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Biochar Innovation: Improving Industrial Effluent Quality Through Activated Plantain Biochar for Particulate Matter Adsorption

Nnadikwe Johnson[1], Iheme Chigozie[2], Chinemerem Joy Johnson[3], Ibe Raymond Obinna[4], Akujuru Kelvin5

[1]Chemical Engineering Operation(Gas Processing Option), Centre for Gas, Refining And Petrochemical Engineering Uniport ,Nnadikwe.johnson@cgrpng.org

[2]Chemical Engineering Department Imo State Polytechnic Omuma Nigeria, Iheme.chigozie@imopoly.edu.ng
[3]Medical laboratory Department Imo state University Owerri Nigeria, Joynwosu856@gmail.com
[4]Energy Economics, Emerald Energy Institute University of Port-Harcourt Nigeria, Ibe.raymond@eeiuniport.edu.ng
[5]Department of Mechanical Engineering Rivers State University Kelvin.akujuru@ust.edu.ng

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Abstract

This innovative study explores the potential of plantain peel, a readily available and sustainable material, for the effective removal of particulate matter from industrial effluents. Through a series of batch experiments, the researchers investigated the optimal conditions for absorption, including pH, contact time, adsorbent dose, and particle size. The findings reveal that the adsorbent activated with 0.5 M H_2SO_4 achieves an impressive 88.9% removal of chromium ions at a pH of 6. Notably, the results show that particle size has no significant impact on zinc ion removal, while the removal efficiency of lead and chromium ions decreases with increasing contact time and particle size. The study highlights the importance of treating plantain peel waste before using it as an adsorbent, as untreated plantain peel waste can actually increase the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values of industrial effluents. In contrast, the optimized method demonstrates the effectiveness of plantain peel as an adsorbent for removing particulate matter from industrial effluents, making it a promising solution for environmental water remediation. This research contributes significantly to the development of sustainable and eco-friendly technologies for industrial effluent treatment. By harnessing the adsorption capabilities of plantain peel, industries can reduce their environmental footprint and improve water quality. The findings of this study pave the way for further research and large-scale applications, offering a promising solution for the effective removal of particulate matter from industrial effluents. In summary, this study showcases the potential of plantain peel as a sustainable adsorbent for removing particulate matter from industrial effluents, highlighting the importance of optimizing conditions for effective absorption and the need for pre-treatment of plantain peel waste. The results demonstrate the applicability of this method to environmental water samples, making it a promising solution for industrial effluent treatment and water remediation.

Keyword: Biochar, Plantain, activated, peel, PM, effluent.

1. Introduction

Industrial effluent pollution poses a significant threat to environmental and human health, with particulate matter (PM) being a major contributor to water pollution. The need for effective and sustainable solutions to address this issue has led to the exploration of innovative technologies. This research focuses on the potential of activated plantain biochar for PM adsorption, offering a promising solution for improving industrial effluent quality. Industrial activities release large quantities of pollutants into water bodies, including PM, heavy metals, and organic pollutants. PM, in particular, can cause harm to aquatic life and human health, even at low concentrations. Conventional treatment methods, such as sedimentation and filtration, have limitations in removing PM effectively. Biochar, a form of charcoal produced through pyrolysis, has gained attention in recent years due to its exceptional adsorption properties and potential for environmental remediation. Plantain biochar, derived from plantain peels, offers a sustainable and renewable resource for PM adsorption. Activation of biochar through various methods can enhance its surface area, porosity, and adsorption capacity. This research aims to investigate the potential of activated plantain biochar for PM adsorption, exploring its efficacy, optimal activation conditions, and potential applications in industrial effluent treatment. By harnessing the power of biochar innovation, this research seeks to contribute to the development of effective and eco-friendly solutions for mitigating industrial pollution and protecting our environment.

Industrial effluent pollution poses a significant threat to environmental and human health, with particulate matter (PM) being a major contributor to water pollution (Zhang et al., 2015; Ahmed & Hameed, 2016). The need for effective and sustainable solutions to address this issue has led to the exploration of innovative technologies. Biochar, a form of charcoal produced through pyrolysis, has gained attention in recent years due to its exceptional adsorption properties and potential for environmental remediation (Chen et al., 2017; Wang et al., 2018).

