wastewater stream are presented in (Tables C1 – C10). The tables in appendix show the dilution rates, logarithmic values, panel responses, and odor thresholds for both raw and treated samples under different voltage conditions (10 V, 20 V, 30 V, 40 V) after one hour of treatment.

3.8. Color characteristics of textile dye wastewater

As shown in Figure 11 above, the purity of textile dye wastewater improved significantly at higher voltages with notable improvements in EC efficiency at 30 V and 40 V respectively, the color removal is inconsistent across the voltages with the highest efficiency achieved at 10 V, although, the efficiency at 40 V is close to the efficiency at 10 V. These inconsistencies can be attributed to the pH of the wastewater where a pH close to a neutral state than in extremely acidic and alkaline conditions experience higher efficiency, this observation is similar to [28] where color removal is achieved more at a pH close to a neutral state.

3.9. Effect of voltage, pH, temperature, and electrical conductivity on electrocoagulation efficiency

The electrocoagulation process is significantly influenced by voltage, pH, temperature, and electrical conductivity. It was generally observed from the study that an increase in voltage enhances the removal efficiency for various pollutants. Increased voltage enhances treatment efficiency by elevating current density and promoting faster electrochemical reactions, which improves the removal of turbidity, TSS, TDS, BOD, and COD. However, this must be balanced with energy consumption, particularly in large-scale applications.

The pH level of water or wastewater is crucial in electrocoagulation, affecting current efficiency and the solubility of metal hydroxides, with chloride ions contributing to chlorine release. Aluminum electrodes show higher current efficiencies in acidic and alkaline conditions compared to neutral pH. Optimal pollutant removal generally occurs around pH 7, although power consumption is higher at neutral pH due to conductivity variations. High conductivity diminishes the significance of pH on the process.

Notable pH changes were observed, with initial levels shifting during treatment. The cassava wastewater streams move from acidic towards neutral while the textile dye moves from alkalinity to neutral. The treatment of cassava wastewater streams may have been influenced by volatile fatty acids and organic acids, reducing pH values in the sedimentation tanks for both the starch and fufu streams. [29] suggests that lower starch pH results from its acidification process, while [30] notes that cassava wastewater is characterized by high organic loading and low concentrations of total solids (TS) and pH. The parameters such as TSS, TDS, electrical conductivity, dissolved oxygen, turbidity, BOD, and COD showed dynamic fluctuations due to electrochemical treatment.

After electrocoagulation treatment, the effluent pH changes depending on the pH of the influent. If the influent is acidic, the effluent pH will increase towards a neutral pH of 7, while if the influent is alkaline, the pH will decrease towards a neutral pH of 7. This pH shift is one of the benefits of electrocoagulation. The increase in pH in acidic conditions is mainly attributed to hydrogen evolution at the cathodes, as noted by [7],[9]. Conversely, the formation of $Al(OH)_3$ near the anode can release H^+ ions, leading to a decrease in pH. Additionally, the oxygen evolution reaction also contributes to a reduction in pH.

Temperature impacts the reaction kinetics, and electrical conductivity can alter the system's effectiveness, especially when conductivity is high. The presence of chloride ions can complicate the process by introducing additional chemical reactions.

3.10. Comparison of the results with the federal ministry of environments industrial effluent limitation guide

The industrial effluent limitations set by [31] as presented in Table 1 mandate a pH range of 6 to 9 for wastewater disposal, and none of the treated wastewater exceeded this limit. The treated effluent's electrical conductivity (EC) was suitable for safe discharge into surface water and land application, with temperatures ranging between 25 and 39°C, staying below the 40°C threshold. Although most parameters met the guidelines, elevated levels of BOD, COD, and color exceeded the limits for discharge into water bodies. The results align with [17], [18], and [19] who indicated the necessity of combined pre/post-treatment methods for effective color removal in textile wastewater. Cassava wastewater's significant organic loading, as highlighted in studies [25] and [26], results in high COD and BOD concentrations. While substantial COD was removed, only a limited amount of BOD was reduced, demonstrating a challenge in achieving complete compliance in cassava wastewater streams. This suggests the need for secondary treatment steps, such as biological or filtration processes, to further reduce organic load.

