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Research Article

Oxidation of Abattoir Wastewater Using Cobalt-Catalyzed Potassium Persulfate

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Abstract

Abattoir wastewater (AWW) contains a high level of organic pollutants due to the presence of toxic contaminants such as blood, feces from animals, and detergents from cleaning activities. In this study, the wastewater from the slaughterhouse was treated with a cobalt-catalyzed persulfate oxidation reaction to determine how well persulfate works as an oxidant to get rid of and break down organic materials. The water tested had a high organic load (COD = 2100mg/L), a pH of 7.7, and a BOD of 800mg/L. Time (10–90min), temperature (25–75 ℃), acid content (0.5–2.5M), persulfate (0.025–0.1g), and cobalt catalyst (50–150 mg/L) were all evaluated as operational conditions. Temperature and acid content was found to have a positive effect on COD elimination while increasing the residence time. The reaction conditions were optimized at a constant dose of 0.3 g of potassium persulfate, 1 M acid concentration in 30 minutes, and a maximum temperature of 60 ℃. At optimum conditions, approximately 98.46% of the COD was removed. The COD elimination rate was 92.85% at a low amount of potassium persulfate (0.075g). The study concludes that the developed approach could be used to efficiently treat abattoir wastewater.

Keywords

Chemical Oxidation, Abattoir Treatment, COD, Wastewater, Cobalt

1. Introduction

The rising global demand for water has created a supply crisis that threatens not only the natural world but also the ability of modern societies to function normally [1]. Three of the most pressing issues today are securing reliable sources of water, food, and energy for the world's population [2-5]. The consumption of fresh water is rising because of the growing global population and the improving standard of living [6].

By 2025, the Food and Agricultural Organization (FAO) predicts that 1.8 billion people would be residing in areas with absolute water scarcity (less than 500 m^3 per person per year) [7]. Globally, agriculture is responsible for 92% of the freshwater footprint, with the production of meat products accounting for 29% of that total [8, 9]. As freshwater supplies dry up, the water and wastewater management industries have had to adapt. Physical, chemical, and biological procedures are used to treat wastewater to the point that it can be dis-

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charged into the environment or reused [10].

Abattoirs are a significant industry in which animals (cows, sheep, goats, poultry, and pigs) are killed for consumption by humans to fulfill the requirements for protein in the diets of most the world's nations [11, 12]. The Organization for Economic Co-operation and Development (OECD) predicts that global meat production will rise to 366 Mt by 2029, up from its current level, because of rising meat consumption in recent years [7]. An estimated 15,500 m^3 of water is needed for cattle, 4800 m^3 for pigs, 6100 m^3 for sheep, and 4,000 m^3 for poultry to produce one ton of meat [13].

The meat processing industry is regarded as having the biggest demand for fresh water, accounting for 24% of the total, followed by the drinks industry (13%) and the dairy industry (12%) [10, 14]. The meat industry has a considerable impact on the global water balance, with 1.5–18 m^3 of wastewater discharged per ton of meat produced [15]. Abattoir wastewater consists of both the water used during the slaughtering process and the water required to clean up afterward. Consequently, the growth in the quantity of abattoirs is responsible for the expansion in the quantity of wastewater produced [16].

An additional 328.4 Kg of trash is generated from a slaughtered cow due to its feces, bones, blood, and hoofs [17]. Abattoir wastewater has a high concentration of dissolved contaminants, including blood, which has a chemical oxygen demand (COD) greater than that of any other effluent from abattoir operations. According to Olanrewaju and Adewumi [18], the COD of liquid blood is around 400, 000 mg/L while the COD of congealed blood is around 900, 000 mg/L.

The contemporary industrialized cattle industry producing wastewater is more contaminated with BOD than household sewage [19], and it is characterized by a high organic content and highly variable quality [1]. Also, nutrient levels in the blood are rather high, often coming in at 2,400 mg/L of nitrogen and 1,500 mg/L of phosphorus [11]. As a result, improper disposal can cause hypoxia in rivers and groundwater contamination [20]. In Nigeria, many abattoirs discharge wastewater from them directly into streams and rivers without prior treatment [12, 21-23].

