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SYNTHESIS OF HIGHLY POROUS ACTIVATED CARBON FROM APRICOT STONE SHELLS AND ITS STRUCTURAL CHARACTERISTICS

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Abstract

This article investigates the production of activated carbon with a high specific surface area and a well-developed porous structure from apricot (Prunus armeniaca) stone shells, a widely available local agricultural waste. The raw material was crushed, dried, and processed through a two-stage procedure consisting of carbonization followed by chemical activation with potassium hydroxide (KOH). Samples obtained under different impregnation ratios (1:1, 1:2, 1:3) and activation temperatures (600, 700, and 800 °C) were characterized by nitrogen adsorption-desorption (BET method), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD). The results showed that the sample activated at an impregnation ratio of 1:3 and a temperature of 800 °C exhibited the highest specific surface area (approximately 1450–1600 m^2/g) and micropore volume. FTIR analysis confirmed the presence of oxygen-containing surface functional groups (–OH, C=O, C-O), which enhance the adsorption activity of the material. The obtained activated carbon shows strong potential for use in water treatment, gas adsorption, and energy-storage devices such as supercapacitors. The findings demonstrate the feasibility of converting apricot stone shells, a cheap and abundant agricultural by-product, into a high-value-added carbon material.

Keywords: *activated carbon; apricot stone shell; porosity; KOH activation; specific surface area; BET; agricultural waste*

Introduction

In recent years, the contamination of industrial and municipal wastewater with heavy metals, dyes, and organic pollutants, as well as the emission of harmful gases into the atmosphere, has become a pressing global issue. Adsorption-based methods, particularly activated carbon materials, occupy a special place in addressing these problems due to their high efficiency, affordability, and

versatility (Marsh & Rodríguez-Reinoso, 2006).

Activated carbon is traditionally produced from coal, peat, and wood; however, these raw materials are relatively expensive and their reserves are limited. Consequently, over the past decade there has been growing interest in converting agricultural and food-industry residues – such as nut shells, apricot and peach stones, and fruit pits – into cheap and environmentally friendly lignocellulosic precursors for activated carbon (Şentorun-Shalaby et al., 2006). Uzbekistan is among the world's leading apricot-producing countries, and as a result hundreds of thousands of tons of apricot stone shells remain unprocessed as waste every year. The high carbon content and dense structure of this raw material make it a highly promising source for activated carbon production.

The adsorption properties of activated carbon are primarily determined by its porous structure – specific surface area, pore volume, and pore-size distribution. Previous studies have shown that these parameters can vary within wide ranges depending on the type of raw material, carbonization temperature, activating agent (KOH, H_3PO_4, $ZnCl_2$), and impregnation ratio (Pap et al., 2016; Yağşi, 2004). It is therefore of considerable scientific and practical importance to determine the optimal synthesis conditions for each new type of raw material.

The aim of this study is to synthesize highly porous activated carbon from apricot stone shells using chemical activation with KOH, to investigate the effect of key synthesis parameters (impregnation ratio and temperature) on the structural and morphological properties of the resulting product, and to evaluate the practical application potential of the obtained material.

Research method

Raw material preparation

The hard shell of local apricot (Prunus armeniaca L.) stones was used as the raw material. The shells were separated from the kernels, washed repeatedly with distilled water, and dried at 105 °C for 24 hours. The dried samples were ground using a mechanical crusher, and the 0.5–1.0 mm fraction was separated using a sieve.

Carbonization and chemical activation

Preliminary carbonization was carried out under an inert (nitrogen) atmosphere, heating at a rate of 10 °C/min up to 500 °C and holding at this temperature for 1 hour. The resulting char was impregnated with a potassium hydroxide (KOH) solution at carbon-to-KOH mass ratios of 1:1, 1:2, and 1:3. The mixture was stirred at 80 °C for 4 hours and then dried at 105 °C. The activation stage was performed under a nitrogen flow (100 mL/min) at 600, 700, and 800 °C for 1 hour. After cooling, the samples were washed with distilled water until reaching a neutral pH (≈7), dried at 105 °C, and stored in a desiccator.

The synthesis yield was calculated using the following formula:

$$\text{Yield}\ (\%) = (m_2 / m_1) \times 100 \qquad (1)$$

where m_1 is the mass of the initially carbonized raw material (g), and m_2 is the mass of the final activated carbon obtained after activation and washing (g).

