

GIBBS ENERGY OF HYDROGEN SULFIDE ADSORPTION INTO ACTIVATED SORBENT OBTAINED FROM PAULOWNIA-TOMENTOSA HYBRID WOOD

Mirzokhid Kokhkharov

*Doctor of Chemical Sciences, Associate Professor, Namangan State
Technical University, Namangan, Uzbekistan E-mail: mirzo199008@mail.ru*

Dilnoza Jumaeva

*DSc, leading research scientist, Institute of General and Inorganic
Chemistry of the Academy of Sciences of Uzbekistan, Republic of Uzbekistan,
Tashkent*

E-mail: d.jumayeva@list.ru

Sultonov Amirkhon

Basic Doctoral Candidate of the Namangan State Technical University

E-mail: amirxonsultonov34@gmail.com

Abstract. *For the first time, the fundamental energetic characteristics of hydrogen sulfide (H_2S) adsorption on an activated carbon sorbent derived from the wood of the hybrid form **Paulownia tomentosa** were determined using adsorption microcalorimetry. The differential values of Gibbs free energy were calculated. It was established that the concentration of active sites for hydrogen sulfide on the activated carbon adsorbent derived from the bark of **Paulownia tomentosa** is ~ 0.35 mmol/g. It was proven that, in general, hydrogen sulfide molecules form $4H_2S$ /adsorbent complexes on the activated carbon adsorbent derived from the bark of **Paulownia tomentosa**.*

Key words: *Hydrogen sulfide, adsorption, adsorption microcalorimetry, activated carbon, **Paulownia Tomentosa**, Gibbs free energy.*

INTRODUCTION

Interest in wood-based activated carbons (ACs) arises from the combination of abundant raw material availability- including sawdust, wood chips, and bark residues - high technological flexibility, as well as the ability to “tune” pore texture and surface groups toward specific contaminants. Recent reviews show that the initial wood anatomy, the cellulose–hemicellulose–lignin ratio, and mineral impurities significantly affect pore size distribution (micro/meso/macro), framework stability, and the composition of oxygen-containing surface groups - key factors that determine adsorption capacity and selectivity [1].



A typical production scheme includes carbonization/pyrolysis of wood at 400–700 °C under an inert atmosphere, resulting in the formation of primary microporosity, followed by activation, either physical or chemical. In physical activation, steam or CO₂ at 750–950 °C is used to enlarge and open pores; in chemical activation, reagents such as H₃PO₄ or KOH (less commonly ZnCl₂ and others) enable the development of microporosity or mesoporosity and functionalized surfaces at lower temperatures [2–6].

Alkaline activation (KOH) produces predominantly microporous textures (pores <2 nm) through interlayer potassium intercalation and reduction/gasification reactions of carbon upon heating, yielding K₂CO₃, K₂O, and CO/CO₂. Subsequent leaching removes inorganic phases, “etching” the carbon matrix and leaving a developed micropore network. This scheme typically gives SBET values of 1500–2500 m²/g or more and high selectivity toward small gas molecules [6–8].

For water purification, adsorption of dyes, phenols, pesticides, and pharmaceutical micropollutants by wood-based ACs is usually well described by Langmuir/Freundlich isotherms, while kinetics follow the pseudo-second-order model; the diffusion contribution is parameterized by the Weber–Morris intraparticle diffusion model. For gas-phase applications (CO₂, H₂S, VOCs), microporous ACs (especially KOH-activated) show high capacities and selectivity; for H₂S, impregnated ACs and composites with metal oxides are most effective [9–12].

Life cycle assessment (LCA) and techno-economic analysis (TEA) studies indicate that biomass-derived feedstocks (including wood) can reduce the carbon footprint compared to coal- and peat-based ACs. However, final indicators are sensitive to activation energy regimes, energy sources, and management of side streams (e.g., filtrates after chemical activation). Estimates suggest a wide cost range (on the order of a few USD/kg) and highlight the importance of scale-up, heat recovery, and reagent recycling [13–16].

RESEARCH METHODS

In this study, a universal high-vacuum adsorption apparatus equipped with a Tian–Calvet type differential microcalorimeter (DAC-1-1A) was used.

The unit allows adsorbate dosing by both gas-volume and volume-liquid methods. The principle of operation of the adsorption-calorimetric device used in this work is presented in the works of the authors [15–19].

RESULTS AND DISCUSSION. This article presents the results of a study on the variation of Gibbs free energy and the adsorption mechanism of hydrogen sulfide on an activated carbon adsorbent derived from the bark of *Paulownia tomentosa* at 303 K [20].



Table 1 summarizes the experimental data on the amount of adsorbed hydrogen sulfide, the equilibrium pressure, as well as the theoretically calculated values of Gibbs free energy. It should be emphasized that, due to the high saturation pressure of hydrogen sulfide at the experimental temperature (303 K), equal to 17,932 torr, the adsorption characteristics were determined only up to a relative pressure of $P/P_s = 0.033$ (Table 1).