Similarly, the treated textile dye wastewater complied with FEPA effluent limitations for land application but not for discharge into water bodies, emphasizing the difficulty of breaking down complex dye molecules. Previous studies [2] suggest that while EC effectively reduces color initially, combining it with advanced oxidation processes may enhance decolorization. Increasing voltage consistently improved BOD and COD removal, with COD compliance achieved at 30 V and 40 V in the textile dye stream. All treated effluents met FEPA effluent limitations for TSS and TDS and adhered to WHO standards, showcasing the system’s overall reliability for regulatory compliance.

Table 1. Federal Environmental Protection Agency effluent limitation guidelines in Nigeria for all categories of industries.

Parameters	Units in milligrams per little (mg/l) unless otherwise stated.	
	Limit for discharge into surface water.	Limit for Land Application
Temperature	Less than 40 ^{0}C within 15 meters of the outfall	Less than 40 ^{0}C
Color (Lovibond Units)	7	-
pH	6-9	6-9
BOD_5 at 20^{0}C	50	500
Total suspended solids	30	-
Total dissolved solids	2,000	2,000
Chloride (as CL)	600	600
Sulphate (as SO_42)	500	1,000
Sulphide (as S^2)	0.2	-
Cyanide (as CN-)	0.1	-
Detergents (linear alkylate sulphonate as methylene blue active substance)	15	15
Oil and grease	10	30
Nitrate (as $NO_{3)}$ NO3	20	-
Phosphate (as PO_4^{3-})	5	10
Arsenic (as AS)	0.1	-
Barium (as Ba)		5
Tin (as Sn)		10
Iron (as Fe)	20	-
Manganese (as Mn)	5	-
Phenolic compounds (as phenol)	0.2	-
Chlorine (free)	1	-
Cadmium, Cd	Less than 1	-
Chromium (trivalent and hexavalent)	Less than 1	-
Copper	Less than 1	-
Lead	Less than 1	-
Mercury	0.05	-
Nickel	Less than 1	-
Selenium	Less than 1	-
Silver	0.1	-
Zinc	Less than 1	-
Total Metals	3	-
Calcium (as Ca^{2+})	200	-
Magnesium (as Mg^{2+})	200	-
Boron (as B)	5	5

3.11. Uncertainty analysis of the system

Using U_{in} and U_{out} for each parameter along with the influent parameter value C_{in} and the outlet parameter value C_{out} and substituting them into equations 8-10. The uncertainty on the efficiency of the system for each parameter at various 1-hour 1-hour treatments, with varying voltages, is presented in (Tables B1 – B3). The results offer a comprehensive assessment of the effective uncertainty (U_{eff}) associated with various parameters during the treatment of each wastewater. This effective uncertainty quantifies the potential variability or confidence range of each parameter, thus reflecting the reliability of the observed treatment process. The findings reveal distinct trends that highlight the performance and precision of the system.

The evaluation of the treatment efficiency of cassava wastewater revealed significant findings regarding the uncertainty levels associated with various parameters. Analysis of the BOD and COD indicated relatively high effective uncertainty values, averaging ±15.25 mg/L and ±22.77 mg/L, respectively. This heightened uncertainty can be attributed to the inherent variability in the removal of organic loads, fluctuations in microbial activity, and the complexities of the biodegradation process within the system. Such variability is characteristic of biological

treatment systems, especially when dealing with wastewater rich in complex organic components like cassava. On the other hand, other parameters like TSS, TDS, EC, pH, and DO demonstrated exceptionally low effective uncertainty, with the highest record being TSS averaging ±1.06 mg/L. This finding signifies a highly consistent and reliable removal process for suspended particles, dissolved particles, and neutralization of acid present in cassava wastewater. The low uncertainty reflects the effective design and operation of the treatment system. This outcome suggests a stable and well-controlled treatment process. Particularly, the low effective uncertainty in pH and temperature implies that the system manages to maintain stable conditions, which are crucial for optimizing treatment efficiency and ensuring compliance with regulatory standards. Furthermore, the reliability of the treatment system in managing dissolved constituents is highlighted by the low uncertainty in TDS and EC measurements.

