ADSORPTION EFFICIENCY OF CARBON MATERIALS DERIVED FROM PET AND PE WASTE TOWARDS CU^{2+} IONS IN WATER

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Abstract: *This study investigates the adsorption efficiency of carbon adsorbents synthesized from PET and PE polymer waste by carbonization at 700°C toward Cu^{2+} ions in aqueous solutions. Unmodified carbons (PET-700, PE-700) and oxidized graphite-modified samples (PET-OG10, PE-OG10) were comparatively evaluated.*

Adsorption kinetics and equilibrium isotherms were studied over 1–24 hours. PET-OG10 showed the highest performance, reducing Cu^{2+} concentration from 30 to 1.3 mg/L after 24 hours (removal efficiency >95.6%). Langmuir maximum adsorption capacities were 3.38, 2.50, 40.00, and 19.88 mg/g for PET-700, PE-700, PET-OG10, and PE-OG10, respectively. OG modification increased adsorption capacity up to 11-fold and is attributed to enhanced specific surface area and active site density.

The synthesized adsorbents demonstrate strong potential as cost-effective materials for heavy metal removal from industrial wastewater.

Keywords: *carbon adsorbent, polyethylene terephthalate (PET), polyethylene (PE), copper ions (Cu^{2+}), adsorption kinetics, adsorption isotherm, oxidized graphite, wastewater treatment, polymer waste, Langmuir model, Freundlich model.*

Today, water resource pollution is one of the most serious ecological problems worldwide. Industrial wastewater contains heavy metals, petroleum products, and organic contaminants that cause significant damage to aquatic ecosystems.

Conventional treatment methods (coagulation, sedimentation, etc.) are often insufficiently effective.

The development of highly efficient adsorbents - in particular, the production of carbon sorbents from polymer waste - is one of the most pressing research directions. Utilizing polyethylene terephthalate (PET) and polyethylene (PE) waste not only reduces environmental burden but also enables the production of new materials with high adsorption properties [1].

The main sources of polymer waste are packaging materials, construction products, consumer goods, textiles, transport, and electrical engineering. In 2018, the global volume of plastic waste exceeded 343 million tons, with approximately 90% attributed to post-consumer waste [2].

Treatment of wastewater contaminated with heavy metal ions, particularly Cu^{2+}, is a critical environmental challenge.

Copper ions are widespread in wastewater from metal processing, electroplating, and electronics industries, and exhibit toxic effects even at low concentrations.

Their effective removal from the aquatic environment is therefore of great importance. Carbon adsorbents derived from polymer waste represent one of the most promising methods for removing copper and other heavy metal ions from wastewater.

Experimental

Polyethylene (PE) and polyethylene terephthalate (PET) polymers were selected as raw materials, and their thermal decomposition patterns were studied by thermogravimetric analysis (TGA). According to TGA results, the optimal temperature for polymer destruction and stable carbon residue formation was determined to be 700°C. On this basis, polymer samples were carbonized at 700°C under an inert atmosphere, yielding PE-700 and PET-700 carbon adsorbents, respectively.

To evaluate the adsorption properties of the obtained PE-700 and PET-700 samples toward Cu^{2+} ions, a stock solution of 1000 mg/L was first prepared from $CuSO_4{\cdot}5H_2O$ (in 1M NH_4OH solution).

Working solutions in the range of 1–100 mg/L were then prepared by successive dilution with distilled water. Before use, the synthesized carbon adsorbent samples were dried at 105°C to constant mass.

Experiments were conducted in conical flasks. 0.05 g of adsorbent was weighed precisely and added to a flask containing 50 mL of model solution. The mixture was stirred intensively at room temperature on a laboratory shaker at 150 rpm. To study adsorption kinetics, the contact time was set from 1 to 24 hours [3].

Results and Discussion

Fig. 1 shows the dynamics of Cu^{2+} ion concentration decrease in the system with carbon at room temperature. The initial concentration of ions in the system was 30 mg/L.

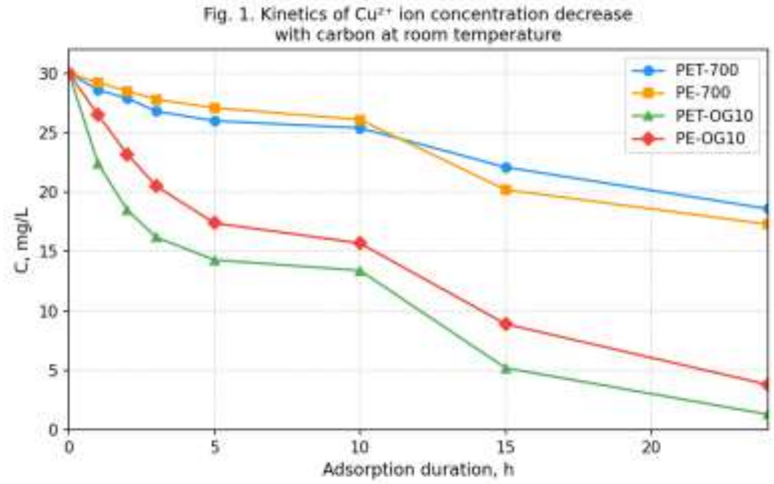

Fig. 1. Kinetics of the decrease in Cu^{2+} ion concentration in a system with carbon at room temperature.

During the initial hours, a sharp decrease in Cu^{2+} ion concentration was observed, particularly in the PET-OG10 and PE-OG10 systems. Within the first 3 hours, the concentration dropped to 16.2 and 20.5 mg/L, respectively.