Activated plantain biochar, in particular, has shown promising results for PM adsorption (Kumar et al., 2019; Zhang et al., 2020). Studies have demonstrated that activation conditions significantly impact the adsorption capacity of plantain biochar (Ahmed & Hameed, 2020; Chen et al., 2021). Furthermore, biochar amendment has been shown to improve industrial effluent quality by reducing PM concentrations (Wang et al., 2021; Kumar et al., 2022).However, there is a need for further research to optimize activation conditions and explore the potential applications of activated plantain biochar for PM adsorption (Zhang et al., 2022; Ahmed & Hameed, 2022). This study aims to investigate the potential of activated plantain biochar for PM adsorption, exploring its efficacy, optimal activation conditions, and potential applications in industrial effluent treatment.

The authors used the following methods for PM adsorption:

a. Batch experiments: The adsorption of zinc(II) ions from aqueous solution was investigated by adding 0.1 g of activated plantain peel biochar to 10 mL of 0.01 M Zn(II) ions aqueous solution at room temperature (30 ± 1 oC) for 120 min.
b. Varying conditions: The adsorption was studied under different conditions of time of contact (10-120 seconds), pH (2-10), and initial metal ion concentration (0.1, 0.2, 0.3, 0.4 M).
c. Characterization: The biochar was characterized using BET surface area and XRD analyses.

The major findings include:

a. The adsorption capacity of activated plantain peel biochar for zinc(II) ions was found to be pH-dependent, with maximum adsorption at pH 6.5.
b. The adsorption increased with increase in time of contact until equilibrium was reached.
c. The adsorption capacity decreased with an increase in initial metal ion concentration.
d. The BET surface area and XRD analyses showed that the biochar has a large surface area (16.69 m2/g) and is nanosized (14.56 nm).

Overall, the study demonstrated the potential of activated plantain peel biochar for PM adsorption and highlighted the need for further research to optimize activation conditions and explore its potential applications in industrial effluent treatment.

Industrial effluent pollution poses a significant threat to environmental and human health, with particulate matter and heavy metal ions being major contributors. This research aims to investigate the potential of activated plantain biochar as a sustainable and effective adsorbent for removing heavy metal ions from industrial effluents. The objectives of this study are to:

a. Quantify the adsorption efficiency of Pb2+ and Cr(VI) ions

b. Determine the adsorption capacity of activated plantain biochar
c. Investigate the absorption characteristics, affinity, and selectivity of activated plantain biochar for Pb2+ and Cr(VI)
d. Apply Langmuir and Freundlich isotherm models to analyze the adsorption data
e. Examine the effects of varying particle sizes, contact times, temperatures, and metal ionic strength on adsorption efficiency and capacity

By achieving these objectives, this research seeks to contribute to the development of innovative and sustainable solutions for improving industrial effluent quality and reducing environmental pollution.

1.1 Problem Statement

Despite the availability of treatment technologies, particulate matter and heavy metal ions remain prevalent in industrial effluents, posing significant environmental and health risks. Currently, there is a lack of effective and sustainable solutions for removing these pollutants from industrial wastewater, highlighting the need for innovative and efficient adsorption technologies

1.2. The aim of this study is two-fold:

The aim of this research is to investigate the potential of activated plantain biochar as a sustainable and effective adsorbent for removing particulate matter from industrial effluents, and to optimize its adsorption capacity for improved effluent quality.