The results for turbidity presented a moderate effective uncertainty of ±6.78 mg/L. Though this level of uncertainty is higher than that of TSS, it remains within acceptable limits. This indicates that the treatment system successfully reduces turbidity, albeit with a slight increase in variability. The turbidity levels are often influenced by the presence of fine colloidal particles and dissolved organic matter, which can vary due to changes in operational conditions.

Notably, the study identified a high degree of uncertainty associated with the color concentration and chemical oxygen demand (COD) parameters. With average effective uncertainty values of ±30.38% for color concentration and ±20.05 mg/L for COD, these findings suggest that the organic load removal process exhibits considerable variability. The significant uncertainty underscores the necessity for further optimization efforts to enhance the reproducibility and control of the treatment process. In contrast, parameters such as TSS, TDS, pH, and temperature showed exceptionally low uncertainty values. Specifically, TSS displayed an effective uncertainty of ±0.17 mg/L, while TDS had a value of ±0.28 mg/L, pH was ±0.27, and temperature demonstrated an uncertainty of ±1.14 °C. These remarkably low uncertainty measurements reflect a high level of consistency and reliability in the removal of suspended particles as well as the stability of key physicochemical parameters. The efficient design and operation of the treatment system's physical and physicochemical components, such as sedimentation, filtration, and coagulation, are evident from these results.

On the other hand, biochemical oxygen demand (BOD) was classified as having moderate uncertainty, with an effective uncertainty value of ±6.78 mg/L. This indicates that while the system demonstrates a reasonable degree of consistency in reducing BOD, there remains an opportunity for enhancement, particularly in the biological treatment stage.

The findings indicate that both the textile and cassava wastewater treatment systems are effective and consistent for most physicochemical parameters, such as TSS, TDS, and turbidity. However, the higher uncertainties related to BOD and COD in both systems highlight the urgent need for improved monitoring and optimization of biological treatment processes. Addressing these issues can enhance predictability and reliability, ultimately boosting confidence in the overall performance of both systems.

4. Conclusion and Recommendations

This study investigated the efficacy of a bipolar electrocoagulation reactor with aluminum electrodes for the treatment of cassava and textile wastewater. The research primarily assessed the removal of critical pollutants such as odor, color, and turbidity, while also examining the influence of operational parameters, particularly voltage, on treatment outcomes. The findings revealed notable improvements in various physicochemical parameters, including BOD, COD, TSS, and turbidity, which met the regulatory standards set by the Federal Environmental Protection Agency (FEPA).

Despite the reactor's success in reducing turbidity and enhancing water quality, the removal of odor and color did not reach optimal levels. In particular, the treatment of textile dye wastewater did not achieve complete color removal, and the efforts to eliminate odor from cassava wastewater demonstrated only marginal improvements. These results underscore the effectiveness of electrocoagulation as a viable technology for treating industrial wastewater, while also highlighting areas for further enhancement.

The study brings to light the need for additional research focused on optimizing the process to better

address the challenges associated with odor and color removal. Future investigations could explore adjustments in electrode spacing and configurations to improve treatment efficiency, as well as the potential role of microbial communities within the electrocoagulation process. Furthermore, examining alternative energy sources might support the system's sustainability, while developing predictive modeling tools could enhance treatment performance and reduce energy consumption. There is also a promising opportunity to investigate the integration of electrocoagulation with other treatment methods to improve pollutant removal.

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Competing Interest Statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and Materials Accessibility

All data generated or analyzed during this study are included in this article.

Author Contributions

- Peter Akinlabi: Conceptualization and Design, Literature Review, Data Acquisition, Data Analysis Interpretation, and Writing – original draft, review & editing.
- Titilayo Adepoju: Conceptualization and Design, Literature Review, Data Acquisition, Data Analysis and Interpretation, Writing – original draft
- Chibueze Achi: Conceptualization and Design, Ethical Considerations, Supervision, Writing – review & editing.
- Akinwale Coker: Conceptualization and Design, Writing and Editing, Ethical Considerations, Supervision
-

Ethical Approval

This research received the Institutional Review Board's approval for human olfactory testing.

