

Synthesis of a Sorbent via Chemical Modification of Lignin with Urea

Abdullayeva Maxliyo

Basic Doctoral Student at the Termez State University of Engineering and Technologies.

Abstract: This research is devoted to the synthesis of a highly efficient nitrogen-containing sorbent by the chemical modification of technical lignin, an industrial byproduct, with urea. The main objective is to enhance the reactivity of the lignin macromolecule and form sorptively active functional groups on its surface. The chemical structure and surface properties of the resulting modified sorbent were characterized using Fourier-Transform Infrared (FT-IR) spectroscopy. The experimental results demonstrated that the urea-treated lignin exhibited a significantly higher sorption capacity for heavy metal ions and organic pollutants in aqueous media compared to unmodified lignin. The synthesized eco-friendly and cost-effective sorbent holds high potential for application in industrial wastewater treatment processes.

Keywords: Lignin, urea, modification, sorbent, sorption, wastewater, heavy metals.

Introduction. The rapid development of industrial technologies and the increasing level of anthropogenic environmental pollution make the development of efficient, eco-friendly, and cost-effective methods for purifying wastewater from various toxic substances, particularly heavy metal ions (Cu^{2+} , Ni^{2+} , Zn^{2+} , etc.) and organic compounds, one of the most pressing tasks [1, 2]. Compared to traditional treatment methods, obtaining environmentally safe and inexpensive sorbents based on agricultural waste and plant raw materials is recognized as one of the key directions for the rational utilization of bioresources [3].

Lignin, isolated from lignocellulosic sources such as rice straw generated in large quantities in agriculture, is a promising natural biopolymer possessing a high aromatic structure and various functional groups [4, 5]. However, the specific surface area and sorption capacity of unmodified (pristine) lignin are relatively low, and its efficiency in removing heavy metal ions from aqueous media is insufficient [6]. Therefore, the chemical modification of the lignin macromolecule—specifically, the targeted enhancement of its sorption properties by introducing new nitrogen-containing, coordination-active functional groups into its structure—is of great scientific interest [7, 8].

The attachment of nitrogen-containing compounds, including urea and other organic reagents, to the lignin macromolecule leads to the formation of amine, amide, and urea residues in the polymer chain [9]. These functional groups possess the ability to form

stable complex compounds and ionic bonds with heavy metal ions, which drastically increases the selectivity and static exchange capacity of the sorbent [10]. In previous studies, technologies for obtaining highly efficient sorbents based on lignin modified with nitrogen-containing organic compounds have been developed, and their structural and sorption properties have been substantiated using FT-IR spectroscopy analysis [11, 12].

Materials and Methods. Lignin extraction from rice straw was carried out via alkaline delignification. To achieve this, 80 g of crushed rice straw with a particle size of 2–3 mm was treated with a 4% NaOH solution in an autoclave reactor at 120 °C for 2–3 hours. Upon completion of the reaction, the separated filtrate was adjusted to an acidic medium pH = 2. to precipitate the lignin. The resulting precipitate was washed until a neutral medium was reached, dried at 50–60 °C to a constant mass, and pulverized into powder form for subsequent modification processes.

A 10 g sample of lignin, weighed on an analytical balance with an accuracy of 0.0001 g, was completely dissolved in distilled water to prepare a homogeneous solution. In a separate vessel, 10 g of urea was placed and dissolved at 70 °C using a magnetic stirrer equipped with a heater. To the urea in the liquid phase, 15 ml of formaldehyde solution was added, and the mixture was stirred vigorously for 10–15 minutes to ensure the initial methylation reaction.

The previously prepared lignin solution was slowly added dropwise to the resulting urea-formaldehyde oligomer. The polycondensation and chemical modification processes were carried out for 3 hours under continuous stirring conditions. By transitioning the reaction medium first to an alkaline and then to an acidic stage, the cross-linking of macromolecular chains and the formation of a network structure were ensured. At the end of the reaction, the synthesized modified lignin sorbent was isolated as a precipitate.

