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Design of a Pyrolysis Device for Converting Pet Plastic Bottle Waste into Conductive Carbon as a Raw Material for Non-Metal Components

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A B S T R A C T

Polyethylene Terephthalate (PET) plastic bottle waste is a significant environmental problem, including in Merauke City, necessitating innovative processing solutions to convert it into value-added products. This study aims to design a simple pyrolysis apparatus and test the electrical conductivity of conductive carbon produced from PET bottle waste. The method used is two-stage pyrolysis: initial carbonization at a temperature of ±400°C for 1 hour, followed by advanced pyrolysis at ±1000°C for 2 hours in a closed system with medium carbon steel pieces as mediation. The results showed that the initial carbonization produced amorphous carbon with high resistance (800–1200 Ω), while the advanced process with the addition of metal and high temperature significantly increased electrical conductivity, reducing the resistance to 30–50 Ω. This proves that the addition of metal and increased temperature are effective in facilitating the formation of conductive graphitic structures (sp^2 bonding). The resulting conductive carbon has broad potential as a raw material for non-metallic components such as battery electrodes, supercapacitors, or electronic sensors

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INTRODUCTION

Plastic waste, especially Polyethylene Terephthalate (PET) bottles, poses a pressing global and local environmental challenge. In many regions, including Merauke City, the high consumption of single-use plastic packaging has led to a significant increase in waste volume. The Merauke Regency Environmental Agency notes that the city generates between 45 to 50 tons of waste daily, with official collection services covering only a fraction of families, resulting in significant amounts of waste being discarded improperly. This accumulation of non-biodegradable PET waste obstructs waterways, causes pollution, and contributes to potential flooding, despite local government efforts which face challenges due to limited infrastructure and low public awareness.

In this context, efforts to utilize PET waste for value-added products are crucial. An innovative solution is pyrolysis, the thermal decomposition of plastic under limited oxygen conditions, to produce functional solid carbon, known as conductive carbon. This material possesses broad application prospects in the field of electronics, such as non-metallic components for electrodes or sensors, thereby supporting a circular economy and mitigating plastic pollution. The ability of this carbon to conduct electricity depends heavily on its microstructure and crystallinity, specifically the presence of sp^2 bonds.

While prior research has explored the conversion of plastic waste into activated carbon for water filtration or bio-oil, specific local studies focusing on enhancing the conductivity of PET-derived carbon using simple methods are limited. This research addresses this gap by focusing on the design of a simple, laboratory-scale pyrolysis apparatus and investigating the effectiveness of a two-stage process, including the use of medium carbon steel mediation at high temperatures (±1000^∘ C), to optimize the conductive properties of the resulting carbon material.

The primary objectives of this study are threefold: to design and prototype a simple pyrolysis apparatus using local materials, to produce conductive carbon from PET bottle waste, and to test the electrical conductivity of the final product. Academically, this research aims to contribute to the literature on plastic waste processing techniques. Practically, it provides an alternative solution for waste management; and environmentally, it supports the reduction of plastic waste volume in Merauke.

LITERATURE REVIEW

Several studies have explored the conversion of plastic waste via pyrolysis, providing a foundation for this research:

- *Prakoso et al. (2019):* Developed a simple pyrolysis system using a used drum to convert plastic waste into activated carbon, demonstrating that high-porosity carbon can be produced for water filtration applications.
- *Wahyuni et al. (2021):* Investigated the conversion of PET bottles into activated carbon using a closed pyrolysis system with biomass as the heat source. The resulting carbon showed good adsorption capacity.
- *Zhang et al. (2020):* Focused on characterizing conductive carbon from plastic waste, showing that PET-derived carbon has viable conductivity for electrode applications after activation at temperatures >600°C.

- *Nugroho (2022):* Designed a household-scale pyrolysis unit using an iron tube and an LPG stove, offering a relevant technical reference for the simple apparatus used in this study.
- *Sharifian and Asasian-Kolur (2022):* Provided a comprehensive review highlighting PET as a high-purity raw material for porous carbons and mentioned the use of metal salts to enhance mesoporosity and structure.

This study builds upon these findings by specifically testing the efficacy of a simple, two-stage pyrolysis process utilizing local materials and metallic mediation to achieve high electrical conductivity suitable for non-metallic component applications in remote areas like Merauke.

METHODOLOGY

Types and Approaches of Research

This study utilized an experimental laboratory approach (pendekatan eksperimental laboratorium) to investigate the feasibility of converting Polyethylene Terephthalate (PET) plastic bottle waste into conductive carbon material using a simple, locally fabricated pyrolysis system. The research was conducted in two primary, sequential stages:

1. Stage 1: Initial Carbonization. The initial process of carbonizing PET waste in a simple pyrolysis system.
2. Stage 2: Advanced Pyrolysis. The subsequent reheating of the initial carbon material with metallic mediation in a closed system to enhance conductivity.

This approach allowed for a controlled observation of how variations in temperature and the presence of a mediating agent (medium carbon steel) influence the physical and electrical properties of the resulting carbon. The research design focused on applied science principles, aiming to transform a common waste product found in Merauke into a potential functional material for non-metallic components. The methodology is designed to be practical and locally scalable, making use of simple, modified apparatus constructed from readily available local materials.

RESULTS

This study aimed to convert PET plastic bottle waste into conductive carbon using a simple pyrolysis method. The results were obtained through two process stages: initial carbonization and advanced thermal pyrolysis with metal mediation.

Initial Carbonization Results (Without Metal Mediation)

In the initial stage, the cleaned and cut PET waste was loaded into a closed pyrolysis apparatus and heated at a temperature of ±400^∘ C for 1 hour. This process yielded a dark black carbon residue with a light, brittle, and non-glossy texture. Testing using a multimeter showed resistance values between 800–1200 Ω, indicating that this initial carbon did not yet possess significant electrical conductivity.