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Appendix A: Sectional design of an electrocoagulation reactor

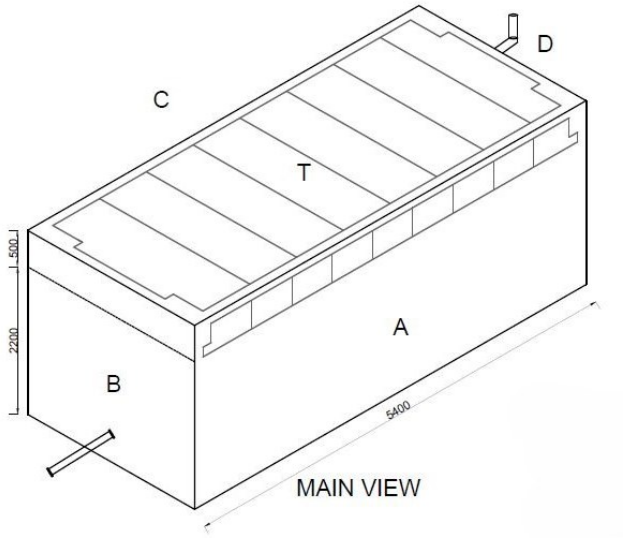

Figure A1. Main-View of electrocoagulation reactor schematical design.

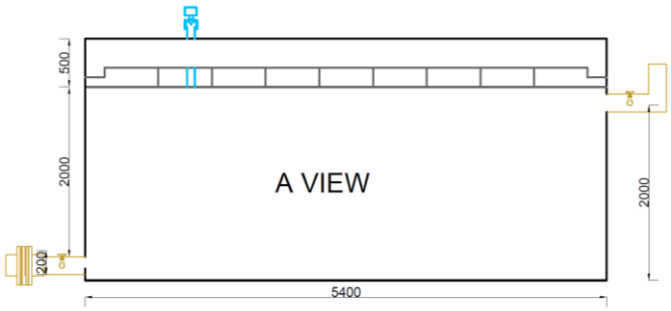

Figure A2. A-View of electrocoagulation reactor schematical design.

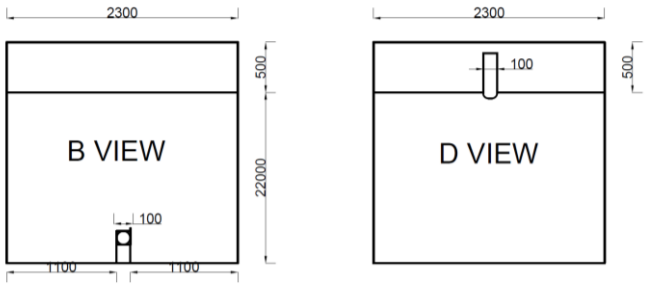

Figure A3. B and D-View of electrocoagulation reactor schematical design.

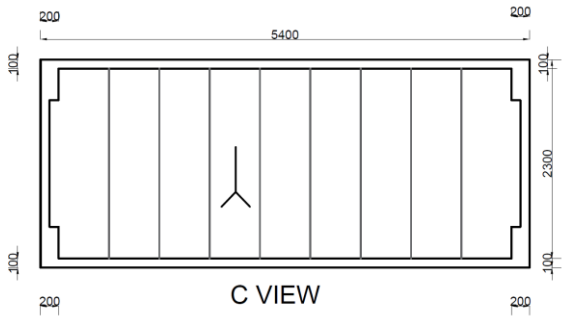

Figure A4. C-View of electrocoagulation reactor schematical design**.**

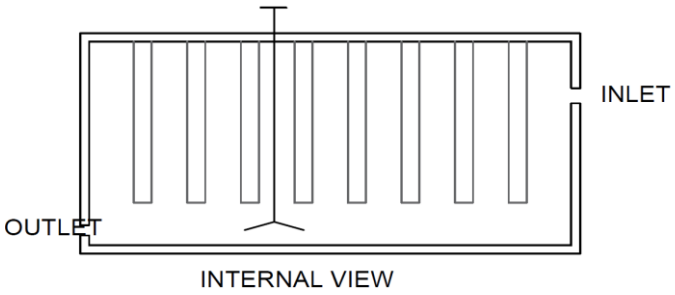

Figure A5. Internal-View of electrocoagulation reactor schematical design.