Conclusion. After being separated from the reaction medium, the synthesized modified lignin sorbent was washed to a neutral pH and dried at 50–60 °C to a constant mass. The dried product was ground in a mortar to obtain a homogeneous powder.

To confirm the chemical structure of the sorbent and the new functional groups formed as a result of the modification, FT-IR spectroscopic analysis was performed. The spectral analysis results are shown in Figure 1:

These spectral changes fully demonstrate the successful covalent attachment of the urea-formaldehyde resin and nitrogen-containing active groups to the lignin framework, as well as the formation of sorption-active functional groups.

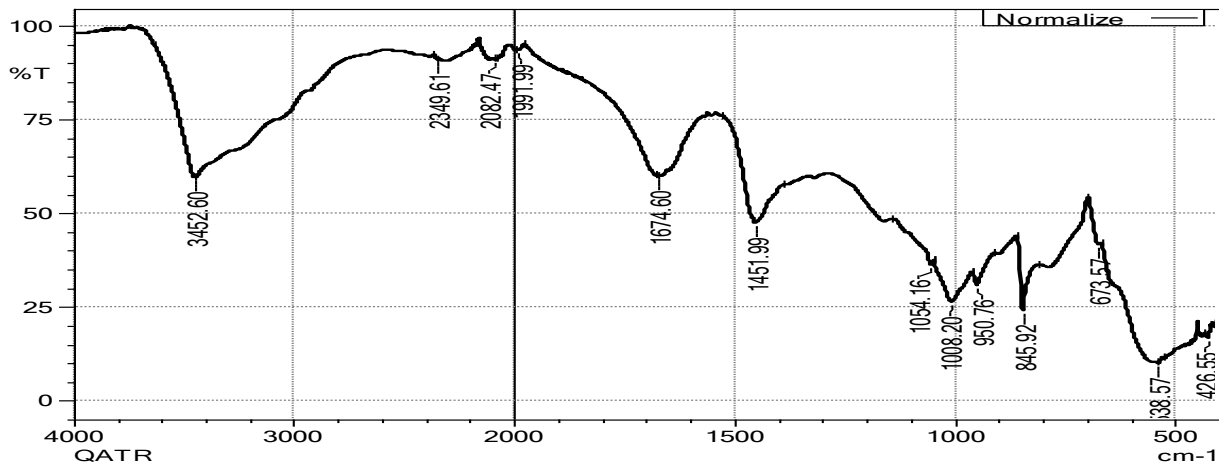


Figure 1. FT-IR spectrum of the L/K/F sorbent.

Figure 2. FT-IR spectrum of the L/K/F sorbent after Cu^{2+} ion sorption.