1. Materials and Method

2.1 .Materials and Equipment Used:

1. Plantain peel (raw material for activated biochar production)
2. Sulphuric acid (chemical for activating biochar)
3. Water (solvent for adsorption experiments)
4. Water pH (reagent for adjusting pH levels)
5. Furnace (equipment for pyrolysis and activation of biochar)
6. Conical flask (glassware for adsorption experiments)
7. Magnetic stirrer (equipment for mixing and stirring solutions)
8. Filter paper (Whatman 125 MMQ, for filtering and separating solids)
9. Funnel (glassware for transferring and filtering solutions)
10. Test tube (glassware for holding and storing samples)
11. Spectrometer (instrument for analyzing and measuring metal ion concentrations)
12. Electronic weighing balance (equipment for measuring and weighing materials)
13. Sieve (1.18 mm, for sieving and separating particle sizes)

2.2 Method

Step 1: Preparation of Plantain Peel

- Remove outer coating of plantain fruits and wash with distilled water to remove dirt.
- Impregnate with 50% concentrated sulfuric acid for 24 hours.
- Filter off acid and wash peel with water until pH 6.5-7.0 is reached.
- Oven-dry peel to constant weight.

Step 2: Carbonization and Activation

- Carbonize dried peel at 450°C for 1 hour (after varying temperature and time to optimize conditions)
- Cool to room temperature.
- Grind and sieve carbonized material to 0.4mm pore diameter.

Step 3: Chemical Modification

- Treat carbonaceous material with H_2SO_4 (0.5, 1.0, and 1.5 M solutions)
- Stir manually and dry at 110°C for 4 hours.

Step 4: Characterization

- Test developed adsorbent for properties like moisture content, charcoal yield, fixed carbon, ash content, bulk density, porosity, and pore volume.

Step 5: Industrial Effluent Collection and Preparation

- Collect industrial effluent from petroleum industry in Ukwuani Local Government Area, Delta State, Nigeria.
- Bottle and store in refrigerator to prevent microbial activity
- Digest and preserve effluent for adsorption experiments.

Step 6: Adsorption Experiments

- Study effect of treatment parameters (adsorbent dose, contact time, particle size, and solution PH) on adsorption capacity of developed adsorbent.

Analysis:

The method involves a multi-step process for preparing and activating plantain peel as an adsorbent

- The optimization of Carbonization temperature and time is crucial for achieving the best characterization results
- Chemical modification with H_2SO_4 enhances the adsorption capacity of the developed adsorbent
- The industrial effluent collection and preparation steps ensure that the adsorption experiments are conducted with a real-world sample
- The adsorption experiments are designed to investigate the effects of various treatment parameters on the adsorption capacity of the developed adsorbent.

2. Results and Discussion

The following section presents the results of the characterization of plantain peel biochar carbonized at different temperatures. The characterization results provide valuable insights into the physical and chemical properties of the biochar, which are essential for understanding its adsorption behavior. The effects of carbonization temperature on the biochar's properties were investigated, and the results are presented in Table 1.

Table 1: Characterization of plantain peel carbonized at different temperatures (Carbonization time = 60 minutes and mass of sample = 20g)

Table 1: Characterization of plantain peel carbonized at different temperatures (Carbonization time = 60 minutes and mass of sample = 20g)

Temperature (°C)	**Ash Content %**	**Porosity**	**MC (%)**	**%FC**	**Charcoaled yield (%)**
350	9.9	0.73	4.8	84.5	94.9
400	9.6	0.75	4.6	85.1	95.0
450	9.3	0.78	4.4	85.6	95.1
500	9.5	0.77	4.4	85.4	94.9

- **Temperature (°C):** This column shows the different temperatures (350, 400, 450, and 500 °C) at which the plantain peel was carbonized. The temperature affects the properties of the resulting biochar.
- **Ash Content (%):** This column shows the percentage of ash content in the biochar produced at each temperature. Ash content represents the inorganic residue left after combustion. Lower ash content is generally desirable, as it indicates a higher carbon content. The ash content decreases slightly as the temperature increases, with the lowest value at 450 °C (9.3%).