Appendix B

Table B1. Uncertainty of system for fufu and starch wastewater.

Parameter	**Uncertainty (±)**									
			Fufu Stream				**Starch**			
	Inlet	Outlet	10 V	20 V	30 V	40 V	10 V	20 V	30 V	40 V
pH	0.05	0.09	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Temperature (°C)	0.05	0.08	0.27	0.27	0.27	0.27	0.27	0.28	0.29	0.27
TSS (mg/L)	0.10	0.12	1.14	1.14	1.14	1.14	1.14	0.93	0.93	0.91
TDS (mg/L)	0.05	0.08	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16
EC (S/m)	0.05	0.08	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.25
DO (mg/L)	0.05	0.08	0.25	0.25	0.25	0.25	0.25	0.23	0.23	0.25
Turbidity (mg/L)	0.02	0.03	7.75	7.75	7.75	7.75	7.75	4.79	4.79	5.94
BOD (mg/L)	0.01	0.03	20.05	20.05	20.05	20.05	20.05	7.29	7.29	7.11
COD (mg/L)	0.04	0.03	30.38	30.38	30.38	30.38	30.38	10.08	10.08	10.08
Odor Concentration	0.05	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B2. Uncertainty of system for textile wastewater.

Parameter	**Uncertainty (±)**					
	Inlet	**Outlet**	**10 V**	**20 V**	**30 V**	**40 V**
Current (A)	0.01	0.07	0.00	0.00	0.00	0.00
pH	0.05	0.09	-0.02	0.69	0.68	1.89
Temperature (°C)	0.05	0.08	0.03	0.03	0.02	0.03
TSS (mg/L)	0.10	0.12	0.07	0.07	0.07	0.10
TDS (mg/L)	0.05	0.08	131.37	131.37	56.72	66.45
EC (S/m)	0.05	0.08	61.47	61.47	57.01	61.34
BOD (mg/L)	0.02	0.03	0.12	0.14	0.21	0.20
COD (mg/L)	0.01	0.03	0.19	0.19	0.18	0.19
Colour Concentration (%)	0.05	0.09	0.01	0.01	0.01	0.02
Purity (%)	0.05	0.09	0.01	0.03	0.04	0.05

Table B3. The efficiency of the system for removal of all parameters using electrocoagulation for 1 hour at various voltage.

Parameters	Fufu				Starch				Textile Dye			
	10 V	20 V	30 V	40 V	10 V	20 V	30 V	40 V	10 V	20 V	30 V	40 V
PH	1.3	1.9	2.2	2	1.6	9	9	9	0.24	16.4	16.65	8.77
TSS	74	76.6	78.4	78.6	58.27	60.6	63.9	71.9	23.17	51.1	74.93	75.9
TDS	42.1	42	46.5	44.36	45	46.2	49.8	51.3	57.21	29.7	99.81	99.8
EC	-2.7	-2.6	-1.8	-0.31	-90.9	-90	-90.4	-90.5	55.67	16.5	29.46	6.31
DO	38.5	44	65.1	72.3	84.1	88.9	92	95.2	N/A	N/A	N/A	N/A
Turbidity	26.2	56.7	57	84.4	30	40.8	44.5	75	N/A	N/A	N/A	N/A
BOD	16.3	17.3	21	26.3	47.8	51.2	51.2	54.6	17.95	21.1	82.9	82.03
COD	26.2	26.6	27.5	30.4	34.14	44.6	44.6	49.1	15.34	37.1	82.6	82.88
Colour	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	45	26.3	1.54	32.8
Odour	0	2.5	2.5	2.5	0	0	2.5	2.5	N/A	N/A	N/A	N/A
Purity (%)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.43	28.2	39.61	46.44

Appendix C

Table C1. Odor results of raw fufu stream wastewater.