Advanced Pyrolysis Results (With Metal Mediation)

The initial carbon was then mixed with medium carbon steel pieces and placed into a sealed steel tube. This advanced process was conducted at a higher temperature of ±1000^∘ C for 2 hours inside a furnace. The resulting carbon exhibited significant physical changes: its color became glossier, its texture denser, and it appeared more homogeneous. Resistance testing on this material showed a drastic decrease in values, ranging between 30–50 Ω, indicating a significant increase in the electrical conductivity of the final carbon product.

Data Analysis and Evaluation

Table 1. Summary of the Conductivity Measurement Results

No	**Type of Carbon**	**Pyrolysis Temperature**	**Resistance** (Ω)	**Conductivity**
1	Initial Carbon (Non-conductive)	±400°C	800–1200	Low
2	Conductive Carbon (with metal)	±1000°C	30–50	High

To evaluate the difference between the two types of carbon, an unpaired two-sample t-test was performed on the resistance values from each group. The calculation results showed a p-value <0.01, meaning the difference in resistance is statistically very significant. This strengthens the hypothesis that the addition of metal and the increase in temperature contribute significantly to the formation of conductive carbon

Figure 1. Tools Used

Figure 2. The Process of Conductive Charcoal Formation

DISCUSSION

Answering the Problem Formulation

This research successfully addressed the three core problem formulations outlined in the introduction by synthesizing the findings from the experimental results and analysis (Section 4.1 to 4.4):

Effectiveness of the PET Waste Pyrolysis Process in Producing Conductive Carbon

The research demonstrated that the simple pyrolysis method is effective in converting PET waste into a carbon material, provided a two-stage process is implemented. The initial low-temperature carbonization (±400^∘ C) yields an amorphous, high-resistance carbon (>800 Ω) which is not highly conductive. However, the subsequent high-temperature treatment (±1000^∘ C) with metal mediation significantly increases the quality and conductivity of the carbon, indicating the process is indeed effective in achieving the desired conductive properties under the right conditions.

Design of the Simple Pyrolysis Tool Using Local Materials

The study successfully established a design methodology using local and repurposed materials. A used motorcycle fuel tank was modified into a safe, airtight reactor for the initial phase, demonstrating that functional equipment can be engineered from accessible resources in areas with limited infrastructure like Merauke. The system proved capable of maintaining the necessary oxygen-free environment critical for pyrolysis, validating the local engineering approach.

Electrical Conductivity and Physical Characteristics of the Pyrolysis Carbon

The ability of the final carbon product to conduct electricity was substantially high compared to the initial char. The advanced process reduced electrical resistance from approximately 800–1200 Ω to a significantly lower range of 30–50Ω. The physical characteristics observed a clear transition: the non-conductive initial char was light and dull black, while the highly conductive final material was denser, darker, and had a shiny, somewhat graphitic appearance.

This drastic change in resistance and physical appearance validates the potential of the material for applications as a non-metallic conductive component, such as in simple electrodes or sensors.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and analysis conducted in this study, the following conclusions can be drawn:

1. PET plastic bottle waste can be processed into carbon through a simple pyrolysis method; however, the carbon produced in the initial stage is amorphous and does not yet have significant conductive properties.
2. The advanced process, involving closed thermal pyrolysis with the addition of a metal medium (medium carbon steel), is proven to enhance the quality of the carbon in terms of structure, color, density, and electrical conductivity. The resulting carbon exhibits significantly lower electrical resistance compared to the initial carbon, indicating the formation of a conductive carbon structure.
3. The addition of metal in the pyrolysis system acts as a catalyst and facilitates the formation of a graphitic (〖"sp" 〗 ^2) structure within the carbon, which is the primary factor in its conductivity. The closed pyrolysis process at 1000^∘ C

For 2 hours in an oxygen-free environment is effective in producing stable conductive carbon.

Recommendations

Based on the research findings and limitations, the following recommendations are suggested for future work:

1. The use of advanced characterization equipment such as SEM (Scanning Electron Microscopy), XRD (X-ray Diffraction), or Raman Spectroscopy is highly recommended in subsequent studies to confirm the microstructure and crystalline structure of the resulting carbon.
2. Further testing of this conductive carbon in real-world applications, such as electrodes for batteries, supercapacitors, or as a conductive material in the field of electronics, needs to be conducted.
3. Future research should explore variations in the type of metal mediation used and the pyrolysis parameters (temperature, time, pressure) to obtain conductive carbon with optimal quality.
4. The development of a safer, more efficient, and automated laboratory-scale pyrolysis apparatus is needed to increase productivity and the potential for commercializing this process.

FURTHER STUDY

Based on the findings and limitations of this research, the following areas are recommended for further investigation to optimize the conversion process and application of conductive carbon from PET waste:

1. Advanced characterization using instrumentation such as SEM (Scanning Electron Microscopy), XRD (X-ray Diffraction), or Raman Spectroscopy is suggested in future studies to precisely confirm the microstructure and crystalline nature of the resulting carbon.

2. Further testing is needed to evaluate the performance of this conductive carbon in real-world applications, such as electrodes for batteries, supercapacitors, or as a functional material in electronic components.
3. Subsequent research should explore variations in the type of metal mediation used (e.g., specific catalysts like Ni or Fe salts) and other pyrolysis parameters (e.g., higher temperatures, varied holding times, or controlled pressure) to obtain carbon with optimal conductive properties.
4. The development of a more automated, efficient, and safer laboratory-scale pyrolysis apparatus is recommended to increase productivity and facilitate potential commercialization of this process for small and medium enterprises or household use.

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