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APPLICATION POSSIBILITIES OF SOLID CARBON RESIDUE AS ADSORBENT OR COKE

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ABSTRACT

This study analyzes the application possibilities of solid carbon residues (char) formed as a result of polymer waste pyrolysis as adsorbent materials and coke. The article examines activated carbon production methods, physical-chemical properties, and industrial applications. Research results indicate that it is possible to obtain activated carbon with a specific surface area of 2712 m²/g from pyrolysis char materials using KOH activator. The efficiency of char materials in adsorbing heavy metals ranges from 85-95%. The article provides a comparative analysis of works by international and national researchers and evaluates the prospects for application in coke production. Technological process optimization methods and economic efficiency indicators are also studied.

Introduction

Solid carbon residues (char) produced during the pyrolysis of gas-chemical waste are a valuable product that can be applied in many industrial sectors [1:817]. These materials have a high carbon content (70–90%) and adaptable structural characteristics, allowing them to be converted into activated carbon or industrial coke when properly treated.

From the perspective of polymer materials science, studying char materials derived from polymer waste pyrolysis is a critical area for developing sustainable polymer technology. Modern polymer science increasingly focuses on the principles of the circular economy, where end-of-life polymer products are converted into high-value materials rather than being disposed of as waste [3:2047]. Thermochemical conversion of polymer waste via pyrolysis not only addresses the growing ecological problems associated with plastic accumulation but also creates opportunities for producing functional carbon materials with tailored properties [4:71].

The demand for adsorbent materials and coke in modern industrial production is constantly rising. The recovery of plastic waste through pyrolysis is attractive not only in terms of solving the problem of plastic waste but also from the perspective of reducing greenhouse gas emissions [5:3]. Polymer wastes, especially polyethylene, polypropylene, and polystyrene, possess high energy content and carbon-rich structures, making them ideal precursors for activated carbon production [7:895]. In this context, the effective utilization of char materials as a secondary product is of significant importance [2:115].

The urgency of this research is further highlighted by recent advancements in the valorization of polymer waste. Studies have shown that char materials obtained from polymer pyrolysis exhibit unique physicochemical properties which can be enhanced through appropriate activation methods [8:136067]. Developing effective methods for converting polymer waste into high-performance adsorbents and coke alternatives addresses the challenges of environmental sustainability and efficient resource utilization faced by the modern polymer industry [9 :1126].

The objective of this research is to analyze the possibilities of applying pyrolysis char materials as adsorbent and coke, evaluate global and national scientific achievements, and define practical application directions.

Metodology

The research is based on a systematic literature review methodology. The following databases were used for data collection:

- Web of Science Core Collection (2020–2024)
- ScienceDirect (2020–2024)
- ACS Publications (2020–2024)
- Royal Society of Chemistry (2020–2024)
- Nature Publishing Group (2020–2024)

Search strategy: Combinations of keywords: "pyrolysis char", "activated carbon", "polymer waste", "adsorbent", "coke production".

Selection criteria: Articles published in peer-reviewed journals, containing experimental research results, and dated between 2020 and 2024.

Results and discussion

Physicochemical properties of char materials

Char materials were obtained from cotton residues and wood chips in a fixed-bed reactor during the pyrolysis process, and these solid products were used as potential materials for activated carbon production. The main properties of char materials are as follows:

Table 1

Properties of char materials obtained from various types of polymer waste

Polymer Type	Char Yield (%)	Carbon Content (%)	Specific Surface Area (m²/g)	Micropore Volume (cm³/g)
Polyethylene	15-25	75-85	150-300	0,08-0,15
Polypropylene	12-20	78-88	180-350	0,10-0,18
Polystyrene	25-35	85-92	200-450	012-0,22
Mixed Plastic	18-28	72-82	120-280	0,06-0,14

Activated carbon production and thermochemical treatment mechanism

The thermochemical treatment mechanism plays a crucial role in converting polymer-derived char into high-performance activated carbon. KOH has been identified as the best activator, enabling the production of activated carbon with a specific surface area of 2712 m^2/g. [11:4].

The activation process involves complex physicochemical changes that occur in two main stages:

Chemical Activation Mechanism

During chemical activation with KOH, H_3PO_4 or $ZnCl_2$ the activating agent penetrates the carbon matrix and initiates several key reactions. When potassium hydroxide (KOH) is used as the activating agent, the following mechanisms occur at high temperatures (700-900°C):

The role of KOH during the activation process is multifaceted. Firstly, it acts as a dehydrating agent, removing hydrogen and oxygen from the char composition, which increases the relative carbon content [5:8]. Secondly, at high temperatures, KOH reacts with carbon according to the following reactions:

$$6KOH + 2C \rightarrow 2K + 3H_2 + 2K_2CO_3$$

$$K_2CO_3 + 2C \rightarrow 2K + 3CO$$

These reactions lead to the rapid evolution of gases (H_2, CO, CO_2) which creates a highly porous structure within the carbon residue. The metallic potassium produced can intercalate into the carbon layers, which may lead to their expansion and the formation of additional micropores and mesopores [8:136070]. This intercalation mechanism is particularly effective in developing a three-dimensional porous network with interconnected channels.

Physical activation mechanism

Physical activation involves treatment with steam or CO_2 at high temperatures (800-1000°C). The activating agents react with carbon through gasification reactions:

$$C + H_2O \rightarrow CO + H_2$$
$$C + CO_2 \rightarrow 2CO$$

These endothermic reactions selectively remove carbon atoms from the char structure, especially from more reactive sites such as edge carbons and defects [9:1132]. The controlled gasification process gradually opens closed pores and expands existing voids, resulting in a sharp increase in the specific surface area. Gas molecules enter the carbon matrix and expand the existing pores, creating new ones, which leads to the development of a porous structure with varying pore sizes.