Fufu Raw Sample											
Dilution Rate		3000	4000	5000	6000	7000	7500	8000	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.77815	3.8451	3.87506	3.90309			
Panel	A	YES	YES	YES	YES	YES	YES	NO	3.889075625		7000
	B	YES	YES	YES	YES	NO			3.811624645	Excluded	6800
	C	YES	YES	YES	YES	YES	NO		3.860079652		7500
	D	YES	YES	YES	YES	YES	YES	NO	3.889075625	Excluded	7800
	E	YES	YES	YES	YES	YES	NO		3.860079652		7300
	F	YES	YES	YES	YES	YES	YES	NO	3.889075625		7600

The result of the panels is 3.8745 which gives the Odor threshold of 39.

Table C2. Odor results of treated fufu stream wastewater at 10V.

Treated Fufu Stream Sample at 10V											
Dilution Rate		3000	4000	5000	6000	6500	7000	7500	8000	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.77815	3.81291	3.8451	3.87506	3.903089			
Panel	A	YES	YES	YES	YES	YES	NO			3.829005698	Excluded	6800
	B	YES	YES	YES	YES	YES	NO			3.829005698		6700
	C	YES	YES	YES	YES	YES	YES	NO		3.860079652		7100
	D	YES	YES	YES	YES	YES	YES	NO		3.860079652		7300
	E	YES	YES	YES	YES	YES	YES	NO		3.860079652		7100
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.889075625	Excluded	7500

The result of the panels is 3.8523 which gives the Odor threshold of 39.

Table C3. Odor results of treated fufu stream Wastewater at 20V.

Treated Fufu Stream Sample at 20V											
Dilution Rate		3000	4000	5000	5500	6000	6500	6800	7200	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.74036	3.77815	3.81291	3.83251	3.85733			
Panel	A	YES	YES	YES	YES	YES	YES	NO		3.822711135		6700
	B	YES	YES	YES	YES	YES	YES	NO		3.822711135		6600
	C	YES	YES	YES	YES	YES	YES	YES	NO	3.844920705		6900
	D	YES	YES	YES	YES	YES	NO			3.795532304	Excluded	6400
	E	YES	YES	YES	YES	YES	YES	NO		3.822711135		6700
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.844920705	Excluded	7000

The result of the panels is 3.8282 which gives the Odor threshold of 38.

Table C4. Odor results of treated fufu stream wastewater at 30V.

Treated Fufu Stream Sample at 30V											
Dilution Rate		3000	4000	5000	5500	6000	6200	6400	7000	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.74036	3.77815	3.79239	3.80618	3.84509			
Panel	A	YES	YES	YES	YES	YES	NO			3.799285832		6100
	B	YES	YES	YES	YES	YES	YES	NO		3.799285832		6300
	C	YES	YES	YES	YES	YES	YES	YES	NO	3.825639007		6500
	D	YES	YES	YES	YES	YES	NO			3.78527147	Excluded	6000
	E	YES	YES	YES	YES	YES	YES	NO		3.799285832		6300
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.825639007	Excluded	6900

The result of the panels is 3.8058 which gives the Odor threshold of 38.

Table C5. Odor results of treated fufu stream wastewater at 40V.

Treated Fufu Stream Sample at 40V											
Dilution Rate		3000	4000	5000	5300	5500	5800	6000	7000	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.72428	3.74036	3.76343	3.77815	3.84509			
Panel	A	YES	YES	YES	YES	YES	NO			3.751895342	Excluded	5600
	B	YES	YES	YES	YES	YES	YES	NO		3.770789622		5900
	C	YES	YES	YES	YES	YES	YES	YES	NO	3.811624645		6400
	D	YES	YES	YES	YES	YES	NO			3.751895342		5700
	E	YES	YES	YES	YES	YES	YES	YES	NO	3.811624645	Excluded	6600
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.811624645		6300

The result of the panels is 3.7864 which gives the Odor threshold of 38.

Table C6. Odor results of raw starch stream wastewater.