The Gibbs free energy was calculated as the work done during the change in gas volume at constant temperature, i.e., from the free energy, using the following equation:

$$\Delta G = -A = -RT \ln(P/P_s) = RT \ln(P_s/P) \quad (1)$$

where R is the universal gas constant, T is the experimental temperature, and $P_s = 17932$ torr.

Table 1. Dependence of Gibbs free energy on the amount of adsorption.

	a , mol/g	P , torr	P/P_s	Δ G , kJ/mol		a , mol/g	P , torr	P/P_s	Δ G , kJ/mol
	0,03	0,8	0,00004	5,4	0.	0,66	40,3	0,0134	0,9
	0,08	1,3	0,00017	1,9	1.	0,74	51,1	0,0140	0,8
	0,13	1,9	0,00053	9,0	2.	0,84	11,1	0,0174	0,2
	0,18	2,5	0,00140	6,56	3.	0,90	70,0	0,0206	0,8
	0,25	5,0	0,00287	4,7	4.	1,02	21,9	0,0235	0,4
	0,34	8,7	0,00550	3,1	5.	1,10	63,6	0,0259	0,2
	0,42	13,4	0,00748	2,3	6.	1,21	105,0	0,0282	0,0
	0,49	17,6	0,00979	1,7	7.	1,32	46,0	0,0305	0,8
	0,58	25,1	0,01255	1,0	8.	1,43	87,7	0,0328	0,6



Figure 1 presents the dependence of Gibbs free energy variation on the adsorption amount of hydrogen sulfide on the activated carbon adsorbent derived from the bark of **Paulownia tomentosa**.

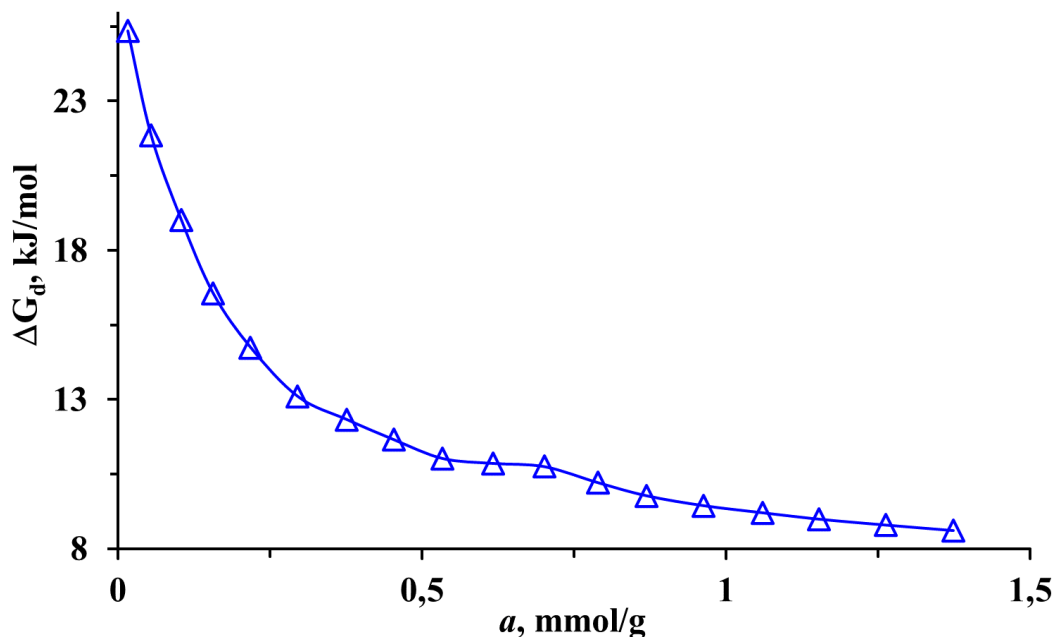


Fig.1. Gibbs free energy versus adsorption amount of H_2S on the activated carbon sorbent from *Paulownia tomentosa*.

The Gibbs free energy values indicate that the sorption process corresponds to physical adsorption. At an adsorption amount of 0.02 mmol/g, the change in Gibbs free energy is ~25.5 kJ/mol. With the progressive filling of the sorption pore volume by hydrogen sulfide molecules, Gibbs free energy decreases sharply and reaches 13 kJ/mol at an adsorption amount of 0.34 mmol/g. As the sorption volume approaches saturation, Gibbs free energy decreases linearly to 11 kJ/mol at 0.68 mmol/g adsorption, forming a step-like change. Up to ~1 mmol/g adsorption, a second linear decrease occurs down to 9.4 kJ/mol, followed by a partial bending, and at 1.43 mmol/g adsorption a third linear decrease is observed, reaching 8.6 kJ/mol, at which point the sorption process terminates.

The adsorption amount corresponding to each linear or step-like transition is ~0.35 mmol/g. This value reflects the concentration of active sites for hydrogen sulfide on the activated carbon adsorbent derived from **Paulownia tomentosa** bark, which equals ~0.35 mmol/g. Thus, on the activated carbon adsorbent derived from the bark of **Paulownia tomentosa**, hydrogen sulfide molecules form a $4H_2S/\text{adsorbent}$ complex.