Aerobic deactivation, electrocoagulation, advanced chemical oxidation, electrochemistry, and chemical coagulation are just some of the existing methods used to treat abattoir waste [12, 24-27]. In addition, improved oxidation techniques and chemicals including chlorine, chlorine dioxide, chloramine, and hydrogen peroxide (H_2O_2) are being employed for treatment [1, 28]. However, many of these techniques are not only inefficient for treating abattoir wastewater but also leave behind hazardous residues. Therefore, effective and trustworthy abattoir wastewater treatment technologies are required to guarantee that the effluent quality is up to code prior to discharge, protecting both economic and environmental health.

Slaughterhouse effluents can be treated using chemical oxidation processes, which are both an attractive alternative and a supplementary treatment approach to biological processes, particularly as a posttreatment method for improving the biodegradability of contaminants in slaughterhouse wastewater [29]. When it comes to the in-situ oxidation of harmful synthetic compounds in soil and groundwater remediation, persulfate has emerged as a frontrunner. Persulfate is unique among oxidants since it possesses characteristics of both responsive and persistent oxidants.

The study's goals are to (1) evaluate the potential for eliminating organic contaminants from the abattoir effluent, and (2) establish the optimum operational parameters for doing so. The operating parameters of the treatment were tested in a laboratory setting, including persulfate concentration, activator dosage, sulphuric acid concentration, and treatment time.

2. Materials and Methods

2.1. Site Description

Akure is the capital of Ondo State in Southwestern Nigeria. It is located between latitudes 7 .2571 ° N, 5.2058 ° E and between longitudes 5 °15' E - 5 °17' E. The Ondo state abattoir house is located along Akure-Ado Way in Akure, a city with a population of approximately 420,000 inhabitants.

2.2. Sample Collection

The wastewater sample was collected from an abattoir house in Akure, Ondo State, Nigeria, in triplicate and in the morning hours of 7 a.m. and 8 a.m., when cows were slaughtered. Samples were collected into clean plastic bottles at the point of discharge, and they were preserved in an airtight bottle. The samples were transported under standard conditions to the laboratory for analysis.

2.3. Chemicals

Potassium persulfate, a powerful oxidant, was purchased from Pascal Scientific Limited, Ondo State, Nigeria, while Cobalt (II) chloride was obtained from the research laboratory of the Chemistry Department, Federal University of Technology, Akure, Nigeria (FUTA).

2.4. Physicochemical Characterization of Abattoir Wastewater

The temperature, pH, and dissolved oxygen were measured in situ using a mercury-filled Celsius thermometer and Hanna Digital pH meter, respectively. Total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS) were carried out according to standards for water analysis, while electrical conductivity was determined using a conductivity meter [30, 31]. Total alkalinity, total acidity, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) were carried out according to Standard Methods for Water and Effluent Analysis by [32].

2.5. Experimental Procedure

In each experimental run, abattoir water was poured into a 250 ml beaker with an effluent working volume of 100 ml. The treatment was carried out by taking 100 ml of the abattoir wastewater sample and measuring it in a 250 ml beaker. Different values of treatment time (10, 20, 30, 60, and 90 minutes) at constant concentrations of 0.3 g of potassium persulfate, 50 mg/L of cobalt chloride, and 1 M of sulfuric acid at room temperature were used to treat the effluent. Moreover, the time was adjusted to 30 minutes with 0.3 g of potassium persulfate and 50 mg/l of cobalt chloride (constant) for 23, 40, 50, 60, and 75 ℃. The effect of potassium persulfate ranging from 0.025 to 0.1g was monitored while keeping other parameters constant for 30 minutes and 50 mg/L of cobalt chloride at room temperature. At the same time, the effects of catalyst concentration (50–100 mg/l), and acid concentration (0.5–2.5 M) were investigated [30, 31].