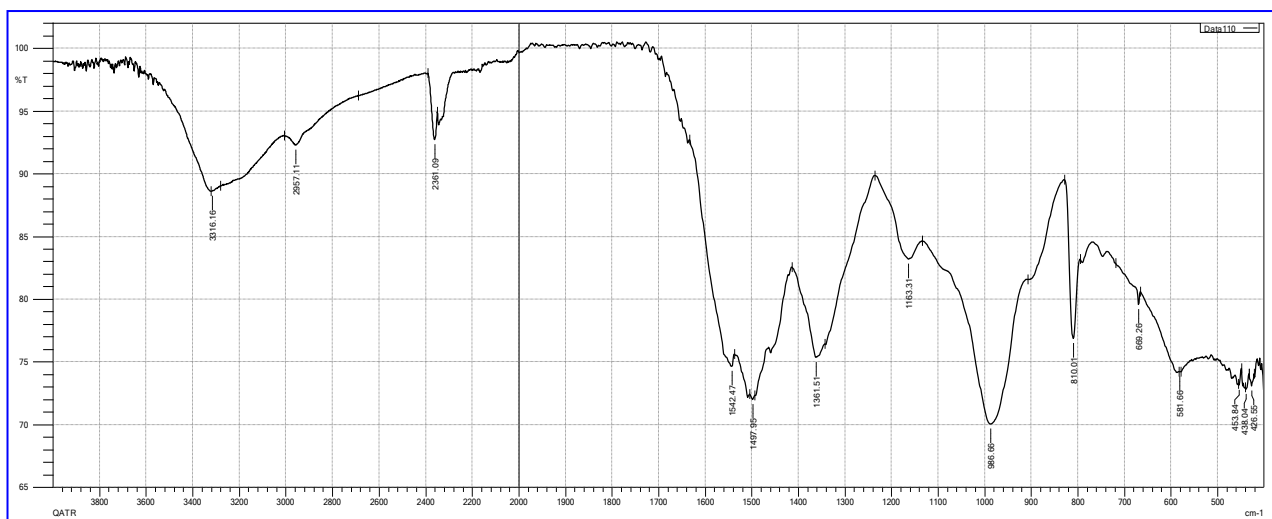


Figure 2. FT-IR spectrum of the L/K/F sorbent after Cu^{2+} ion sorption.

When comparing the FT-IR spectra of the initial sorbent and the samples after Cu^{2+} ion sorption, significant changes were observed in the frequency characteristics of the absorption bands. This indicates the efficient sorption of copper ions on the sorbent surface and the participation of active sites in the process. Additionally, the visual change in the color of the sorbent practically confirms the occurrence of the sorption process.

References:

- [1] **Ahmaruzzaman m.** Industrial by-products as low-cost adsorbents for the removal of heavy metals from wastewater // *advances in colloid and interface science*. – 2011. – vol. 166, № 1–2. – p. 36–59.
- [2] **Wang j., chen c.** Chitosan-based biosorbents for removal of heavy metal ions from aqueous solutions: a review // *bioresource technology*. – 2014. – vol. 160. – p. 129–141.
- [3] **Klason c., kubat j.** Structure and properties of lignins and their applications // *progress in polymer science*. – 1986. – vol. 12, № 2. – p. 79–139.
- [4] **Abdullaeva m.j. Et al.** Получение сорбентов на основе лигнина, модифицированного органическими соединениями // *center for scientific publications (buxdu.uz)*. – 2026.
- [5] **Sidiras d. Et al.** Extraction and characterization of lignin from agricultural residues // *industrial crops and products*. – 2018. – vol. 120. – p. 220–228.
- [6] **Popov a.a. Et al.** Structure and reactivity of lignin-based materials // *russian chemical reviews*. – 2020. – vol. 89, № 4. – p. 412–435.
- [7] **Abdullaeva m.j.** Obtaining sorbents based on lignin modified by organic compounds // *7universum: технические науки*. – 2026. – № 4 (135).
- [8] **Melro e. Et al.** Lignin as a green raw material for the production of advanced adsorbent materials // *international journal of biological macromolecules*. – 2021. – vol. 183. – p. 1530–1541.
- [9] **Zhao y. Et al.** Chemical modification of lignin with nitrogen-containing groups for enhanced heavy metal removal // *journal of hazardous materials*. – 2019. – vol. 368. – p. 745–755.
- [10] **Ungureanu d. Et al.** Removal of heavy metals from aqueous solutions by sorption on modified lignin materials // *desalination and water treatment*. – 2017. – vol. 78. – p. 240–251.
- [11] **Urozov m.k., abdullaeva m.j. Va boshq.** Guruch samoni lignini asosida o'lingan azot tutuvchi sorbentlarning tuzilish xususiyatlari // *o'zbekiston kimyo jurnali*. – 2025–2026.
- [12] **Kai d. Et al.** Sustainable lignin-based materials for biomedical and environmental applications // *green chemistry*. – 2016. – vol. 18, № 5. – p. 1175–1200.