Starch Raw Sample											
Dilution Rate		3000	4000	5000	5500	6000	6500	7000	7500	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.74036	3.77815	3.81291	3.8451	3.875061			
Panel	A	YES	YES	YES	YES	YES	YES	NO		3.829005698	Excluded	6600
	B	YES	YES	YES	YES	YES	YES	YES	NO	3.860079652		7300
	C	YES	YES	YES	YES	YES	YES	NO		3.829005698		6900
	D	YES	YES	YES	YES	YES	YES	NO	NO	3.860079652		7800
	E	YES	YES	YES	YES	YES	YES	YES	NO	3.860079652	Excluded	7400
	F	YES	YES	YES	YES	YES	YES	NO	NO	3.860079652		6900

The result of the panels is 3.8523 which gives the Odor threshold of 39.

Table C7. Odor results of treated starch stream wastewater at 10V.

Treated Starch Stream Sample at 10V											
Dilution Rate		3000	4000	5000	6000	6500	7000	7500	8000	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.77815	3.81291	3.8451	3.87506	3.903089			
Panel	A	YES	YES	YES	YES	YES	NO			3.829005698	Excluded	6800
	B	YES	YES	YES	YES	YES	NO			3.829005698		6700
	C	YES	YES	YES	YES	YES	YES	NO		3.860079652		7100
	D	YES	YES	YES	YES	YES	YES	NO		3.860079652		7300
	E	YES	YES	YES	YES	YES	YES	NO		3.860079652		7100
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.889075625	Excluded	7500

The result of the panels is 3.8523 which gives the Odor threshold of 39.

Table C8. Odor results of treated starch stream wastewater at 20V.

Treated Starch Stream Sample at 20V											
Dilution Rate		3000	4000	5000	5500	6000	6500	7000	7500	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.74036	3.77815	3.81291	3.8451	3.87506			
Panel	A	YES	YES	YES	YES	YES	NO			3.795532304	Excluded	6000
	B	YES	YES	YES	YES	YES	NO			3.795532304		6400
	C	YES	YES	YES	YES	YES	YES	NO		3.829005698		6900
	D	YES	YES	YES	YES	YES	YES	NO		3.829005698		6600
	E	YES	YES	YES	YES	YES	YES	NO		3.829005698		6800
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.860079652	Excluded	7300

The result of the panels is 3.8118 which gives the Odor threshold of 38.

Table C9. Odor results of treated starch stream wastewater at 30V.

Treated Starch Stream Sample at 30V											
Dilution Rate		3000	4000	5000	5500	6000	6200	6400	7000	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.74036	3.77815	3.79239	3.80618	3.84509			
Panel	A	YES	YES	YES	YES	YES	NO			3.799285832		6100
	B	YES	YES	YES	YES	YES	YES	NO		3.799285832		6300
	C	YES	YES	YES	YES	YES	YES	YES	NO	3.825639007		6500
	D	YES	YES	YES	YES	YES	NO			3.78527147	Excluded	6000
	E	YES	YES	YES	YES	YES	YES	NO		3.799285832		6300
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.825639007	Excluded	6900

The result of the panels is 3.8058 which gives the Odor threshold of 38.

Table C10. Odor results of treated starch stream wastewater at 40V.

Treated Starch Stream Sample at 40V											
Dilution Rate		3000	4000	5000	5200	5400	5600	5800	6500	Threshold of Each Panel	Exclusion of Maximum and Minimum Values	Actual Value of Panel
Logarithm		3.47712	3.60206	3.69897	3.716	3.73239	3.74819	3.76343	3.81291			
Panel	A	YES	YES	YES	YES	YES	NO			3.740290893	Excluded	5400
	B	YES	YES	YES	YES	YES	YES	NO		3.75580801		5700
	C	YES	YES	YES	YES	YES	YES	YES	NO	3.788170675		6000
	D	YES	YES	YES	YES	YES	NO			3.740290893		5600
	E	YES	YES	YES	YES	YES	YES	YES	NO	3.788170675		6100
	F	YES	YES	YES	YES	YES	YES	YES	NO	3.788170675	Excluded	6400

The result of the panels is 3.7681 which gives the Odor threshold of 38.