A treated wastewater sample was taken after 30 minutes except for the effect of time, which was transferred into a 100 ml flask to analyze for chemical oxygen demand, which was used as criteria for monitoring pollutants removal efficiency. The quality of the abattoir wastewater before and after chemical oxidation experiments was determined using standard methods for water and wastewater analysis [33, 32]. The parameter that was noted during the chemical oxidation experiments was chemical oxygen demand (COD). After the chemical oxidation process, the treated abattoir wastewater was also analyzed for chemical oxygen demand, which was determined by the closed reflux titrimetric method. The removal efficiency was calculated using the following equation:

$$\%RE = \frac{C_o - C_f}{C_o} \times 100$$

Where:
%RE = Percentage removal efficiency of the pollutants,
C_o = Initial COD before treatment,
C_f = Final COD after treatment.

2.6. Statistical Analysis

Microsoft Excel and SPSS (Software version 20.0) were used to perform descriptive statistics on all data collected to assess statistical variance during the period of the study. The statistics presented in the figures and tables were all means, which were then converted to percentages for elucidation.

3. Results and Discussion

3.1. Physicochemical Parameters of Raw Abattoir Wastewater

Raw AWW samples were analyzed for their physicochemical parameters. The mean value was calculated, and the results are presented in Table 1.

The pH of water in the study was slightly alkaline, with a mean value of 7.7, which falls within the USEPA and WHO [20, 34] guideline range of 6.5 – 9.5. This is considered highly favorable for conventional wastewater treatment processes, which depend on the various bacteriological activities and analyses involved in the decomposition of organic contents in wastewater [35, 38]. Water had a temperature of 25.9 ℃ which was below the WHO [34] standard limit of 30-35 ℃ for abattoir wastewater. The low-temperature value could be attributed to the increased anthropogenic activities in the area, which have dire consequences and a residual effect on the suitability and sustainability of aquatic species and organisms in the receiving water body. Chukwu and Adewumi [21, 35] also obtained mean temperature values lower than the WHO standard for abattoir waste in Minna and Akure respectively. These affect and play inhibitory roles in the activities of bacteria, significantly influencing the decomposition of organic constituents in wastewater [21, 39].

The electrical conductivity (EC) of the wastewater (1233 μS cm^{-1}) was higher than the WHO [34] permissible limit (500 μScm^{-1}). This indicates that the abattoir wastewater contains appreciable amounts of dissolved ions such as nitrate, sulfate, iron ions, and other ions [11]. In addition, turbidity (970 NTU), total solids (3742 mg/l), and total suspended solids (2863 mg/l) were far above the USEPA and WHO [20, 34] recommended values of 5 NTU, 50 mg/l, and 20 mg/l, respectively. According to Mulu and Ayenew [11], the discharge of solid wastes, as well as blood and urine, has the potential to increase the turbidity of wastewater. These also indicate a high potential for leachate to cause organic pollution.

Table 1. *Mean Physicochemical Characteristics of Raw Abattoir Wastewater.*

Parameters	Range	WHO/USEPA (2004)
pH	7.7	6.5-9.5
Temperature	25.9 ℃	<40 ℃
Conductivity	1233 μScm^{-1}	500 μScm^{-1}
Turbidity	970 NTU	5 NTU
Electrode potential	45 V	
Total Dissolved Solid	897 mg/l	2000 mg/l

Parameters	Range	WHO/USEPA (2004)
Total Solid	3742 mg/l	50 mg/l
Total Suspended Solid	2863 mg/l	20 mg/l
Alkalinity	164 mg/l	400 mg/l
Acidity	452 mg/l	
Chemical Oxygen Demand	2100 mg/l	1000 mg/l
Biology Oxygen Demand	800 mg/l	
Dissolved Oxygen	1.1 mg/l	4 mg/l
Colour	Dark red	
Odour	Very offensive	