The combined effect of chemical and physical activation transforms the relatively non-porous char material into a highly porous activated carbon with excellent adsorption properties. The specific surface area can increase from 150-450 m^2/g in untreated char to up to 2700 m^2/g in fully activated carbon.[11:7]. This drastic improvement in porosity provides strong adsorbent qualities, allowing the material to effectively capture various pollutants, heavy metals, and gases from aqueous and gaseous environments.

The activation process significantly alters the micro- and mesopore structure of the char materials, creating a material with an optimized pore size distribution suitable for specific applications [3:2049]. Biochar is obtained through biomass pyrolysis, and activated carbon is biochar that has undergone chemical or physical activation, resulting in improved surface area and adsorption capacity.

Application as adsorbent

Activated carbons possess surfaces that can easily adsorb foreign molecules (liquids and gases) due to their porosity and the presence of active chemical functional groups [8:136067]. Key areas of application include:

In water treatment systems

Research on heavy metal removal shows that char-based adsorbents exhibit 85–95% efficiency. The ability to adsorb Cd^{2+}, Pb^{2+}, Cu^{2+} and Zn^{2+} ions is highly valued [8:136075]. The adsorption mechanism involves physical adsorption in the micropores and chemical interaction with oxygen-containing functional groups on the carbon surface.

In Gas Purification Systems

The increase in atmospheric CO_2 levels demands the immediate development of effective capture technologies. Char-based adsorbents are promising materials for CO_2 capture [10 :27653]. Studies have shown that activated carbons with narrow micropores (0,5-0,8 nm**)** demonstrate excellent CO_2 adsorption capacity through physical adsorption mechanisms under ambient conditions.

Application as coke

The properties and reactivity of coke produced in polyethylene pyrolysis have been studied [7:898]. There are possibilities for applying pyrolysis char materials as a coke substitute in the metallurgical industry:

Table 2

Comparative properties of char and conventional coke

Indicator	Pyrolysis Char	Conventional Coke	Difference (%)
Carbon Content (%)	75-85	85-95	-10
Ash Content (%)	3-8	8-12	-30
Heat Value (MJ/kg)	28-32	30-35	-8
Mechanical Strength (MPa)	15-25	25-40	-35
Porosity (%)	35-45	40-50	-12

Comparison of International and National Research

Extensive research on the application of char materials is being conducted within the international scientific community. Recent studies on pyrolysis-derived char show that it is a valuable additive with multiple applications in soil and water remediation, agricultural productivity enhancement, supercapacitors, fuel cells, as well as catalysts and carbon sequestration in sustainable chemistry [2:12251].

Advanced research indicates that polymer-derived char materials can be engineered with specific porous structures and surface chemistries for targeted applications [5:5]. The production of activated carbon from waste plastics is a significant advancement in circular economy approaches in polymer materials science.

National research, however, is mainly in the initial stages. The activities of Uzbek scientists primarily focus on theoretical aspects, while practical application issues have not been sufficiently studied [6 :311]. Nevertheless, recent initiatives on the valorization of gas-chemical waste show promising directions for implementing this industry in the Uzbek polymer sector.

Technological challenges and solutions

Main technological challenges:

- Complexity of the activation process – high energy consumption
- Stability of product quality – dependence on raw material composition
- Economic efficiency – production costs

Proposed Solutions:

- Optimization of the activation process
- Implementation of microwave-assisted activation
- Introduction of a two-stage activation process
- Creation of a catalyst reuse system

Economic Assessment

The economic efficiency of producing char materials as adsorbents depends on the raw material cost, energy expenditure, and the market price of the product. 0,2-0,3 tons of char can be obtained from one ton of polymer waste, from which 0,15–0,25 tons of activated carbon can be produced [5 :9].

The market price of activated carbon is 2-5 USD/kg, and additional income can be generated by recycling char materials. The valorization of polymer waste through pyrolysis and activation processes contributes to sustainable polymer waste management strategies, bringing both environmental and economic benefits.

Conclusion

The analysis of research in the field of applying solid carbon residues from polymer waste pyrolysis as adsorbent or coke yields the following conclusions:

Key achievements:

1. Technological potential – high-quality adsorbent can be obtained using modern activation methods [11 :9]

2. Application areas – water and air purification, metallurgical industry, and energy storage applications [2 :12260]
3. Environmental benefit – environmental protection by recycling waste and reducing the accumulation of polymer waste [3 :2050]
4. Economic efficiency – creation of additional income sources by valorizing waste

Directions for development**:**

Scientific research:

- Developing new activation methods with reduced energy requirements [5:15]
- Studying the structural properties of char materials and their correlation with the precursor polymer structure [9 :1140]
- Optimizing catalytic processes to increase activation efficiency

Practical application**:**

- Constructing and testing pilot plants for industrial-scale production
- Developing product quality standards specific to polymer-derived activated carbons
- Improving economic efficiency indicators through process integration [6:313]

Technological improvement**:**

- Introducing microwave activation technology for energy efficiency
- Implementing automated control systems for product quality stabilization
- Developing energy-saving processes utilizing waste heat recovery.

The application of pyrolysis char materials as adsorbent or coke is a promising direction for the Uzbek chemical industry, and it can be implemented in large enterprises such as the Ustyurt Gas Chemical Complex. This direction not only solves the waste problem but also brings additional economic benefits while contributing to the sustainable management of polymer materials.

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