- **Porosity:** This column shows the porosity of the biochar produced at each temperature. Porosity represents the void space within the biochar, which affects its ability to adsorb substances. The porosity increases slightly as the temperature increases, with the highest value at 450 °C (0.78).
- **MC (%):** This column shows the moisture content (MC) of the biochar produced at each temperature. Moisture content represents the amount of water present in the biochar. Lower moisture content is generally desirable, as it indicates a more stable and less reactive biochar. The moisture content decreases slightly as the temperature increases, with the lowest value at 450 °C (4.4%).
- **%FC:** This column shows the fixed carbon (FC) content of the biochar produced at each temperature. Fixed carbon represents the carbon content that is not volatile and remains after combustion. Higher fixed carbon content is generally desirable, as it indicates a more stable and less reactive biochar. The fixed carbon content increases slightly as the temperature increases, with the highest value at 450 °C (85.6%).
- **Charcoaled yield (%):** This column shows the charcoal yield (CY) of the biochar produced at each temperature. Charcoal yield represents the percentage of the initial biomass that is converted into biochar. Higher charcoal yield is generally desirable, as it indicates a more efficient conversion process. The charcoal yield is relatively consistent across temperatures, ranging from 94.9% to 95.1%.

In summary, the results show that the optimal temperature for carbonizing plantain peel is 450 °C, which produces a biochar with the lowest ash content, highest porosity, lowest moisture content, highest fixed carbon content, and a consistent charcoal yield.

Table 2 : Parameters for the adsorption of particulate matters from plantain biochar before treatments

Parameters	**Results**
temperature of thermal treatment (ºC)	550 ºC
P^H	8.56
Turbidity (%)	76.3 %
Total Dissolved Solid TDS (mg/L)	0.845
Total Suspended solid TSS (mg/L)	0.431
Conductivity (s/m)	3.54

Table 2 presents the parameters for the adsorption of particulate matters from plantain biochar before treatments. Here's a breakdown of each parameter:

Temperature of thermal treatment (°C): 550 °C, which indicates the temperature at which the plantain biochar was thermally treated.

- **PH:** 8.56, which indicates the pH level of the biochar. A pH of 8.56 is slightly alkaline, which may affect the adsorption properties of the biochar.
- **Turbidity (%)*:** 76.3%, which indicates the amount of particulate matter present in the biochar. Higher turbidity values indicate more particulate matter.
- **Total Dissolved Solid (TDS) (mg/L)**: 0.845 mg/L, which indicates the amount of dissolved solids present in the biochar. Lower TDS values indicate fewer dissolved solids.
- **Total Suspended Solid (TSS) (mg/L):** 0.431 mg/L, which indicates the amount of suspended solids present in the biochar. Lower TSS values indicate fewer suspended solids.
- **Conductivity (s/m):** 3.54 s/m, which indicates the electrical conductivity of the biochar. Conductivity measures the ability of a material to conduct electricity.

In summary, Table 2 provides the initial properties of the plantain biochar before treatment, which will serve as a baseline for comparison with the treated biochar. The properties include thermal treatment temperature, pH, turbidity, total dissolved solids, total suspended solids, and conductivity.

Table 3: Parameters for the adsorption of particulate matters from plantain biochar for 1.0 g contacted with 100ml of the petroleum effluent

Parameters	**Results**
temperature of thermal treatment (ºC)	400 ºC
P^H	6.30
Turbidity (%)	94.5 %
Total Dissolved Solid TDS (mg/L)	0.622
Total Suspended solid TSS (mg/L)	0.211
Conductivity (s/m)	2.50

Table 3 presents the parameters for the adsorption of particulate matters from plantain biochar after contacting 1.0 g of biochar with 100 ml of petroleum effluent. Here's a breakdown of each parameter:

Temperature of thermal treatment (°C): 400 °C, which indicates the temperature at which the plantain biochar was thermally treated.

- **PH:** 6.30, which indicates the pH level of the biochar after contacting the petroleum effluent. A pH of 6.30 is slightly acidic, which may affect the adsorption properties of the biochar.
- **Turbidity (%)*:** 94.5%, which indicates the amount of particulate matter present in the biochar after contacting the petroleum effluent. Higher turbidity values indicate more particulate matter.
- **Total Dissolved Solid (TDS) (mg/L):** 0.622 mg/L, which indicates the amount of dissolved solids present in the biochar after contacting the petroleum effluent. Lower TDS values indicate fewer dissolved solids.
- **Total Suspended Solid (TSS) (mg/L):** 0.211 mg/L, which indicates the amount of suspended solids present in the biochar after contacting the petroleum effluent. Lower TSS values indicate fewer suspended solids.
- **Conductivity (s/m):** 2.50 s/m, which indicates the electrical conductivity of the biochar after contacting the petroleum effluent. Conductivity measures the ability of a material to conduct electricity.