The chemical oxygen demand (COD) recorded in the study (2100 mg/l) was higher than the guideline of WHO and USEPA [34, 20], indicating the presence of chemical oxidants in wastewater, which is a serious environmental problem. As reported by Hoekstra & Mekonnen and Mulu & Ayenew [36, 11], blood contributes immensely to the organic load within the environment, hence having a residual effect on the COD and BOD levels in the location. Biological oxygen demand (800 mg/l) can be attributed to the presence of large quantities of organic materials, the confluence of domestic sewage, solid wastes, and high-oxygen-demanding substances disposed of in the environment. The analysis of DO, BOD, and COD indicates that the area receives a high amount of sewage waste containing a high level of organic matter. Such elevated concentrations of organic substances exacerbate anoxia or hypoxia by raising the BOD and COD and depleting the DO. An oxygen-depleted water column will therefore negatively impact aquatic communities by producing changes in the distribution and abundance of aquatic flora and fauna [36]. In addition, the result obtained from the study supports the relationship between biological oxygen demand and chemical oxygen demand, as the biological oxygen demand values were lower than the COD values.

3.2. Chemical Oxygen and Parameters: Matrix Effects

3.2.1. Interaction with Potassium Persulphate

Persulfate has been a critical factor in chemical oxidation, on which the bulk of the experiment hinges. The level of increase in the removal of COD from the abattoir wastewater was up to 92.85% at 0.075 g/100 mL of potassium persulphate and thereafter it decreased to 68.71% at 0.1g/100 mL (*Figure 1*). This may be attributed to the solubility capacity, as small amounts of potassium persulfate will easily dissolve in water, and it is similar to the findings of Asselin et al., Peña et al., and Türgay et al. [25, 37, 38].

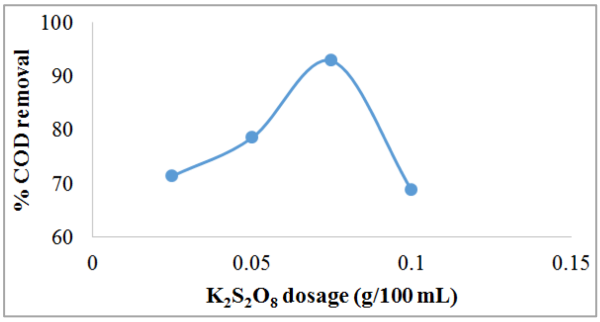

Figure 1. *Effect of persulfate concentration on COD removal.*

3.2.2. Interaction with Cobalt Catalyst

Cobalt, which is a transition metal, plays the role of an activation metal, which helped generate free radicals from the persulfate (*Figure 2*). The highest value was recorded at 50 mg/L with 99.46% COD removal, while the lowest value was recorded at 150 mg/L with 38.6% COD removal, indicating that a low dosage of the catalyst is required.