CONCLUSION. In conclusion, adsorption–calorimetric studies demonstrated that hydrogen sulfide adsorption on the activated carbon adsorbent derived from the bark of **Paulownia tomentosa** is characterized by



distinct linear and stepwise changes in Gibbs free energy. These variations indicate that the concentration of active sites with respect to hydrogen sulfide molecules is ~ 0.35 mmol/g. Furthermore, the results suggest that, in general, hydrogen sulfide molecules form $4\text{H}_2\text{S}$ /adsorbent complexes on this carbonaceous sorbent.

REFERENCES:

1. Danish, M.; Ahmad, T. A review on utilization of wood biomass as a sustainable precursor for activated carbon production and application. *Renewable & Sustainable Energy Reviews*, 2018, 87, 1–21.
2. Jumayeva D.J., Raxmatullayeva N.T., Toirov O.Z, Numonov B.O., Shamuratova M.R. Obtaining of highly energy-efficient activated carbons based on wood. *E3S Web of Conferences* 410, 01018 (2023) (3).
3. Jumaeva D. J., Rakhmatullaeva N. T., Abdurakhimov A. A., Babaeva G. O. Study of the physicochemical characteristics of wood-based adsorbents. No. 4 (106), April 2023. DOI: 10.32743.
4. Jumaeva D. J., Rakhmatullaeva N. T., Shamuratova M. R., Abdurakhimov A. Kh., Ergashev O. K. Activation methods of Paulownia wood waste. *Scientific Journal “Mechanics and Technology,”* Namangan Institute of Engineering and Construction, No. 3(3), 2022.
5. Neme, I.; et al. Activated carbon from biomass precursors using phosphoric acid: A review. 2022.
6. Yang, Z.; et al. Lignin-based activated carbon using H_3PO_4 activation. *Polymers*, 2020, 12(12), 2829.
7. Murphy, O. P.; et al. A review on adsorption isotherms and design for water treatment. *ACS Omega*, 2023.
8. Choleva, E.; et al. Adsorption of hydrogen sulfide on activated carbon: mechanisms and practice. *Processes*, 2023.
9. Pet, I.; et al. Recent developments in the implementation of activated carbon in water treatment. *Current Pollution Reports*, 2024.
10. Bunker, B.; et al. Thermal regeneration of activated carbon used as an adsorbent. *Sustainability*, 2023, 15, 6435.
11. Vilén, A.; et al. Comparative life-cycle assessment of activated carbon production from various raw materials. *Journal of Cleaner Production*, 2022.
12. Luanwuthi, S.; et al. Techno-economic and environmental assessment of biomass-derived activated carbon. *ACS Sustainable Chemistry & Engineering*, 2024.



13.Nandi, R.; et al. Impact of KOH activation on biomass-derived porous carbon (высокие S_{BET}). ACS Omega, 2023.

14.Quintas Salamba, M.; et al. Porosity of activated carbon in water remediation. ACS ES&T Water, 2025.

15.Kh.Bakhronov, O.Ergashev, G'.Ochilov, N.Esonkulova, A.Ganiev, N.Akhmedova, O.Ochilova Study of isotherm, thermodynamic characteristics and sorption mechanism of toluene adsorption on zeolite CsZSM-5 by adsorption-calorimetric method //Edelweiss Applied Science and Technology, 2026, vol. 8, №6, -PP. 6959-6966, <https://doi.org/10.55214/25768484.v8i6.3508>

16.O.Ergashev, Kh.Bakhronov, M.Asfandiyorov, M.Kokhkharov, A.Ganiev, N.Akhmedova, Sh.Tulyaganova, K.Nazirov, N.Esonkulova Isotherm and main thermodynamic characteristics of adsorption of carbonyl sulfide molecules on zeolite KA (MSS-558) //Edelweiss applied science and sechnology, 2025, vol. 9, №6, -pp. 287-301, <https://doi.org/10.55214/25768484.v9i6.7795>

17.Reymov A., Raxmatkarieva F., Koxxarov M., Bakhronov Kh., Isotherm of ammonia adsorption in zeolite CaA (M-34) //Science and Education in Karakalpakstan, 2024, №3/2, ISSN 2181-9203, pp.257-262.

18.Kokhkharov M., Rakhmatkarieva F., Bakhronov Kh., Rakhmatullaeva M, Absalyamova I., Karimov Y. Differential entropy and thermokinetics of ammonia molecule adsorption on CaA zeolite (M-22) //E3S Web of Conferences 563, 01024, ICESTE 2024.

19.Kokhkharov M., Rakhmatkarieva F., Bakhronov Kh., Akhmedova N., Rakhmatullaeva M., Karimov Y. Adsorption isotherm, differential heat, and sorption mechanism of ammonia on CaA zeolite //E3S Web of Conferences 587, 01017 Green Energy 2024.

20.Jumaeva D. J., Bakhonov KH. N., Sultanov A. U. Technology for obtaining sorption material based on Paulownia. **Scientific and Technical Journal of Andijan Machine-Building Institute, Special Issue No. 1, 2024**, pp. 252–259