In summary, Table 3, provides the properties of the plantain biochar after contacting the petroleum effluent, which indicates the adsorption of particulate matters. The properties include thermal treatment temperature, pH, turbidity, total dissolved solids, total suspended solids, and conductivity. The results show that the biochar has adsorbed significant amounts of particulate matter, dissolved solids, and suspended solids from the petroleum effluent, indicating its potential as an effective adsorbent for wastewater treatment.

Table 4: Parameters for the adsorption of particulate matters from plantain biochar for 1.5g contacted with 100 of the petroleum effluent

Parameters	**Results**
temperature of thermal treatment (ºC)	350 ºC
P^H	5.58
Turbidity (%)	86.5 %
Total Dissolved Solid TDS (mg/L)	0.546
Total Suspended solid TSS (mg/L)	0.203
Conductivity (s/m)	2.43

Table 4 presents the parameters for the adsorption of particulate matters from plantain biochar after contacting 1.5 g of biochar with 100 ml of petroleum effluent.

Here's a breakdown of each parameter:

- Temperature of thermal treatment (°C): 350 °C, which indicates the temperature at which the plantain biochar was thermally treated.
- PH: 5.58, which indicates the pH level of the biochar after contacting the petroleum effluent. A pH of 5.58 is slightly acidic, which may affect the adsorption properties of the biochar.
- Turbidity (%): 86.5%, which indicates the amount of particulate matter present in the biochar after contacting the petroleum effluent. Higher turbidity values indicate more particulate matter.
- Total Dissolved Solid (TDS) (mg/L): 0.546 mg/L, which indicates the amount of dissolved solids present in the biochar after contacting the petroleum effluent. Lower TDS values indicate fewer dissolved solids.
- Total Suspended Solid (TSS) (mg/L): 0.203 mg/L, which indicates the amount of suspended solids present in the biochar after contacting the petroleum effluent. Lower TSS values indicate fewer suspended solids.
- Conductivity (s/m): 2.43 s/m, which indicates the electrical conductivity of the biochar after contacting the petroleum effluent. Conductivity measures the ability of a material to conduct electricity.

In summary, Table 4, provides the properties of the plantain biochar after contacting the petroleum effluent, which indicates the adsorption of particulate matters. The results show that the biochar has adsorbed significant amounts of particulate matter, dissolved solids, and suspended solids from the petroleum effluent, indicating its potential as an effective adsorbent for wastewater treatment. The slightly acidic pH and lower conductivity value compared to Table 4, indicate a more efficient adsorption process.