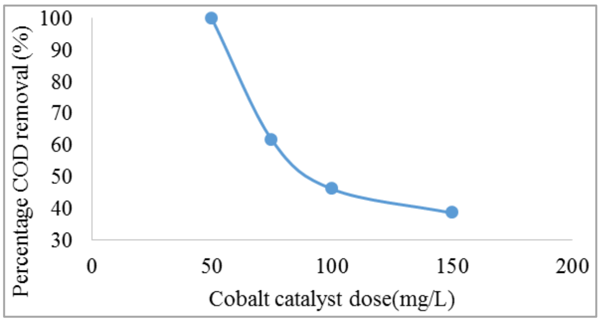

Figure 2. *Effect of catalyst on COD removal.*

3.2.3. Interaction with Sulphuric Acid

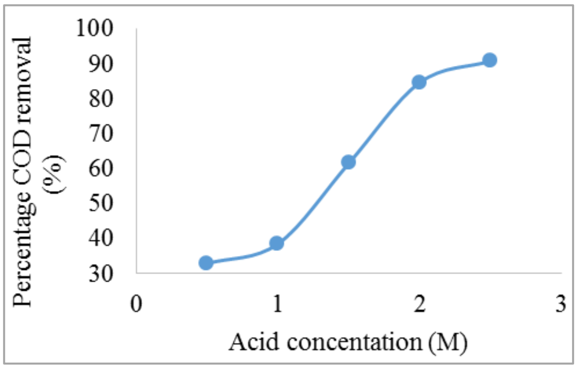

Figure 3. *Effect of acid concentration on COD removal.*

The initial COD of the raw wastewater sample was 650 mg/l. The decrease in COD concentration had a direct relationship with the increasing acid concentration. Due to the increase in reactant concentration, there was an increase in the rate of the reaction, which aids the removal efficiency. The increase in acid concentration from 0.5, 1.0 up to 2.5 M caused the respective COD reductions of 450, 400, 250, 100, and 60 mg/l, with the highest reduction observed at 2.5 M at 90.76% (*Figure 3*). The increase in humic acid caused an increase in the organic pollutant's decomposition.

3.2.4. Interaction with Time

The effectiveness of the removal of COD as a function of time reveals the effect of time on chemical oxygen demand and pollutant removal. It was deduced that the removal of pollutants increased as the treatment time increased (*Figure 4*). As the time increases from 30 to 90 minutes, the percentage removal efficiency increases from 84.61% to 98.46%. This could be attributed to the fact that the longer the time, the greater the dissolution of the oxidant used. The results agree with the findings of Adebayo et al., [36], who worked on the removal of organic pollutants from abattoir wastewater using electrocoagulation.

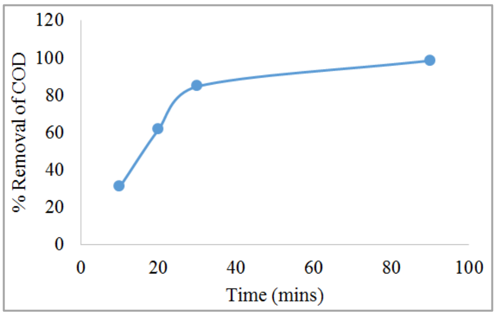

Figure 4*. Effect of time on COD removal.*

3.2.5. Interaction with Temperature

Regarding the temperature, there was an increase in COD removal from the abattoir wastewater as the temperature increased (*Figure 5*). The highest value was recorded at 60 ℃ with 98.46% COD removal, while the lowest value was recorded at 25 ℃ with 38.46% COD removal. This is because higher temperatures bring about higher reaction rates and increase radical generation.

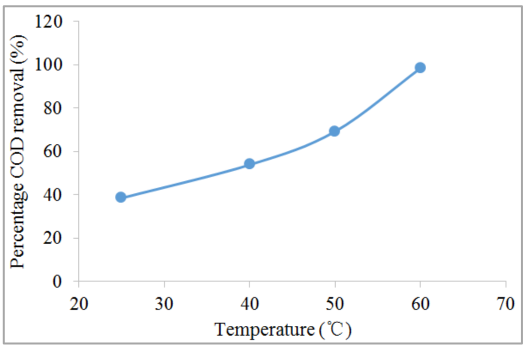

Figure 5*. Effect of temperature on COD removal.*

4. Conclusion

The study deduced that an increase in time, temperature, potassium persulfate dosage, and acid concentration caused an increase in pollutant removal from wastewater. It was also established that a smaller dosage of the oxidant (potassium persulfate) and the catalyst (cobalt chloride) increases the removal efficiency compared to a high dosage. A closer examination of this study shows the feasibility of chemical oxidation using cobalt-catalyzed persulfate as an effective and technically feasible method for the removal of organic pollutants from abattoir wastewater. Therefore, chemical oxidation using persulfate catalyzed by cobalt is recommended for the effective treatment of organic pollutants in abattoir wastewater.

Author Contribution Statement

Ayoola R. A.: Conceived and designed the experiments; performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis tools, or data; wrote the paper. Adebayo A. O.: Conceived and designed the experiments; contributed reagents, materials, analysis tools, or data. Ahuchaogu C. D.: Reviewed and revised the manuscript. Akinola J. O.: Analyzed and interpreted the data; revised the manuscript.

Additional Information

No additional information is available for this paper.

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Conflicts of Interest

The authors declare no conflict of interest.

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