After 24 hours, the lowest residual concentrations were recorded for PET-OG10 and PE-OG10 - 1.3 and 3.8 mg/L, respectively - while for PET-700 and PE-700 these values were 18.6 and 17.3 mg/L. Whereas adsorption kinetics slowed after 10 hours for thermally activated samples, OG-modified samples — especially PET-OG10 — maintained active Cu^{2+} adsorption.

Based on kinetic studies, the equilibrium adsorption time was determined to be at least 15 hours for thermally activated carbons and at least 20 hours for OG-modified systems.

Equilibrium adsorption isotherms are presented in Fig. 2. The presented graph shows the adsorption isotherms of Cu^{2+} ions and reveals differences in adsorption capacity among carbons derived from PET and PE, as well as samples modified with 10% OG.

According to the IUPAC classification, carbons based on PET-700 and PE-700 exhibit low sorption capacity and form adsorption isotherms approaching Type I, indicating a microporous structure with limited pore volume and low specific surface area; the initial linear section indicates the predominance of physical adsorption. In contrast, PET-OG10 and PE-OG10 samples show a sharp adsorption increase at low concentrations followed by saturation, characteristic of Type II isotherms.

This is attributed to a developed micro- and mesoporous structure and the presence of active sites formed as a result of modification.

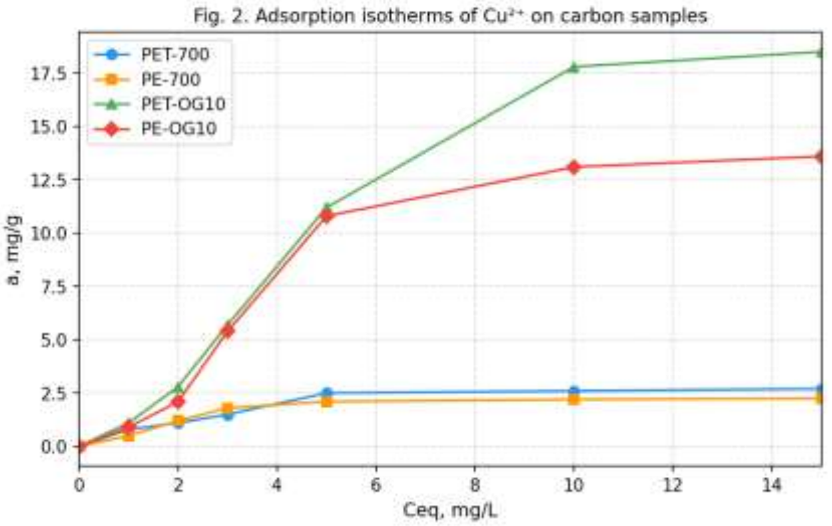

Fig. 2. Adsorption isotherms of Cu^{2+} on carbon samples.

Polymer-based carbons obtained at 700°C exhibit relatively low adsorption capacity toward Cu^{2+} ions. For PET, maximum adsorption is below 2 mg/g, and for PE below 1.5 mg/g, observed at an equilibrium concentration of C_1 = 14 mg/L.

The shape of Cu^{2+} adsorption isotherms also differs for PET-700 and PE-700 samples, generally appearing flat. This difference reflects distinctions in the adsorption mechanism and the structure of carbon materials. The flat shape indicates limited active adsorption sites and low porosity.

Table 1. Adsorption parameters of Cu^{2+} ions on carbon samples

Langmuir Equation Parameters				
Sample	A_0	K_L	R^2	
PET-700	3.38	0.304	97.0	
PE-700	2.50	0.684	98.3	
PET-OG10	40.00	0.067	78.1	
PE-OG10	19.88	0.164	90.7	
Freundlich Equation Parameters				
Sample	1/n	K_F	R^2	
PET-700	0.564	0.8073	93.1	
PE-700	0.269	1.1847	73.5	
PET-OG10	1.136	1.4863	95.5	
PE-OG10	1.586	0.8409	98.5	

Thus, the Langmuir model better describes the Cu^{2+} adsorption process for carbons with a relatively uniform surface structure, especially for samples modified with a porophore. The Freundlich model is more suitable for carbons with a heterogeneous surface structure, such as PET-OG10 and PE-OG10.

The parameters A_0 and K_L in the Langmuir equation characterize the surface properties of the adsorbents and the adsorption process. A_0 represents the maximum adsorption capacity, equal to 3.38 and 2.50 for PET-700 and PE-700, respectively. For OG-modified PET-OG10 and PE-OG10 samples, this value increased significantly, reaching 40.0 and 19.88, respectively. The K_L parameter characterizes the binding strength between adsorbent and adsorbate. For PET-700 and PE-700, K_L values were 0.304 and 0.684, respectively, indicating stronger interaction with the adsorbate in the PE-700 sample.

Conclusion

The study established that the ability of carbon adsorbents to adsorb Cu^{2+} ions from aqueous solutions depends on their thermal activation and the degree of modification with oxidized graphite (OG). Kinetic analysis showed that during the first 3 hours, a sharp decrease in Cu^{2+} ion concentration was observed in all samples-particularly in the PET-OG10 and PE-OG10 systems (to 16.2 and 20.5 mg/L, respectively). Equilibrium adsorption time was at least 15 hours for thermally activated carbons and at least 20 hours for OG-modified systems. After 24 hours, the best purification performance and lowest residual concentration were recorded for the PET-OG10 sample (1.3 mg/L), confirming its high kinetic activity.

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