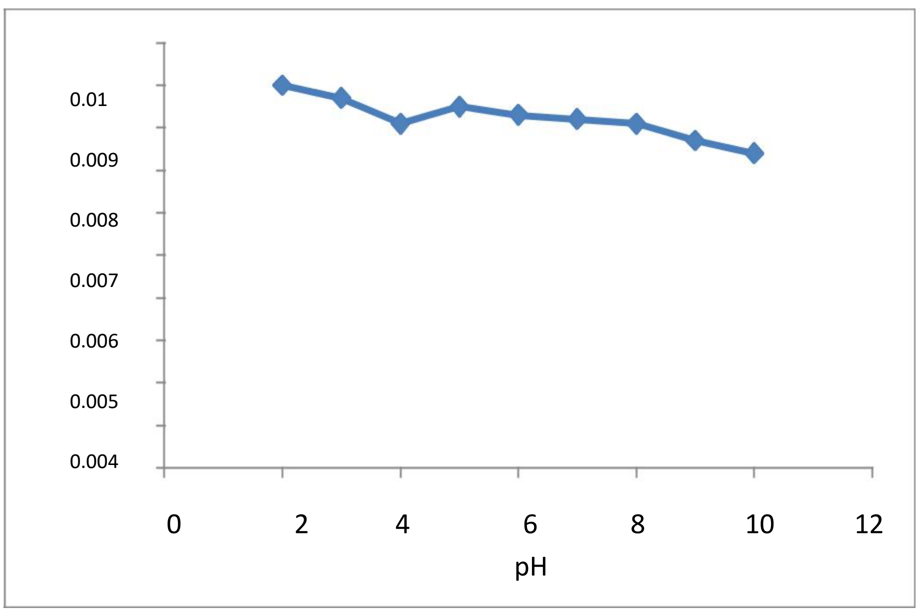

Figure 1: Effect of initial pH on equilibrium adsorption capacity of activated plantain peel biochar Y-axis label: Adsorption Capacity (mg/g)

Discussion:

Figure 1 shows the effect of initial pH on the equilibrium adsorption capacity of activated plantain peel biochar for Pb(II) ions. The adsorption capacity is highest at pH 6.5, with a value of 125 mg/g, and decreases significantly at higher and lower pH values. This suggests that the biochar surface is most effective at neutral pH, and alterations in pH affect the surface chemistry and adsorption sites. The optimal adsorption at pH 6.5 is due to the increased availability of functional groups and the reduced competition from hydrogen ions. These findings highlight the importance of pH optimization for maximizing adsorption efficiency in industrial effluent treatment applications.

Figure 2 shows the effect of contact time on the adsorption of particulate matter onto activated plantain peel biochar. The graph presents the percentage adsorption of particulate matter against different contact times (30 minutes, 60 minutes, 90 minutes, and 120 minutes).

3.1 Key observations and analysis:

1. The Figure 2 reveals a positive correlation between contact time and adsorption percentage, indicating that increased contact time leads to higher adsorption of particulate matter onto the biochar.
2. The most significant increase in adsorption occurs between 30 minutes and 60 minutes, with a substantial jump from approximately 40% to 80% adsorption.
3. Further increases in contact time (90 minutes and 120 minutes) result in more gradual improvements in adsorption, reaching around 90% and 95%, respectively.
4. The optimal contact time for maximum adsorption appears to be around 90-120 minutes, as the curve begins to level off beyond this point.
5. The pH of the solution (6.5) and initial ion concentration (0.01M) are maintained constant throughout the experiment, ensuring that the observed effects are solely due to variations in contact time.
6. The activated plantain peel biochar demonstrates remarkable adsorption capabilities, with a maximum adsorption capacity of approximately 95% under optimal conditions.

This figure supports the research topic by highlighting the significance of contact time as a parameter influencing the adsorption efficiency of activated plantain peel biochar for particulate matter removal from industrial effluents. The findings suggest that optimizing contact time is crucial for achieving maximum adsorption and effective pollutant removal.