Sample characterization methods

The porous structure and specific surface area of the samples were determined by nitrogen adsorption-desorption at –196 °C using the Brunauer-Emmett-Teller (BET) method; micropore volume was calculated using the t-plot method. Surface morphology was examined by scanning electron microscopy (SEM) at magnifications of 5,000–20,000×. Fourier-transform infrared spectroscopy (FTIR, in the range of 4000–400 cm^{-1}) was used to identify surface functional groups. Crystal structure and the degree of graphitization were evaluated by X-ray diffraction (XRD, Cu-Kα radiation, 2θ = 10–80°). Ash content and moisture were determined gravimetrically in accordance with ASTM standards.

Results analysis

Yield and basic physicochemical parameters

It was observed that the product yield decreased as both the activation temperature and the impregnation ratio increased, which is explained by the intensive gasification and degradation of the carbon skeleton under the action of KOH at higher temperatures. At 600 °C, the yield was 55–60%, whereas at

800 °C with a 1:3 ratio it dropped to 32–35%. At the same time, it was precisely under these conditions that the most developed porous structure was formed (Table 1).

Table 1. *Main structural characteristics of samples obtained under different synthesis conditions*

Sample	Impregnation ratio	Activation temperature, °C	Yield, %	SBET, m²/g	Micropore volume, cm³/g
AC-1	1:1	600	58.4	612	0.28
AC-2	1:2	700	46.7	1024	0.44
AC-3	1:3	700	40.1	1287	0.55
AC-4	1:2	800	38.9	1341	0.58
AC-5	1:3	800	33.2	1568	0.71

Note: The data are presented based on experimental results obtained by the author

The highest specific surface area (SBET ≈ ≈ 1568 m²/g) and micropore volume (0.71 cm³/g) were recorded for sample AC-5 (1:3 ratio, 800 °C). This value is considerably higher than the 700–1100 m²/g range reported in the literature for apricot-stone-derived carbons activated with H_3PO_4 or steam (Şentorun-Shalaby et al., 2006; Pap et al., 2016), confirming the high efficiency of KOH chemical activation in generating micropores.

Morphological and spectral analysis

SEM images showed that samples obtained at lower temperatures (600 °C) retained a relatively smooth and dense surface, whereas increasing the activation temperature and KOH content led to the formation of numerous pores and cracks on the surface. This is associated with the reaction of KOH with the carbon matrix at elevated temperatures (mainly forming K_2CO_3, K_2O, and metallic potassium), which creates additional pore channels.

FTIR spectra revealed a broad band around 3400 cm^{-1} corresponding to hydroxyl (–OH) groups, a peak in the 1700–1720 cm^{-1} region corresponding to carbonyl (C=O) groups, and a band near 1580 cm^{-1} corresponding to aromatic C=C ring vibrations. Bands in the 1000–1200 cm^{-1} range correspond to C-O-C and C-OH bond vibrations. The intensity of these bands decreased in samples activated at higher temperatures, reflecting the partial decomposition of oxygen-containing surface groups (decarboxylation and dehydration) with increasing temperature.

XRD patterns of all samples showed broad, low-intensity peaks near 2θ ≈ 23° and 43°, corresponding to the (002) and (100) planes of graphite structure. The broadness of these peaks indicates an amorphous, disordered carbon structure, i.e., the presence of poorly ordered graphitic layers associated with high porosity.

Practical significance

Sample AC-5, with its high specific surface area and well-developed micropore structure, is a promising sorbent for the adsorption of heavy metal ions, synthetic dyes, and organic pollutants from aqueous solutions, as well as for capturing harmful gas-phase substances (CO_2, volatile organic compounds). In addition, the high porosity and conductive carbon skeleton also make the material suitable for use as an electrode material in supercapacitors.

Conclusion

This study successfully synthesized highly porous activated carbon from apricot stone shells through a two-stage process consisting of carbonization and chemical activation with KOH. The following was established:

1) an increase in activation temperature and impregnation ratio reduces product yield but significantly increases specific surface area and micropore volume;

2) the highest structural parameters (SBET ≈ 1568 m²/g, micropore volume of 0.71 cm³/g) were achieved at an impregnation ratio of 1:3 and an activation temperature of 800 °C;

3) FTIR and XRD analyses confirmed the presence of active oxygen-containing functional groups on the surface and an amorphous carbon structure.

These results demonstrate that apricot stone shells, a local and inexpensive agricultural waste, can be converted into a high-value-added, environmentally friendly, and efficient adsorbent material. Future research should focus on studying the adsorption capacity and kinetics of the obtained activated carbon toward specific pollutants, as well as its regeneration capability.

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