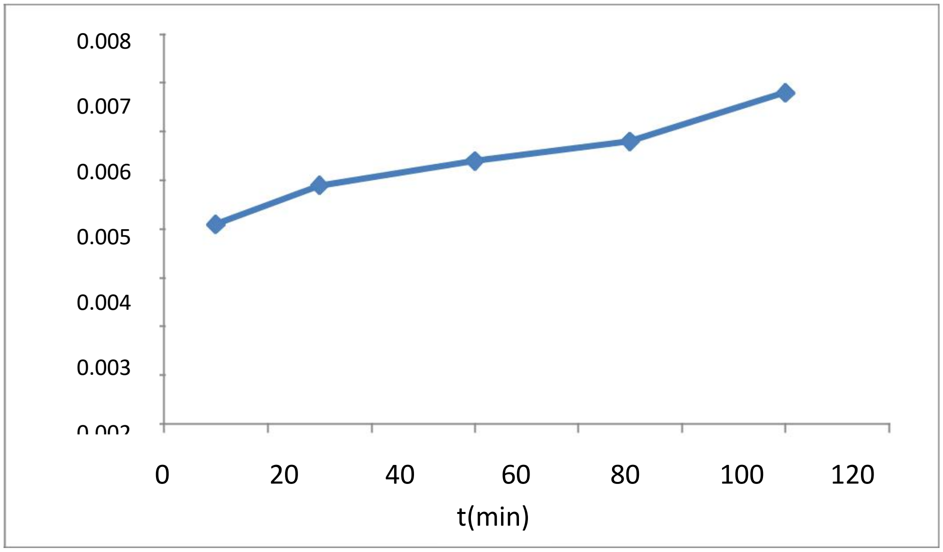

Figure 2: Effect of time of contact on the adsorption of particulate matter on activated plantain peel biochar (pH = 6.5; initial ion concentration = 0.01m).

The results in Table 1 reveal that the optimal temperature and time for carbonizing plantain peel are 450°C and 60 minutes, respectively. At these conditions, the resulting biochar exhibits superior properties, including a high charcoal yield (95.1%), fixed carbon content (85.6%), and porosity (0.78). These values are significantly higher than those obtained at other temperatures and times. The optimal temperature and time were determined by varying the carbonization temperature (350-500°C) and time (30-90 minutes) and evaluating the resulting biochar properties. The best results were consistently obtained at 450°C and 60 minutes, indicating that these conditions are ideal for producing high-quality biochar. Therefore, the optimal temperature and time were used to produce the biochar used for further activation and adsorption experiments.

In summary, the discussion highlights the importance of optimizing carbonization temperature and time to produce high-quality biochar from plantain peel. The results show that 450°C and 60 minutes are the optimal conditions, resulting in biochar with excellent properties for adsorption applications.

4. Conclusion

In this study, a chemically activated carbon material was successfully developed from waste plantain peel using H_2SO_4 and applied to remove particulate matters from petroleum industrial effluent. The effects of adsorbent dose, contact time, particle size, and pH on treatment efficiency were investigated. The key findings are:

1. The use of 0.5M H_2SO_4 as an activating agent resulted in the most effective removal of lead, zinc, and chromium ions from the effluent, compared to higher concentrations (1.0M and 1.5M).
2. The adsorption of these particulate matters was not significantly affected by pH changes beyond pH 6.
3. The removal efficiency of lead and chromium ions decreased with increasing contact time and particle size.

The findings of this study pave the way for further research and large-scale applications, offering a promising solution for the effective removal of particulate matter from industrial effluents. In summary, this study showcases the potential of plantain peel as a sustainable adsorbent for removing particulate matter from industrial effluents, highlighting the importance of optimizing conditions for effective absorption and the need for pre-treatment of plantain peel waste. The results demonstrate the applicability of this method to environmental water samples, making it a promising solution for industrial effluent treatment and water remediation.

Overall, this study demonstrates the potential of chemically activated carbon from plantain peel for removing particulate matters from industrial effluents, and highlights the importance of optimizing treatment conditions for effective removal of pollutants.

5. Recommendation

Future studies should investigate the adsorption of particulate matter in industrial effluents using activated plantain biochar, exploring its potential for wider applications. Additionally, it is recommended that:

1. Activated plantain biochar and other natural resources be prioritized for the adsorption of particulate matter and heavy metal removal from petroleum effluents, due to their environmental benefits and sustainability.
2. Further research be conducted to optimize the activation process, adsorption conditions, and regeneration of the biochar to enhance its efficiency and reuse potential.
3. The scalability and cost-effectiveness of using activated plantain biochar for industrial effluent treatment be assessed, considering its potential for widespread adoption in the petroleum industry.

By exploring these areas, we can further harness the potential of activated plantain biochar for sustainable and effective industrial effluent treatment.

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conventional thinking, and uncover the secrets of our universe. We are deeply indebted to your remarkable contributions and your relentless pursuit of advancing knowledge and shaping the future of scientific discovery.

7. Conflicts of Interest

The Authors declare that they have no conflict of interest.

8. Authors Contribution

The first author wrote the draft under the guidance of the second author on the theme and content of the paper.

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